

PHONE

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

STUDY OF GATE VALVES AND GLOBE VALVES
AS FLOW REGULATORS FOR IRRIGATION
DISTRIBUTION SYSTEMS UNDER HEADS
UP TO ABOUT 125 FEET OF WATER

Hydraulic Laboratory Report No. Hyd-337

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Subject: Study of gate valves and globe valves as flow regulators for irrigation distribution systems under heads up to about 125 feet.

PURPOSE

The object of the valve study was to investigate the hydraulic and mechanical characteristics of irrigation-type gate valves, standard gate valves, and standard globe valves to determine their suitability as flow regulators under heads up to about 125 feet of water.

CONCLUSIONS

1. Low head irrigation-type valves should not be used at heads in excess of the maximum specified by the manufacturer unless there is assurance by tests or guarantee that the structural characteristics are adequate and the valve will operate satisfactorily at higher heads. Some valves have large factors of safety compared to the manufacturer's specifications while others have small factors of safety.
2. Zones of low pressure form at and just downstream of valves in conduits when they are operated at partial openings. Cavitation, with vibration, noise, and damage, may occur in these zones depending upon the differential head and back pressure to which the valves are subjected.
3. The cavitation characteristics of valves are influenced somewhat by the configuration of their flow boundaries. The flow boundaries of the low-pressure irrigation-type gate valves, usually being more irregular than those of waterworks standard valves, make them more susceptible to local cavitation. However, the cavitation tendencies are not sufficiently different from those of the waterworks standard valves to justify any variation in cavitation design criteria (Figure 6).

4. None of the valves tested are satisfactory for regulating flow at high differential heads unless some means of preventing cavitation or cavitation-erosion is provided. Cavitation may be prevented either by admitting air to the low pressure regions or by supplying sufficient back pressure by submerging or constricting the downstream conduit. Cavitation-erosion may be minimized by using a special cavitation resistant section of conduit immediately downstream, and possibly eliminated by causing a valve to discharge directly into a much larger compartment in the conduit (sudden enlargement). A neoprene- or rubber-lined steel section is an example of downstream protection. It is believed that this type of protection should be used only for mild cavitation where the cavitation index is greater than 1.0. If protection of this nature is provided immediately downstream of a valve the cavitation index should never be less than 0.4 in order to confine the damaging action to the lined section. A value less than 0.4 in the equation of (5) below will result in the damage occurring farther downstream.

5. The maximum allowable pressure differential which will not cause cavitation in a valve can be determined by using the critical value of the cavitation index " K_i " for the valve in the relationship

$$K = \frac{H_2 - H_v}{H_t - H_2} \text{ where:}$$

K = cavitation index

H_2 = pressure in feet of water in pipe 12 pipe diameters distance downstream of the valve

H_v = vapor pressure for location of distribution system referred to atmosphere (about -33 feet at sea level)

H_t = total head upstream of valve (velocity head plus pressure head) in feet

6. The critical cavitation index, K_i , for gate valves of both the irrigation and waterworks type is greater than unity. A value of $K = 2.0$ should be used in the equation of (5) above for design purposes when the differential head exceeds 35 feet and it is desired to eliminate any chance of cavitation-erosion. This value will give sufficient back pressure to eliminate cavitation.

Where minor erosion of the surfaces immediately downstream of the valve seat will not be objectionable a cavitation index as small as 1.0 can be permitted since any cavitation at this or a slightly greater index value will be mild.

For cavitation index values of less than unity the severity of cavitation increases as the index value decreases and some means of protecting against or eliminating the damage must be provided.

7. The critical cavitation index obtained for a specific valve may be used in evaluating the cavitation characteristics of another of the same type placed in a similar setting.

8. A critical cavitation index of 1.0 was obtained for a 6-inch globe valve.

9. Gate valves and globe valves are not suitable for releasing water under high heads directly into erodable channels, particularly at partial openings, because of the widely dispersed and high-velocity jets that are discharged.

10. Hub-end gate valve A does not appear to be suitable for high head irrigation distribution systems.

11. Hub-end gate valve B appears suitable for irrigation distribution systems where the heads range up to 125 feet of water.

12. The suitability of a commercially-produced valve C for irrigation systems where heads range up to 125 feet of water could not be determined from the test valve because it was made up mainly of welded sections of floor plate and contained a leaf from another commercial valve.

13. Hub-end gate valve E is not suitable for irrigation distribution systems where the head exceeds appreciably that specified by the manufacturer.

14. Hub-end gate valve F is considered suitable only for heads specified by the manufacturer.

15. The (GV-7) gate valve developed by the Bureau which is shaped to cause separation of the flow from the valve body surfaces below the gate seat and provide a sudden enlargement immediately downstream is most satisfactory where it is necessary to throttle under high heads (Figure 17).

RECOMMENDATIONS

1. Do not use low head irrigation valves at heads in excess of the maximum specified by the manufacturer unless there is assurance either by tests or guarantee that the design is adequate and the construction is consistently sturdy.

2. Wherever feasible use the back pressure below gate valves in distribution systems to prevent cavitation.

3. Use venting to prevent cavitation below the valves only when it is not feasible to supply sufficient back pressure to do so and when entrained air will not interfere with the operation of meters or other equipment downstream.

4. When neither (2) or (3) above are feasible, provide protection against cavitation-erosion downstream from the valve either in the form of a sudden enlargement of the flow passage (using the Bureau's GV-7 valve), or a cavitation-resistant lined section. If a cavitation-resistant lined section is to be used immediately downstream of the valve, be sure that the cavitation index is greater than 0.4 to confine the damaging action to the lined section. Preferably the cavitation index for this type of protection should not be less than 1.0. This would assure that only mild cavitation would occur.

5. Use the equation $K = \frac{H_2 - H_v}{H_t - H_2}$ together with data on Figure 16

to determine what measure must be taken to minimize or eliminate cavitation below valves in irrigation distribution systems.

6. Whenever feasible to do so make a study of the cavitation tendencies of gate valves installed in irrigation systems where the heads exceed 50 feet.

7. Make periodic inspections of valves in distribution systems where operation is at cavitation index values less than 2.0.

ACKNOWLEDGEMENT

Engineers of the Canals and of the Hydraulic Laboratory Branches collaborated in the studies discussed in this report. The irrigation-type valves used in these studies were loaned to the Bureau by various valve Manufacturers.

INTRODUCTION

As land and water resources of the western United States become more fully utilized, closed conduit distribution systems are used more extensively to conserve the water which would be lost by evaporation and seepage in earthen-ditch systems. These closed systems have generally been designed to operate at pressures not exceeding 50 feet of water, but in recent years have been planned for

pressures more than double this value. The use of the higher pressures posed a problem since there were two general classes of commercial valves manufactured and the costs differed widely. One class, known as the irrigation valve, was generally suitable for heads of about 50 feet, while the second, known as the waterworks standard valve, was for heads upward from 300 feet. The cost of a system using the waterworks valve would be quite high compared to one using the irrigation type, particularly when a distribution system contains numerous turnouts for small tracts of land. The wide difference in the initial cost of these two types of valves made it desirable that some economical means of regulation be obtained for the intermediate heads. It was believed that some of the commercial irrigation-type valves would provide satisfactory service for heads up to 125 feet, so several valve manufacturers were contacted for test samples which could be tested to determine their suitability for the higher heads.

The valves had to operate without vibration, chatter or other undesirable characteristics to be suitable for these heads. The valves were to be considered for free discharge and for use in line, thus the laboratory study concerned mainly the determination of capacity, leakage, head loss, mechanical operating characteristics, vibration and cavitation characteristics of the various sample valves.

A gate valve developed by the Bureau includes features for minimizing cavitation tendencies and for preventing excessive water hammer by rapid closure. The shaping of the valve body immediately downstream of the seat to make a sudden enlargement, as shown in Figure 17, reduces the cavitation tendency. The inverted V-notch at the bottom of the gate leaf insures against rapid shutoff as the gate nears the closed position, thus preventing excessive water hammer. The valve has not been tested for cavitation tendencies, but it should prove even better than a standard gate valve when used with a sudden enlargement to release flows under high heads.

THE INVESTIGATION

Test procedure. The valves were placed in settings with several diameters length of pipe upstream attached to the laboratory supply system and several diameters length of pipe attached to the downstream sides of the valves. The back pressure on the test valve was regulated by another valve in the downstream pipe. A 45-degree down pipe was used to return the flow to the laboratory supply system (Figure 1). The entire downstream pipe section was removed for free discharge tests.

Piezometers were placed at various points upstream and downstream of the test valves for investigating pressure distribution, determining the head and indicating the head losses. Water was supplied to the test valves by two 12-inch centrifugal pumps in series and measured by venturi meters. Test data for all valves were recorded for various valve openings and discharges. The test valves included: ^Aa 10-inch hub-end gate valve; ^Ba 12-inch hub-end gate valve; ^Can 8-inch cone-end gate valve; ^Da 10-inch Waterworks standard gate valve; ^Ean 8-inch bellmouth gate valve; ^Fa 12-inch 20 psi hub-end gate valve; ^Ga 12-inch 55 psi hub-end gate valve; ^Ha 6-inch standard waterworks valve; and ^Ia 6-inch standard globe valve. In discussing the results of the tests on these valves they will be referred to by the letters A, B, C, D, etc. Except in the case of Valve D no attempt was made to duplicate an actual field installation in concrete pipe. The valves were examined for ease of operating by applying a head of about 127 feet of water and alternately opening and closing the leaf. Pressures in the conduit upstream, downstream, and in some of the valves were obtained for various discharges and openings. Discharge coefficients for closed-conduit and free flow conditions and cavitation index values were computed from these data. Sections of concrete-lined pipe were placed at various distances downstream of Valve H to determine the location of cavitation-erosion for various back pressure conditions. A section of 12-inch concrete pipe was placed below a 12-inch hub-end gate valve for one cavitation test.

Valves discharging into atmosphere. The jet from the first gate valve tested at the end of a pipeline was dispersed widely at partial openings (Figure 2A). This condition was typical for all gate valves in similar settings and precludes the use of gate valves for discharging flow directly into irrigation ditches. The jet must be confined and its energy destroyed in order to prevent undue eroding and saturating of the ground. The jet below globe valves when discharging into the atmosphere is quite widely dispersed but the dispersion changes only slightly with head and opening.

Gate Valves

Leakage tests. Various amounts of leakage were noted for the different irrigation-type valves as they were tested under heads varying from 15 to 127 feet. Leakage through Valve C was excessive until the wedging cam was machined to permit complete closure of the leaf. There was no leakage at the closed position after the wedging cam was machined.

Some leakage was noted for Valve A shortly after it was placed under test. Examination of the valve disclosed that the seat and leaf had been damaged so that complete shutoff was not possible. There was no leakage past Valve B when it was closed at any time during the tests and the valve was opened and closed under heads of about 125 feet numerous times.

Fracture of the leaf of Valve E occurred before observations were made concerning leakage.

No note was made of the leakage for Valves G and H since this type of valve is usually satisfactory for complete shutoff, and the valves had been used in the laboratory previously.

Mechanical operation. There was a wide variation in the force which had to be applied to the handwheels to operate the various test valves. Very little effort was required to operate Valve B under the test heads (15 to 127 feet). The valve operated easily throughout the tests.

