UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

IMPORTANCE OF SMOOTH SURFACES ON FLOW