Operation of Valve A was more difficult as the head increased. The handwheel moved easily at low heads but required considerable force at the higher heads and smaller openings. This indicated contact of the seating surfaces of the body and leaf which was later confirmed by damage to the seat ring and leaf. During limited operation of the valve under heads varying from 15 to 127 feet part of the seat was sheared from the leaf due to interference between the leaf and body seat rings, and four cracks appeared in the gate leaf (Figure 2B). There was insufficient threads on the stem of the test valve to permit the valve to be opened more than 91 percent of the nominal leaf travel.

Considerable force was required to operate Valve C, particularly at small openings and high heads. The fact that it was a small valve with the body made of welded parts may account at least in part for the excessive force required for its operation.

No difficulty was experienced in operating Valve D, but the operation required more force on the handwheel as the head increased. This was true also of the Valves G and H. The leaf of Valve E was fractured when the leaf was set at 22-1/2 percent open and a head of 95 feet was applied. Although the pieces of the leaf were held together by the bronze seat ring the leaf was deformed sufficiently to

prevent operation by the stem. Upon reporting the damage to the manufacturer it was learned that the valve was for low water pressure (20 psi) and was not recommended for higher heads. A gate valve of the same design for higher heads was later tested (55 psi).

Of the valves tested Valve B was the only one where the leaf and body seats did not seem to be in sliding contact during opening or closing. The contact of the seats on this valve seemed to take place and form a watertight seal just as the leaf reached the bottom of its travel.

Capacity of valves. Discharge coefficients, based on the nominal valve area and the total head (pressure plus velocity head) upstream of the valve, were computed from the test data for the various valves. In general the coefficient curves for the several valves were similar (Figure 3) with the value for the wide open condition being about 0.95. There were two exceptions. Valve A had insufficient threads on the stem to permit opening the leaf more than 91 percent. Although the coefficient for this opening was about 0.85, a plot of the data indicated that the coefficient for the wide open position would be the same as that for the other valves. With Valve D wide open it was noticed that the jet would expand, at times tending to fill the downstream bell. This would cause the pressure just downstream of the leaf to be subatmospheric, increasing the effective head and the discharge. The coefficient based on the total head upstream of the valve (not effective head) was 1.02 when this condition existed. When the jet did not diffuse and the pressure at the leaf was near atmospheric, the effective head was then closely represented by the total upstream head on the valve. The discharge coefficient for this condition was 0.85. It is believed that the upstream bell caused a contraction in the valve which decreased its capacity over the other types.

Cavitation characteristics. When a gate valve in a conduit is partially open and a high velocity jet of water passes through the opening, there is a low pressure zone formed in the fluid downstream from the leaf. Low pressure zones form also downstream from irregularities in the flow boundary such as the downstream edge of the leaf recess noted by the area marked X in Figure 1. The pressures in these zones are influenced by the differential head across the valve and the downstream pressure, thus it was considered possible to determine the permissible head differential for a given back pressure, or, the back pressure required to prevent cavitation in these low pressure zones (keep the pressure in the zones above the vapor pressure of the water). This could best be accomplished by using some form of cavitation number or index. Several plots of pressure data were made before an appropriate index was discovered.

The relationship used was:

$$K = \frac{H_2 - H_v}{H_t - H_2}$$

where

K = dimensionless number - cavitation index

H_2 = pressure head in pipe 12 diameters downstream of valve, feet of water

H_v = vapor tension pressure relative to atmospheric pressure (about -33 feet at sea level)

H_t = total head (pressure plus velocity) 2 pipe diameters upstream of the valve

Plots of K against discharge coefficients, C , for different gate openings revealed that the coefficient was constant when there was no cavitation in the system and that it decreased as cavitation developed with an increase in differential head (Figures 4 and 5). These plots offered a means of indicating the conditions for incipient cavitation or for determining the critical cavitation index (K_1). The coefficient used in this case was that given in the expression

$$Q = CA \sqrt{2gH}$$

where

Q = flow quantity in cfs

A = nominal area of pipe, square feet

g = acceleration of gravity

H = differential head on valve measured between stations 2 pipe diameters upstream and 12 pipe diameters downstream of valve

C = coefficient of discharge

The first attempts to establish critical values of K based on audible cavitation were made from plots of the data for given openings by taking those values of K at the intersection of two lines on the plots, one (a) representing the constant discharge coefficient for the valve opening without cavitation, and the other a sloping line (b)

representing the average for the points where cavitation was definitely audible (Figure 6). The initial analysis gave a maximum value of K_1 of about unity which appeared to be about the same for all valve openings. However, further analysis, using additional data, showed a decrease in efficiency at values of K higher than those for which audible cavitation was noted. In some cases this critical value of K seemed to be near 2.0. The coefficient for any condition divided by the coefficient where there is no cavitation was used to generalize the data for all valves and openings (Figure 6). This led to an investigation of the above equation. It was investigated assuming general cavitation to occur in the pipe immediately downstream of the valve leaf and a loss from the gate to the recovery pressure downstream equal to the Borda loss. This was done to determine whether or not the cavitation influencing the efficiency of the system was of a general nature and downstream of the leaf. An evaluation of the critical cavitation index values for various gate openings showed an increase with increase in opening until the valve was 50 percent open then a decrease with larger opening (Figure 7). From this curve it appears that the critical value of the cavitation index should reach a maximum at about 65 percent valve opening. While the K_1 value is about 1.0 for this case, a value somewhat different might be expected depending upon where the downstream pressure is measured and whether or not the data are referred to a common base. Local regions of cavitation might also be an influencing factor. This seems to be the case for gate valves because the value of K_1 at all conditions tested is much greater than indicated by the curve for general cavitation (Figure 7).

A comparison of the curve for general cavitation conditions with points based on the data of Figures 4 and 5 indicates the presence of local regions of cavitation.

The tests to this point had disclosed that cavitation was present to some degree at values of K below approximately 2.0, that cavitation was present in mild form for values of K greater than about 1.0, and that the intensity and severity of cavitation increased with decreasing values of K below 1.0. These results seemed to offer a source of design criteria so studies were made to further define the limitations.

Protection of the flow passage surfaces attacked by cavitation was considered as one means of permitting the use of gate valves as flow regulators with low back pressures. The alteration of the flow passage to form a sudden enlargement immediately downstream of the valve seemed to offer another possible solution. Some idea as to the nature, location, and extent of the damage caused by cavitation was needed to evaluate these possibilities. Tests were performed for this purpose by using rubber-lined and concrete-lined pipe sections below the valves and special specimens of rubber material vulcanized to metal shapes in special cavitation testing facilities.

A section of 12-inch pipe with a neoprene lining vulcanized in it was placed downstream from a 12-inch irrigation type gate valve. The intensity of the cavitation obtained in this arrangement was not sufficient to provide any visual evidence of damage after many hours operation so some means of accelerating the test was sought. Metal blocks with specimens of 1/16-, 1/8-, and 3/16-inch lining vulcanized to them were tested in a special venturi-type cavitation test apparatus (Figure 8). The time involved to give visual evidence of cavitation was so great that other specimens were prepared for testing in a magnetostriction oscillator. Lining thicknesses of 1/16 and 1/8 inch were represented by these specimens. Damage similar to that for metal but at a very slow rate was obtained for the 1/16-inch-thick specimen (Figures 9 and 10). A tear or rupture at the center of the 1/8-inch specimen occurred after a very short period of testing (Figure 11). The tests indicated that the value of rubber lining for any but mild cavitation would be questionable.

Whether or not a rubber-lined section could be used even for the mild cases would depend on where cavitation occurred under the various operating conditions. The location for these conditions was therefore investigated. Since concrete has relatively little resistance to cavitation erosion a short section of concrete pipe placed at different locations below the valve was considered. A section of concrete pipe was first placed below a 12-inch valve, but only slight damage occurred adjacent to the valve because of inadequate laboratory facilities for testing this size valve at high heads (Figure 12). An arrangement using a 6-inch standard waterworks valve and a 2-foot-long section of 8-inch pipe lined with 1 inch of concrete was then used.

The tests showed that cavitation with the valve partially open first began at the downstream edge of the leaf recess and that the cavitation envelope extended farther downstream as the back pressure on the valve decreased or the head increased.

With the 2-foot-long concrete-lined section of pipe placed different distances downstream, it was possible to determine where damage would occur under various conditions. The location of the damage varied with the back pressure and thus with the cavitation index. It was possible to get cavitation damage as much as 20 pipe diameters distance downstream of the valve by decreasing the back pressure (Figure 13). A plot of distance of damage below valve against cavitation index showed that the damage would be confined to the downstream end of the valve when the index exceeded 0.4 and that the damage occurred farther downstream as the downstream pressure was reduced and the cavitation index was decreased below this value (Figure 14). Most of the tests on this valve were at about 20 percent opening and 130 feet of upstream head. Tests on a 12-inch gate valve and a 6-inch globe valve showed good agreement. However, even with much smaller values of K the damage was confined to the globe valve. For

the openings tested on the gate valve (20 to 30 percent) there seemed to be a circulation of water on top of the jet and immediately downstream of the gate leaf. This appeared to prevent the occurrence of general cavitation conditions in this region. Cavitation pressures will no doubt occur in this region as the gate leaf nears the wide open position. Inadequate pump capacity for the large openings prevented determining if, and under what conditions, the cavitation pressures would occur in this region. In most cases in irrigation distribution systems the valves would not be operated at the larger openings except under reduced head where cavitation is not likely to occur, thus this factor was not important in this particular study.

A change in shape of the flow passage immediately downstream of a valve will alter the flow conditions and thus the cavitation characteristics. The placing of a cone downstream may increase the cavitation tendency while a sudden enlargement will decrease the tendency. A sand-cement-mortar-lined, 14-inch tee section (Figure 15) placed immediately below an 8-inch standard gate valve sustained no damage after 9 hours operation under heads of 118 and 150 feet with the valve 6-1/4 and 12-1/2 percent open. A cavitation index curve for this arrangement is shown as Curve A, Figure 6. The critical cavitation index for this case appears to be about 0.8.

An examination of the data taken from the various gate valves indicated that the test results could be used as design criteria for turnouts controlled by valves. In general, for valves in pipelines and values of K above 2.0 there was no evidence that cavitation was present. For values of K above 1.0 and below 2.0 the cavitation was of a very mild nature. For values of K below 1.0 the intensity of cavitation increased as the value of K decreased. For values of K above about 0.4 the damage caused by cavitation was confined at the downstream end of the valve. For values of K below 0.4 the damage occurred farther downstream as the value decreased. For a value of K computed for a particular installation and with the above information it is possible to ascertain whether or not cavitation would be of particular concern and to decide what steps should be taken to alleviate the conditions. A design chart which indicates the seriousness of the cavitation conditions and the treatment to be applied was prepared by the designers. The chart based on a vapor pressure of 31 feet below atmospheric provides a rapid, convenient means for examining an installation for cavitation tendencies and corrective treatment. It is believed that the proposed corrective treatments of a rubber-lined pipe section or a steel-lined expanded section are the most practical at the present; however, the best solution in all cases where cavitation is present is to provide a sudden enlargement immediately downstream of the valves. A plot of the chart data was prepared for this report (Figure 16).

Actually the placing of a suddenly enlarged section immediately below the valves in all cases would assure a minimum of cavitation damage, particularly when the gate valve developed by the

Bureau is used (GV-7 valve, Figure 17). It appears that this treatment would be satisfactory for heads up to 150 feet when the valve openings are kept small, probably below 50 percent. However, further testing is required to establish ultimate limits of this design, both in head and relative size of valve and expanded section.

Globe valves. The jet dispersion for the globe valve was not as great as for the gate valve and the amount of dispersion changed little with opening (Figure 18).

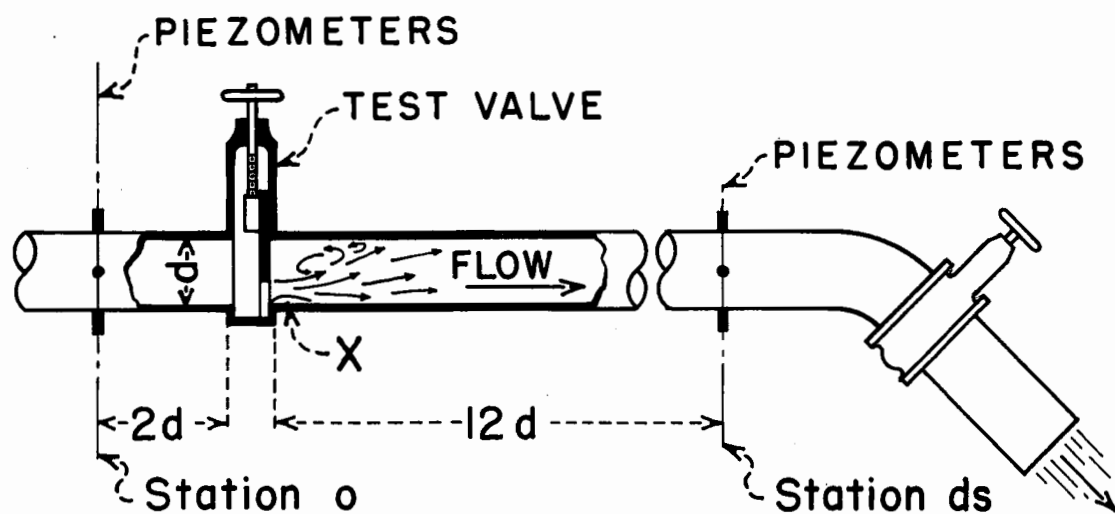
Globe valves are noted for their high losses and the free-discharge and in-line coefficients of about 0.34 for flow tending to open the disc, and the in-line coefficient of 0.29 with the flow tending to close the disc are evidence of this characteristic. The fact that there was very little change in the discharge coefficient for openings greater than about 80 percent indicates that the disc exerts very little control on the flow over this range of opening. The characteristic is the same regardless of the direction of flow in the valve.

The initial tests on globe valves were made on a valve having screw-joints. The tests were made at about 2/3 opening with the flow tending to close the disc and then tending to open it. The sharp edges of the pipe within the valve were conducive to cavitation and some damage was noted in the pipe a short distance downstream of the edge of the downstream joint after 64 hours of operation under a differential head of 126 feet with the flow tending to close the disc. Considerable pitting of the downstream surface of the valve diaphragm was noted after the valve was operated for 129 hours under the same head conditions with the flow tending to open the disc.

It was believed that the objectionable features of the screw-joints would be eliminated by using valves with flanged joints. Tests on a 6-inch globe valve with flanged joints gave clear evidence of cavitation in similar locations after the valve had been operated for 48 hours at a differential head of about 118 feet with the flow tending to close the disc.

The critical cavitation index for globe valves seems somewhat smaller than for gate valves. In fact cavitation was not audible at any value of K greater than 0.9 and the index curves for flow tending to open or close the valve disc show the critical value to be about 1.0 (Figures 19 and 20). This was the case when the flow was tending to close the disc even though the efficiency of the valve was decreased by cavitation when the opening was small and increased by cavitation when the opening was large (Figure 20).

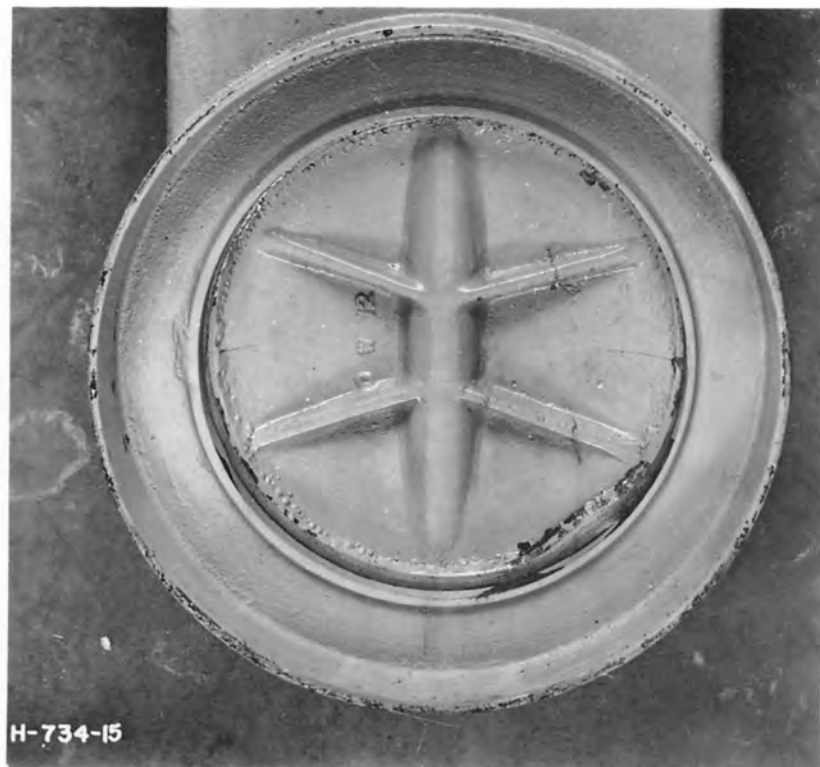
Since cavitation is mainly confined within a globe valve it is important that any installation using one provide sufficient back pressure in the pipe 12 diameters downstream to keep the cavitation index K above 1.0. Globe valves cannot be operated at high differential heads and low back pressures without cavitation being present.



IRRIGATION VALVE STUDY
VALVE TEST ARRANGEMENT

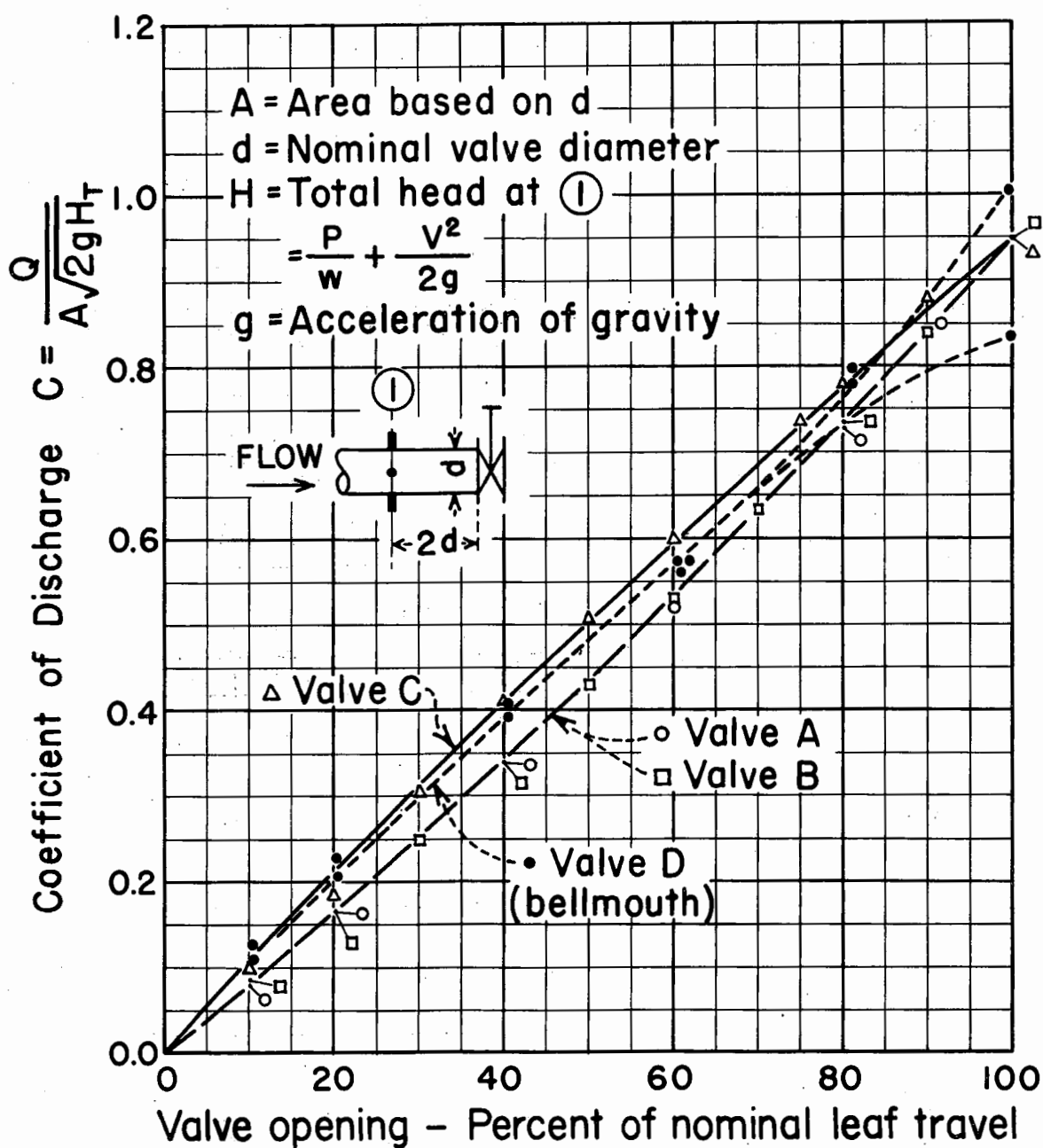


A. Gate valve with 6.1 cfs free discharge at 125-foot head - valve 17.5 percent open.



B. Fractured leaf and damaged seat caused when valve was operated under head of 127 feet.

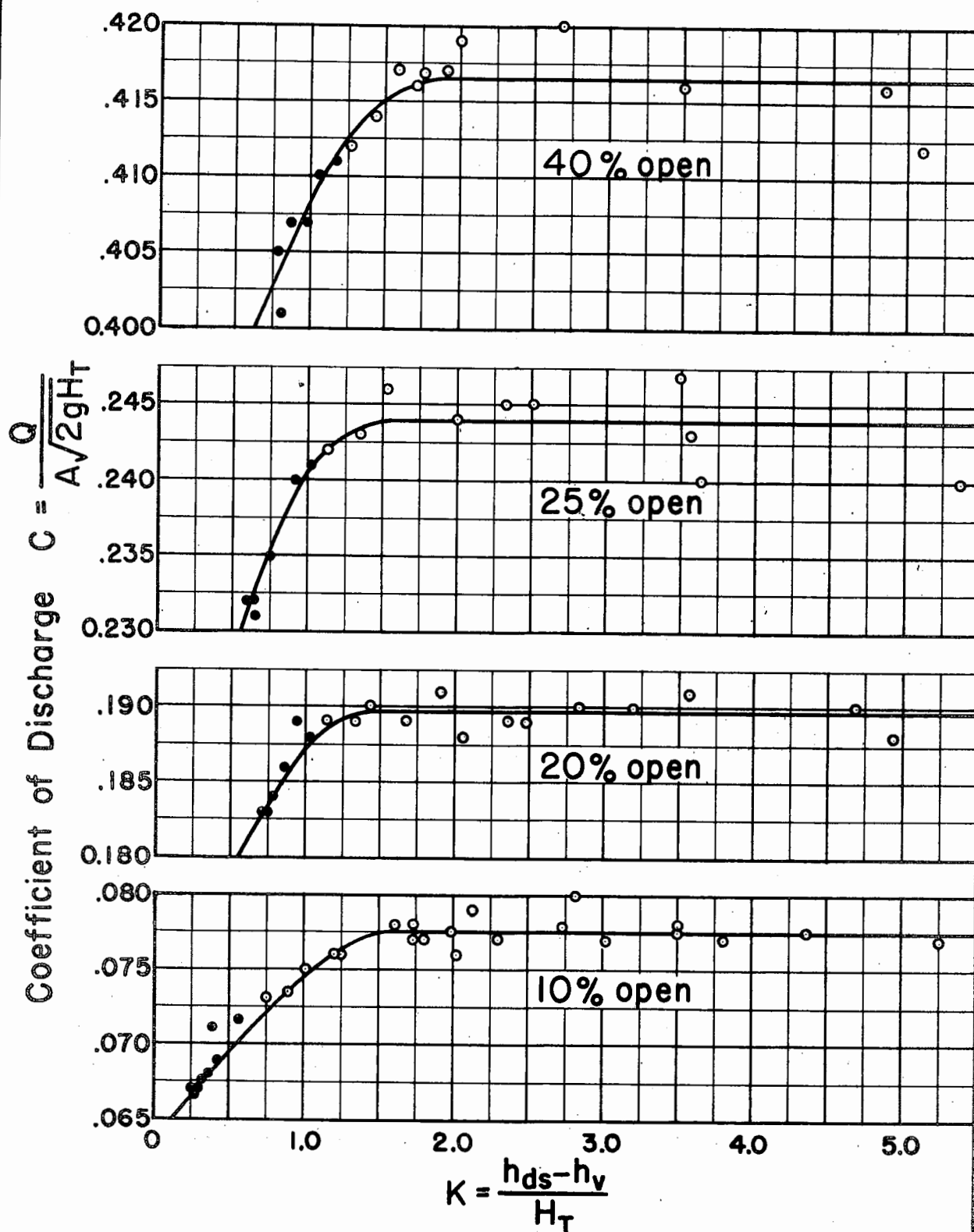
Irrigation Valve Study
Flow conditions for partially open
gate valve and damage to leaf of Valve A.



IRRIGATION VALVE STUDY

DISCHARGE COEFFICIENT FOR FREE-FLOW
FROM GATE VALVES

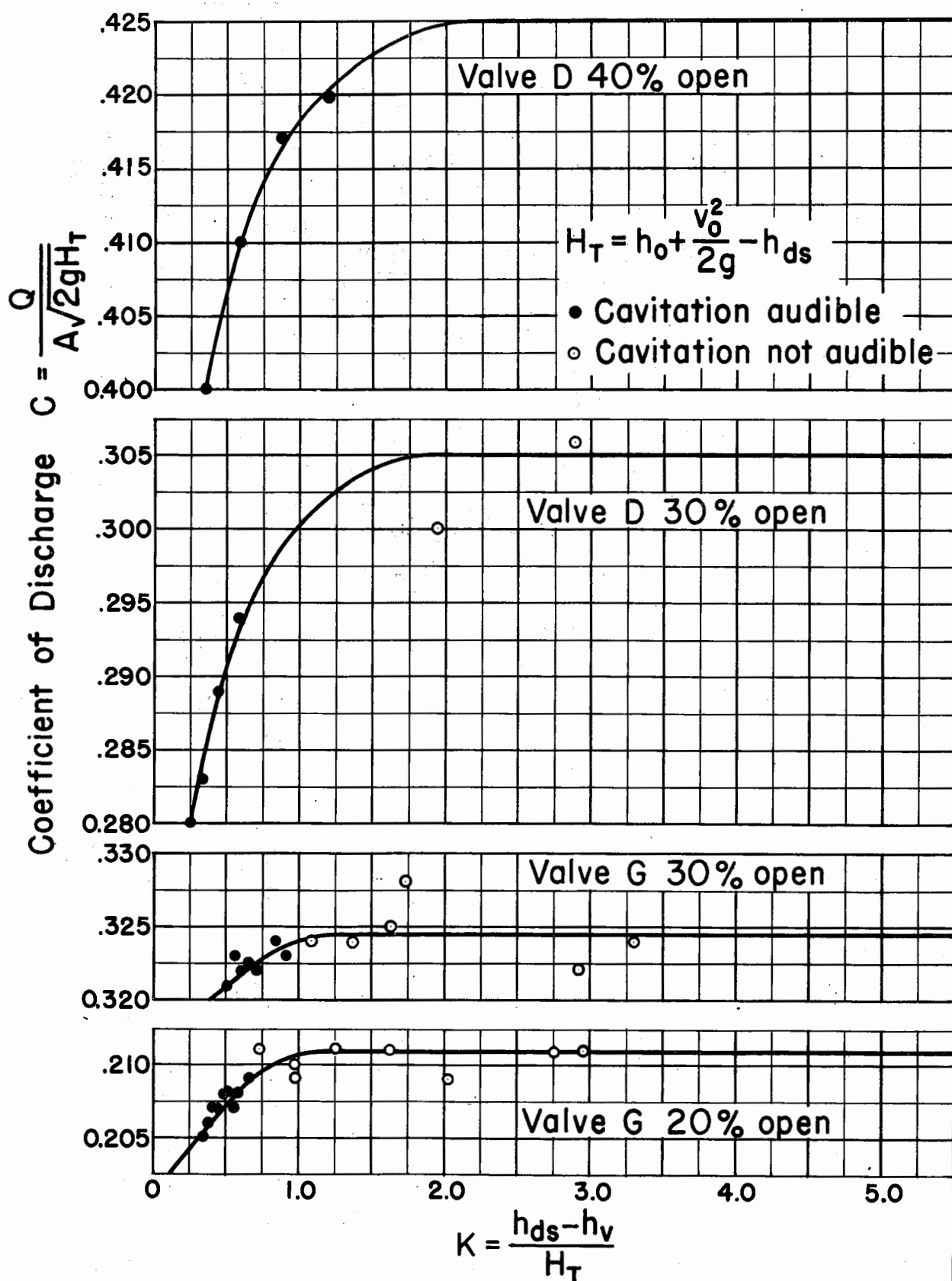
FIGURE 4
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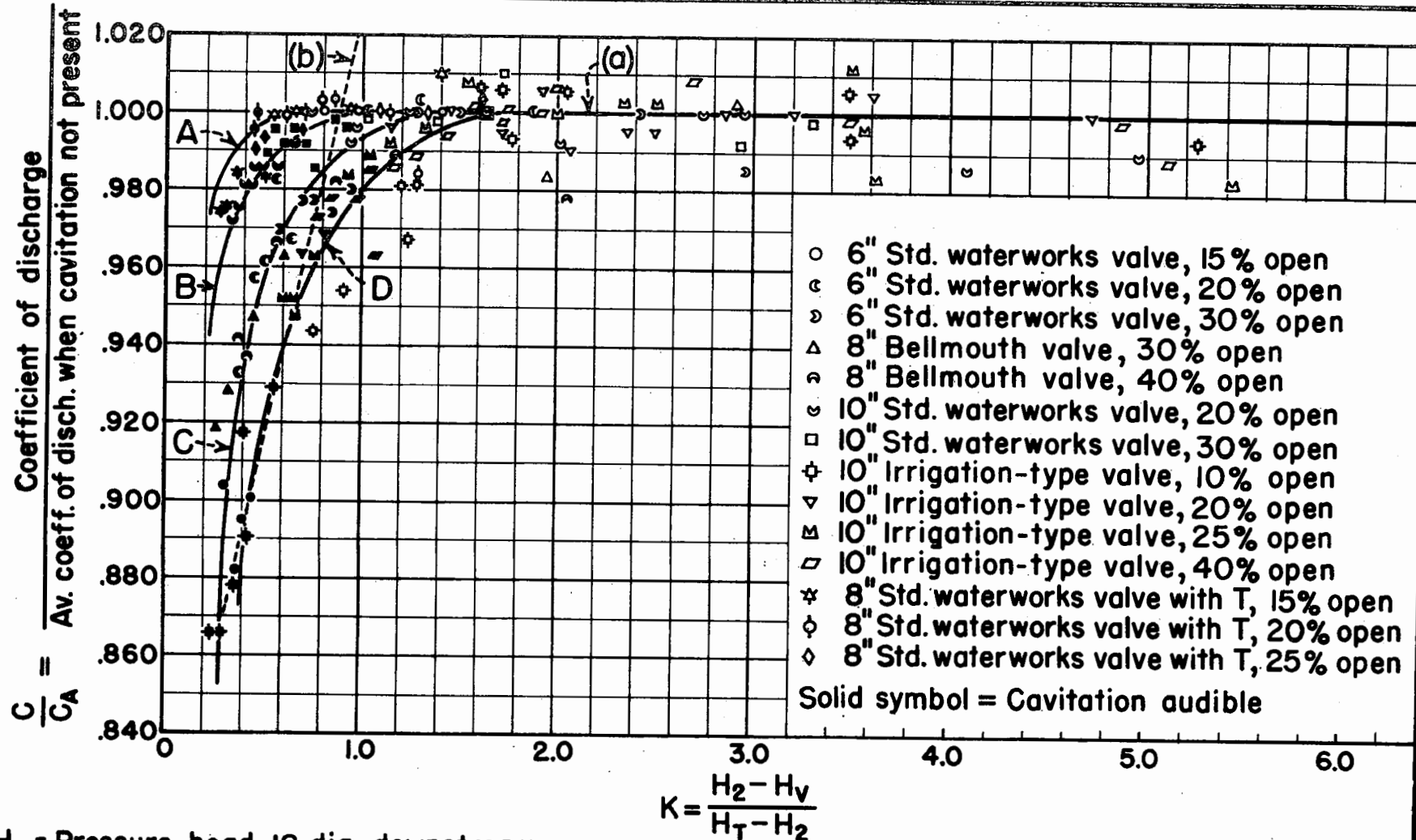
$$H_T = h_0 + \frac{v_0^2}{2g} - h_{ds}$$

- Cavitation audible
- Cavitation not audible

IRRIGATION VALVE STUDY
CRITICAL VALUES OF
CAVITATION INDEX
VALVE B

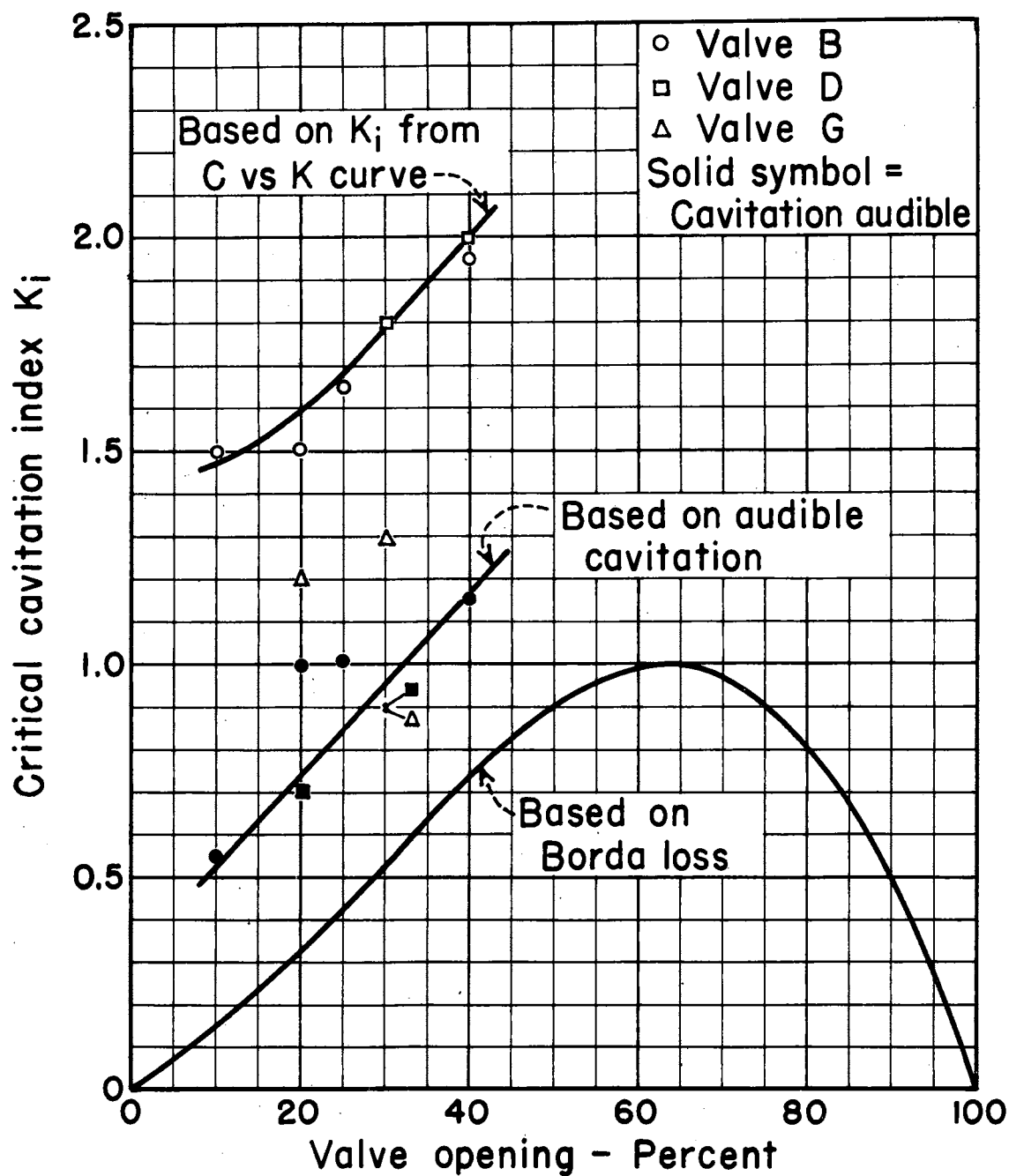


IRRIGATION VALVE STUDY
 CRITICAL VALUES OF CAVITATION INDEX
 VALVES D AND G

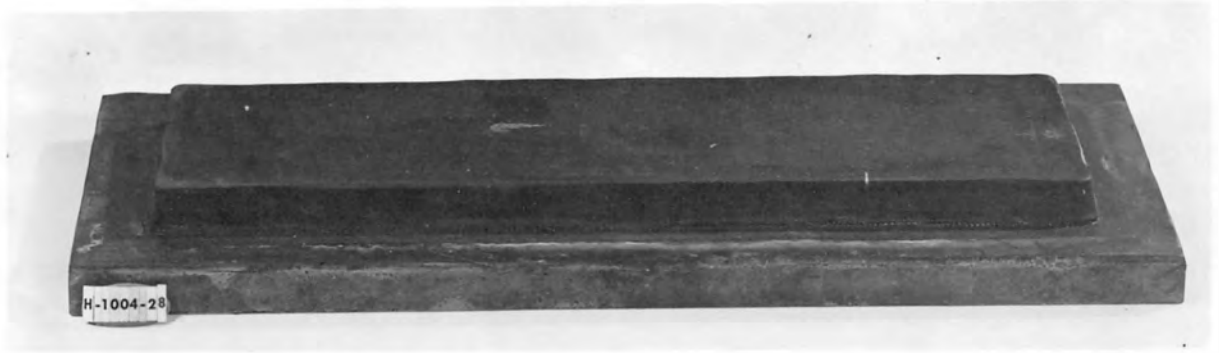

 FIGURE 6
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H_2 = Pressure head 12 dia. downstream
 H_v = Vapor pressure relative to atmospheric pressure
 H_T = Total head 2 dia. upstream

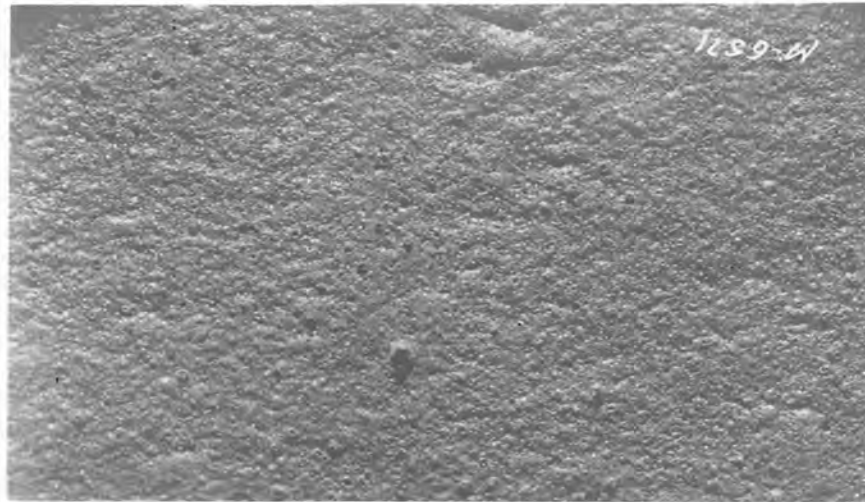
IRRIGATION VALVE STUDY
 CAVITATION INDEX
 FOR GATE VALVES



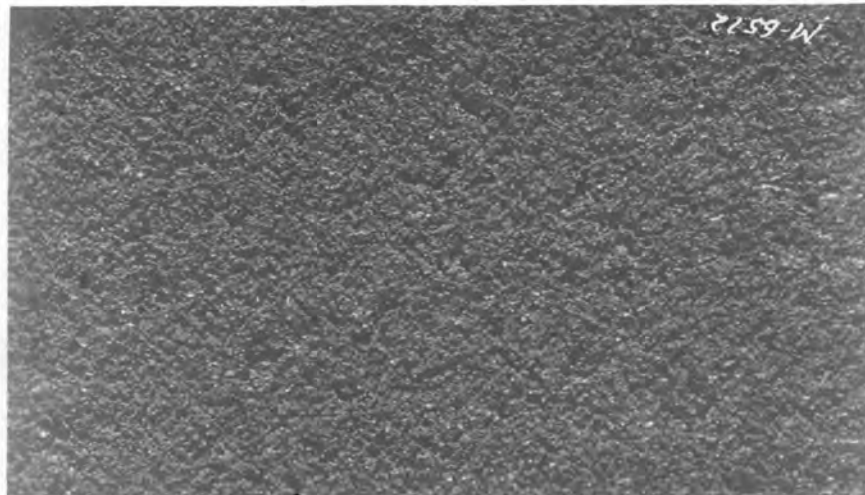
IRRIGATION VALVE STUDY
CRITICAL CAVITATION INDEX
FOR GATE VALVES



... specimen used for cavitation tests - 1/8-inch rubber vulcanized to steel.

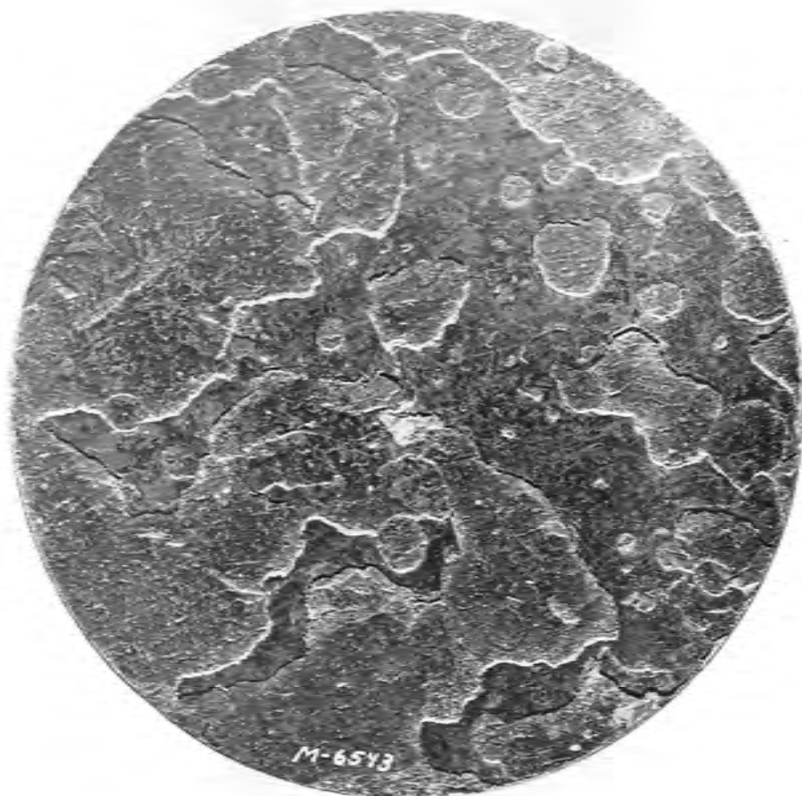


B. 1/8-inch-thick rubber surface not subjected to cavitation.



C. 1/8-inch-thick rubber - surface subjected to cavitation for 100 hours.

**Irrigation Valve Study
Cavitation damage to rubber coatings in
Venturi-type cavitation machine**

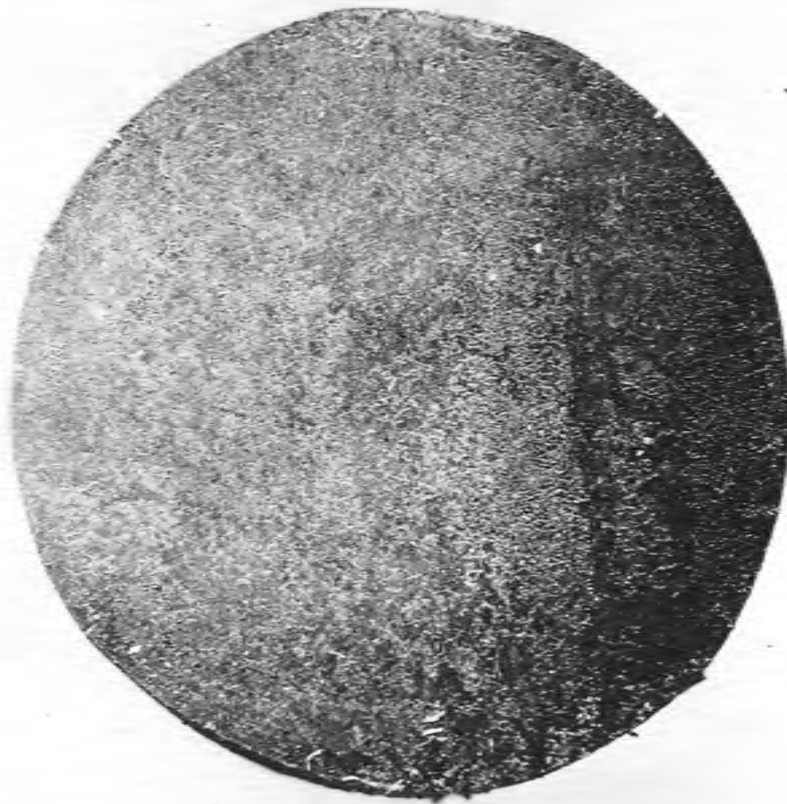


A. Surface of 5/8-inch diameter steel specimen before test - Mill scale on surface.



B. Surface of steel specimen after 10 hours in magnetostriction oscillator.

Irrigation Valve Study
Cavitation damage to steel surface
tested in magnetostriction oscillator

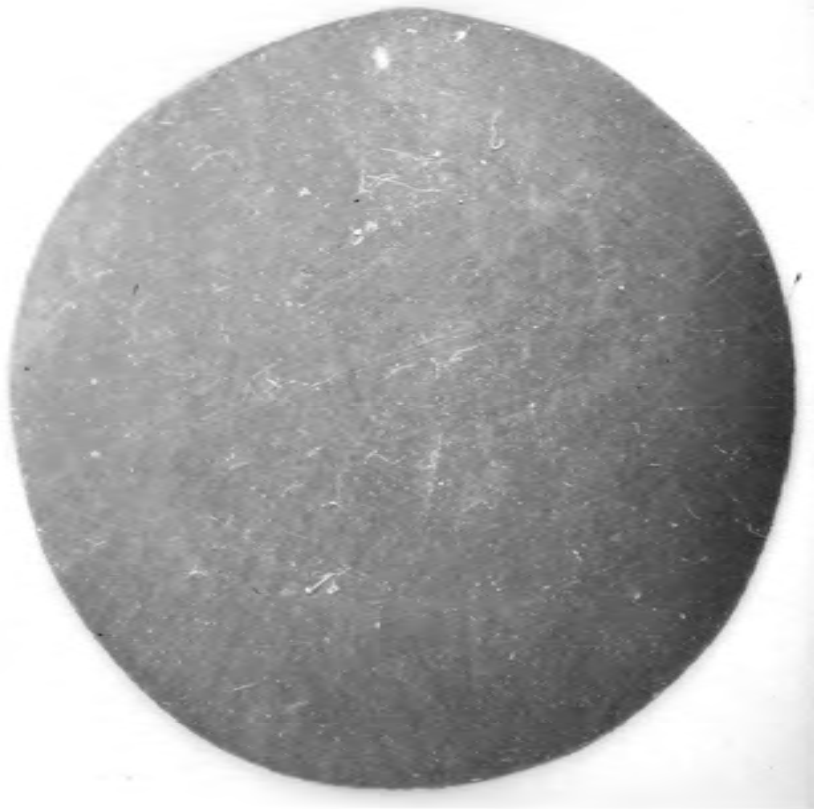


A. Surface of 5/8-inch diameter, 1/16-inch thick rubber disc vulcanized to steel - before test.



B. Surface of 1/16-inch thick rubber specimen after 34 hours in magnetostriction oscillator.

Irrigation Valve Study
Cavitation damage to surface of 1/16-inch thick rubber
disc tested in magnetostriction oscillator



A. Surface of 5/8-inch diameter, 3/16-inch thick rubber disc vulcanized to steel - before test.



B. Surface of 3/16-inch thick rubber specimen after 5 hours in magnetostriction oscillator.

Irrigation Valve Study
Cavitation damage to surface of 3/16-inch thick
rubber disc tested in magnetostriction oscillator

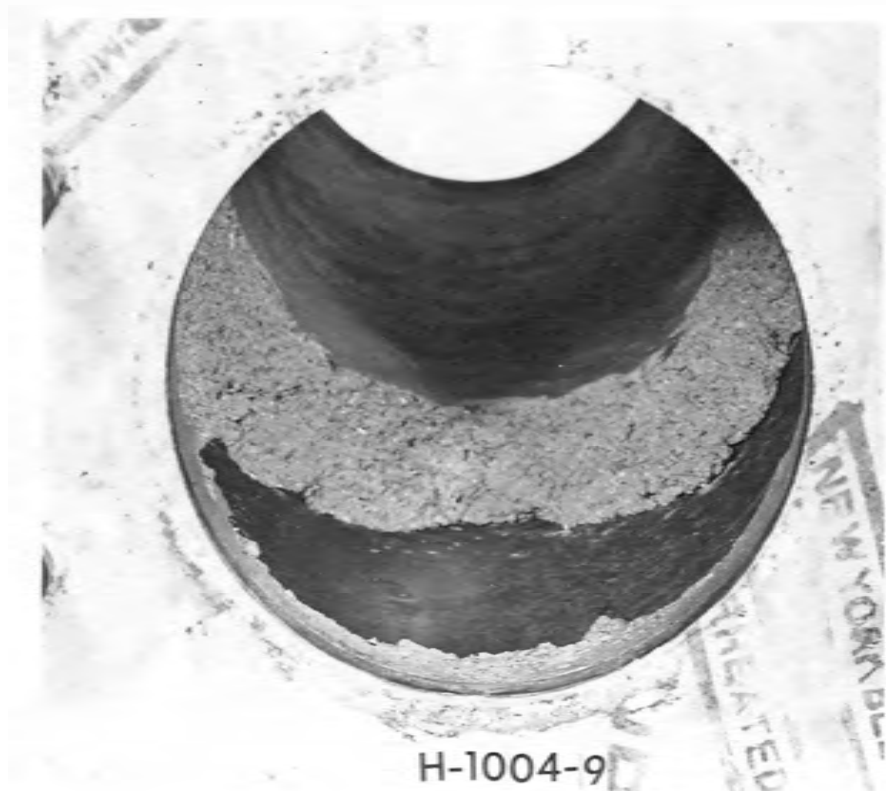


A. Section of 12-inch concrete pipe before test.

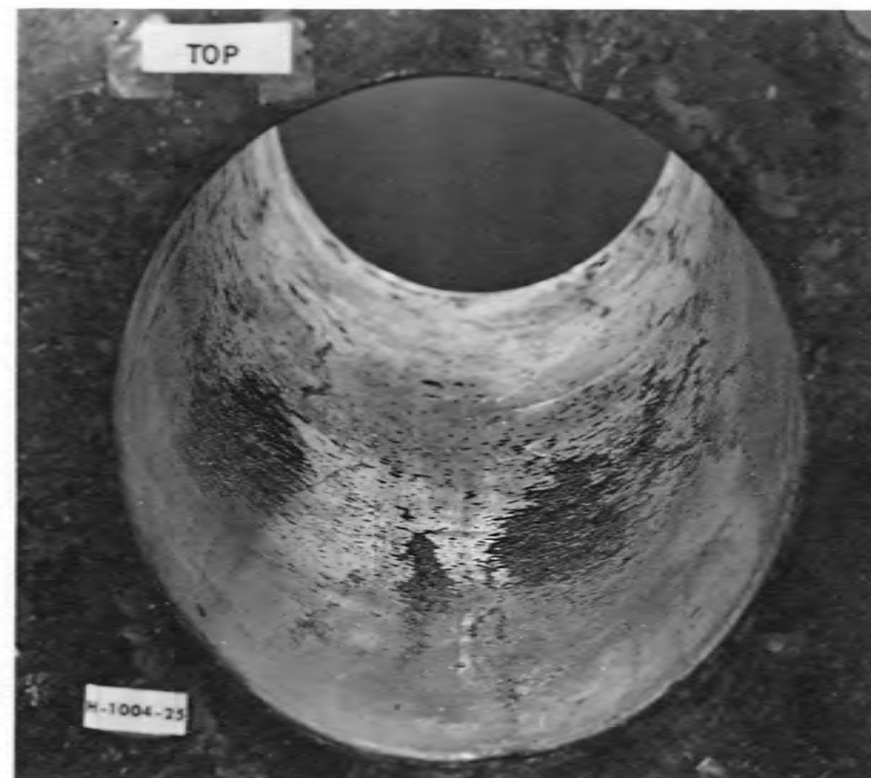


**B. Upstream end of pipe section after valve was operated
23 percent open for 33 hours under head of 81 feet.**

Irrigation Valve Study
**Cavitation damage to concrete pipe placed downstream
of 12-inch gate valve**

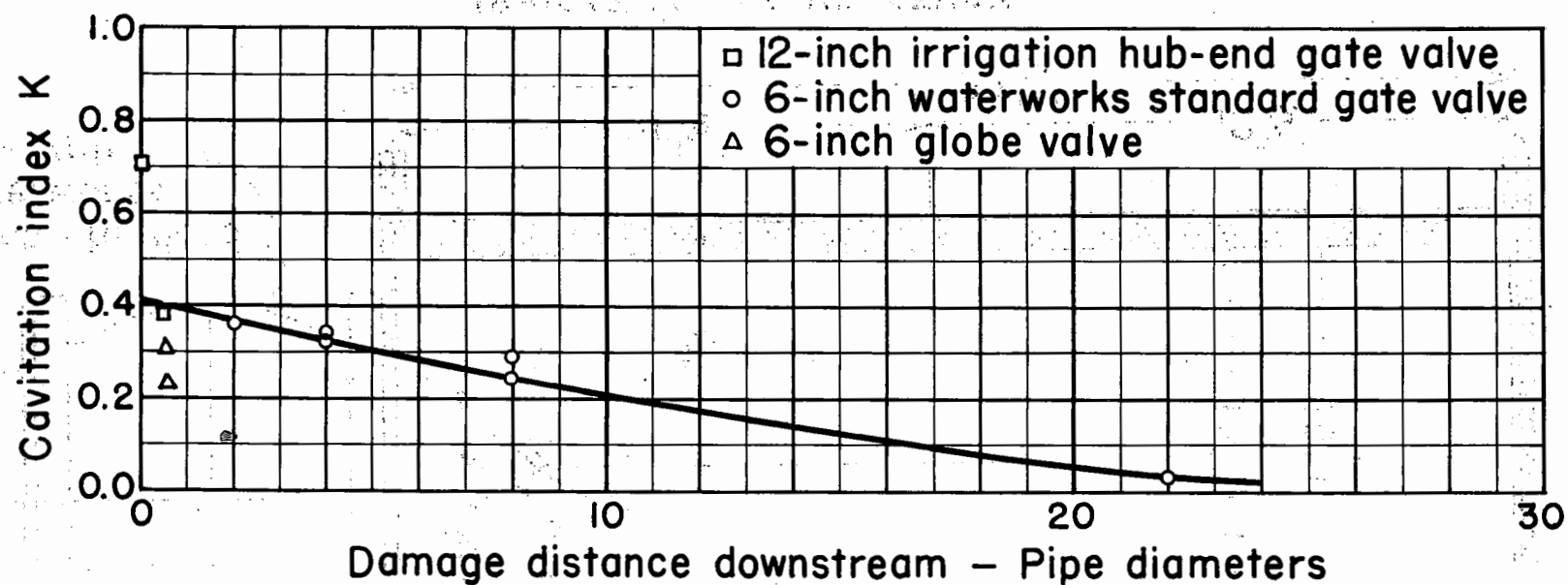


A. Concrete pipe section attached to 6-inch Waterworks standard gate valve. Valve operated for $7\frac{1}{2}$ hours with upstream head of 127.2 feet, downstream head of 13.6 feet, cavitation index of 0.36.

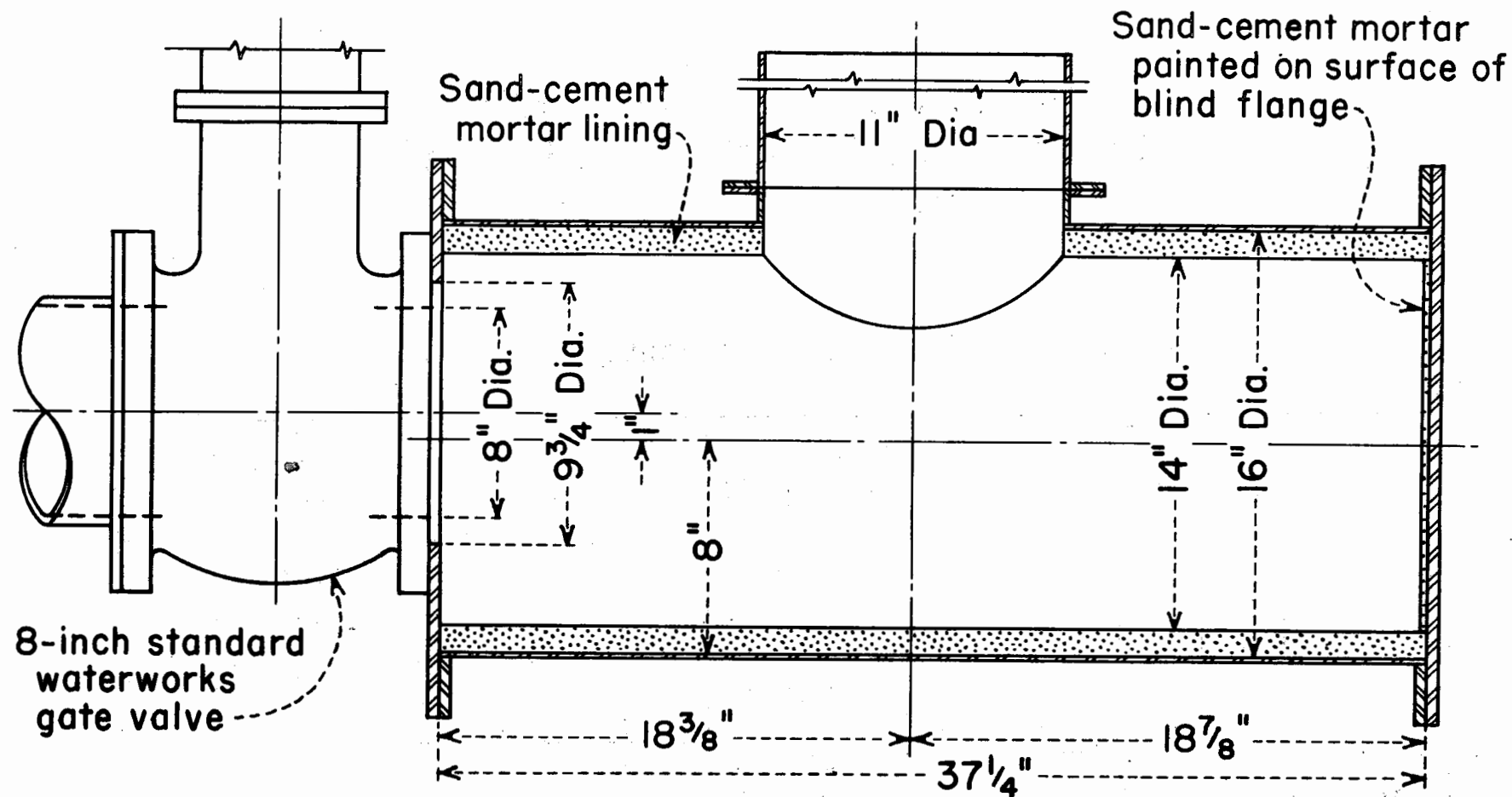


B. Concrete pipe section placed $8\frac{1}{2}$ feet downstream from 6-inch Waterworks standard gate valve. Valve operated for 7 hours with upstream head of 168.5 feet, downstream head of -23.8 feet, cavitation index of 0.20.

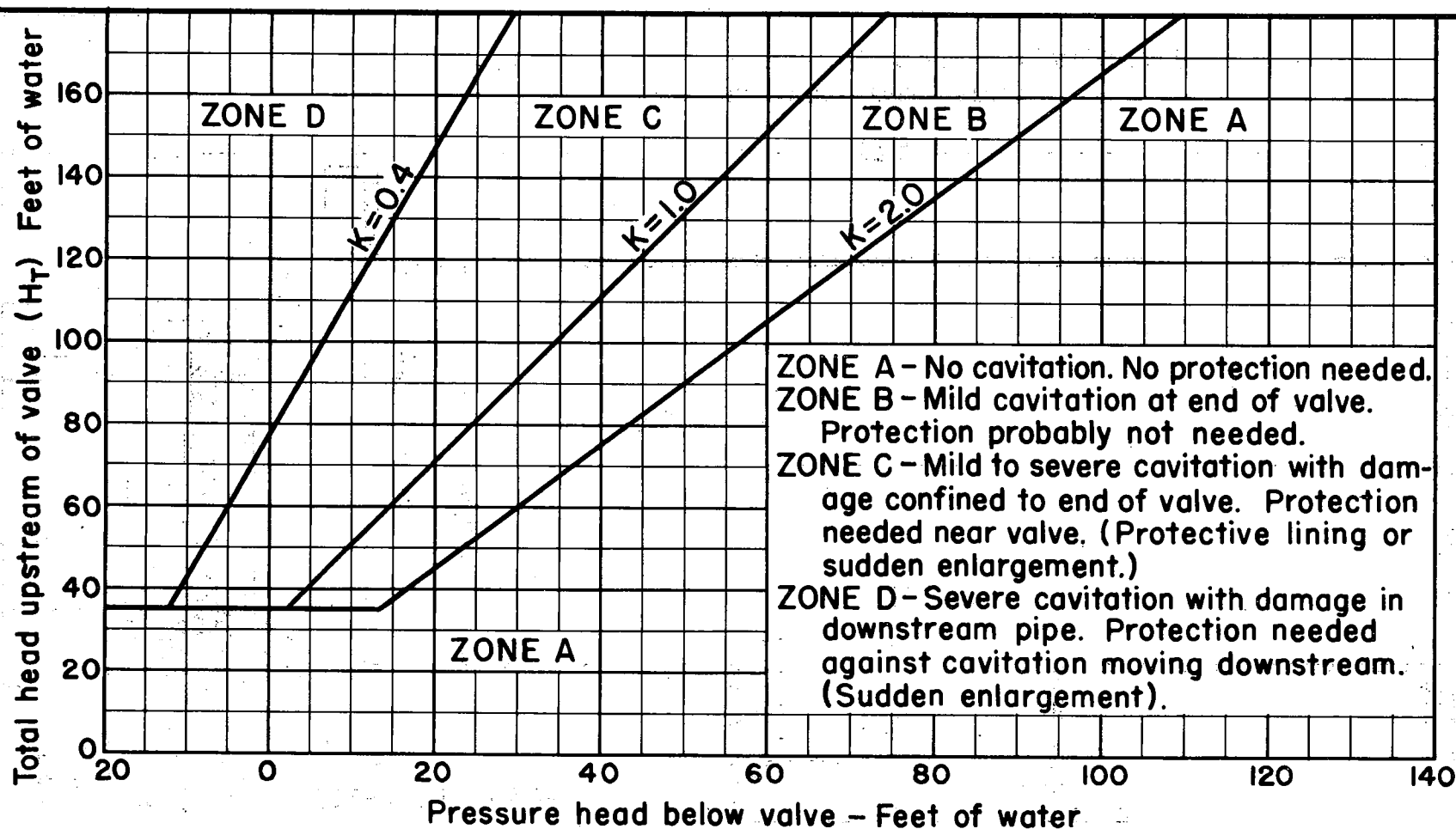
Irrigation Valve Study
Cavitation damage in 2-foot-long section of concrete pipe
downstream of gate valve operated at partial opening.



IRRIGATION VALVE STUDY
DISTANCE OF CAVITATION DAMAGE
DOWNSTREAM OF VALVE



IRRIGATION VALVE STUDY
 CONCRETE LINED T-SECTION
 AS SUDDEN ENLARGEMENT BELOW GATE VALVE



Note: Plot based on -

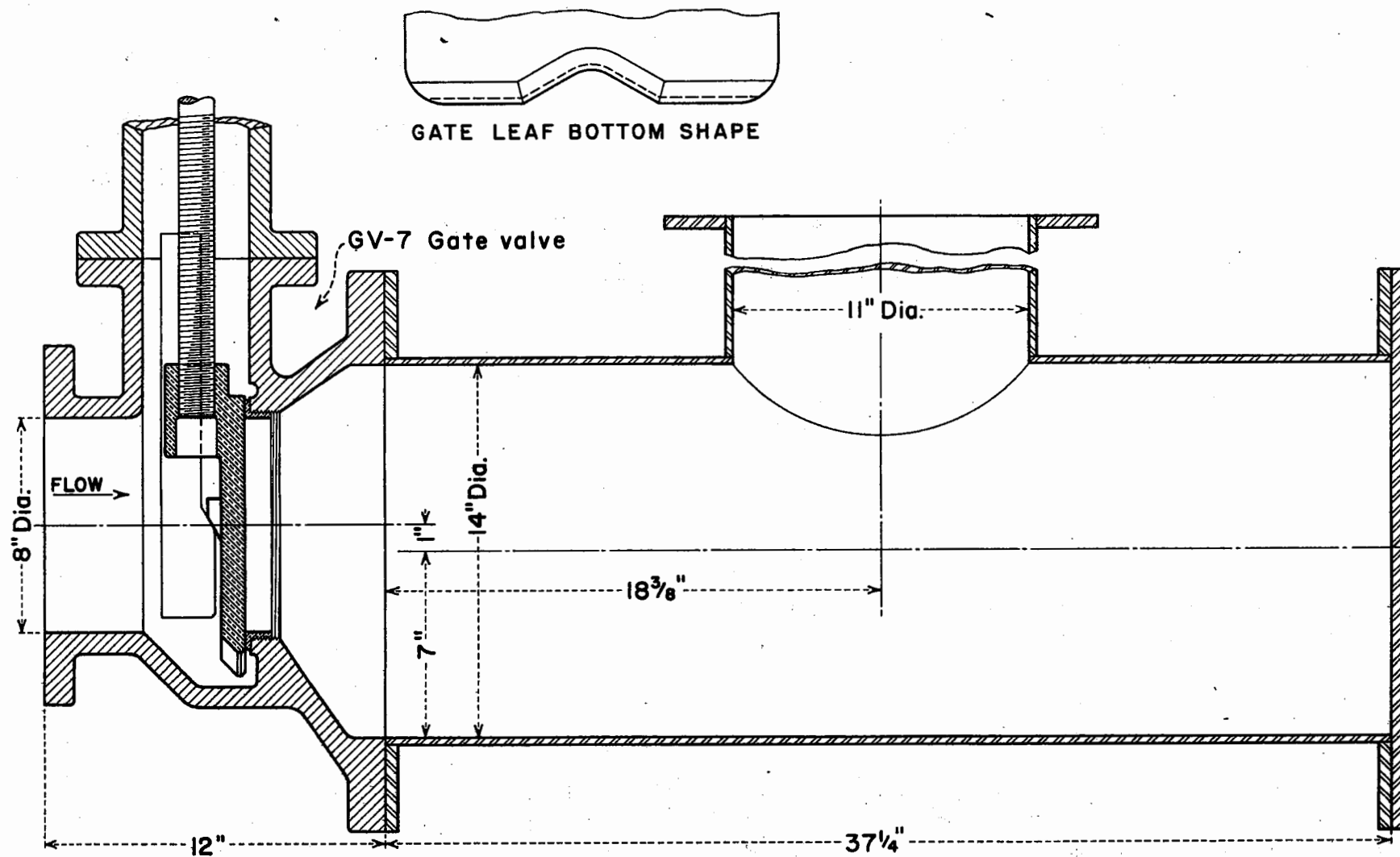
$$K = \frac{H_2 - H_v}{H_T - H_2} = \text{Cavitation index.}$$

H_2 = Pressure head 12 dia. downstream.

H_T = Total head 2 dia. upstream.

H_v = Vapor pressure relative to atmospheric pressure (assumed to be -31 feet).

IRRIGATION VALVE STUDY CAVITATION CHARACTERISTICS OF GATE VALVES IN PIPE LINE



IRRIGATION VALVE STUDY

GV-7 VALVE WITH SUDDEN ENLARGEMENT

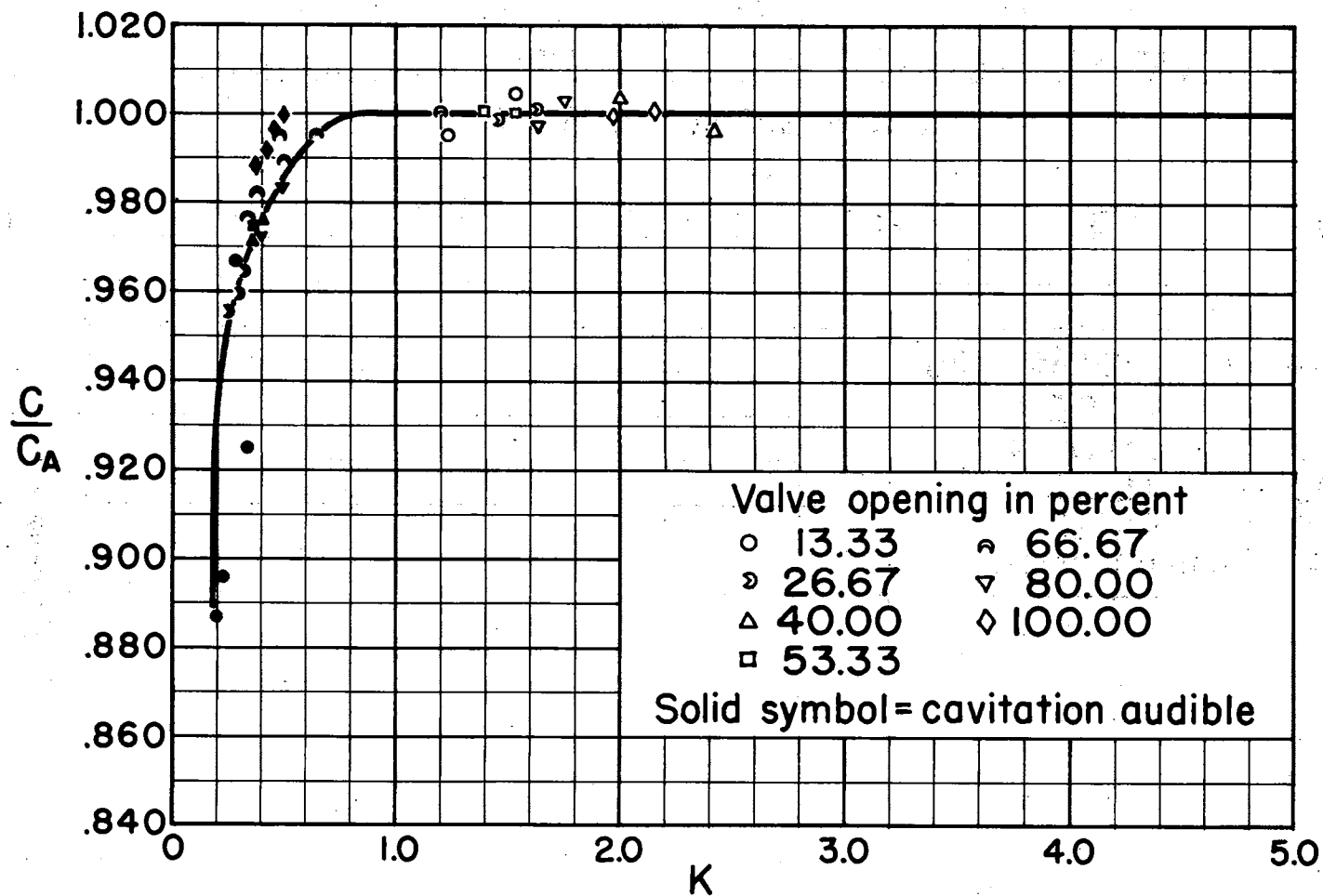


A. Valve open 1/2 of stem travel.

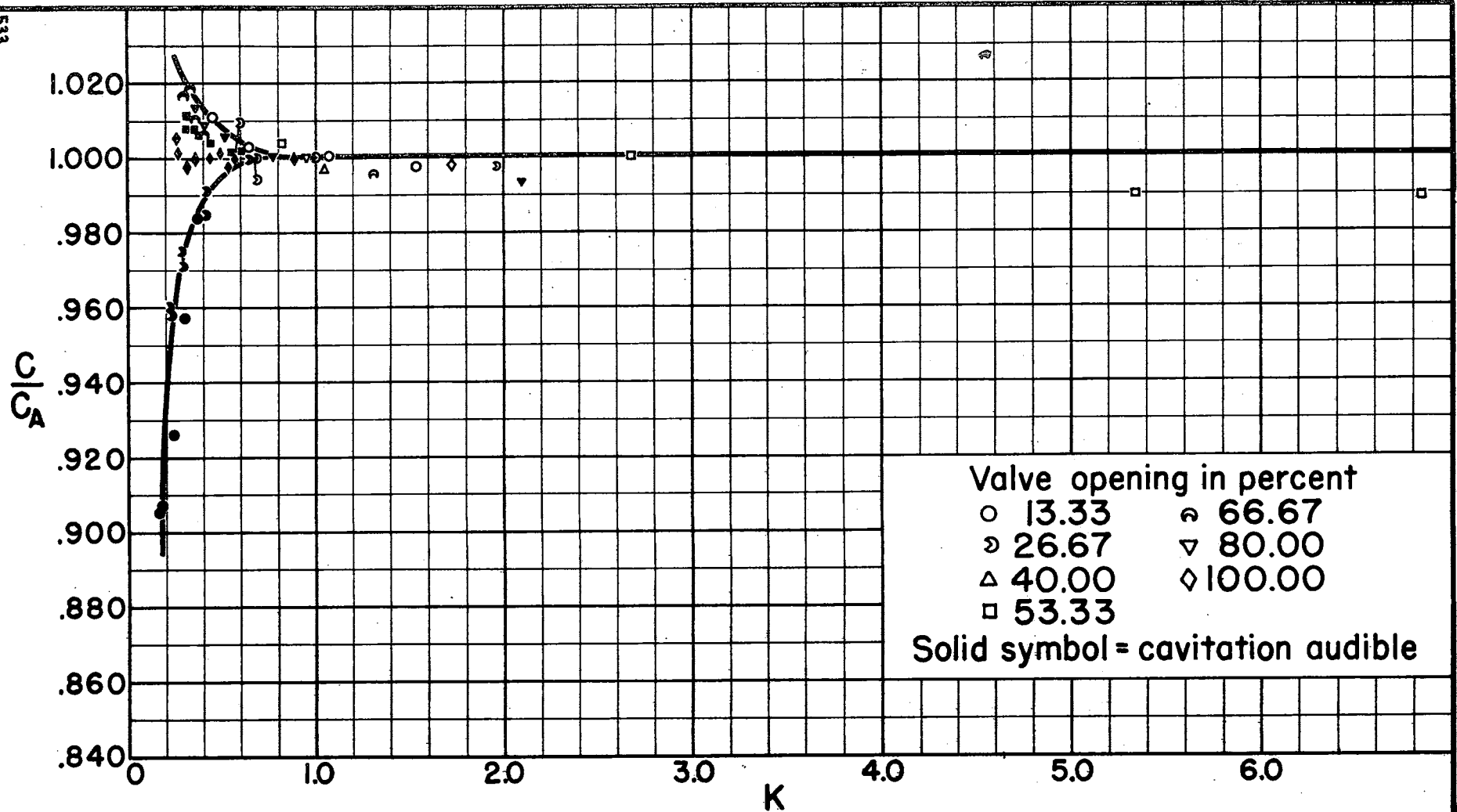


B. Valve fully open.

Irrigation Valve Study
Flow conditions for free discharge of 3 cfs from 6-inch
globe valve under 35-foot head.



IRRIGATION VALVE STUDY
 CAVITATION INDEX FOR 6" GLOBE VALVE
 DISC SEATING AGAINST FLOW



IRRIGATION VALVE STUDY
CAVITATION INDEX FOR 6" GLOBE VALVE
DDISC SEATING WITH FLOW

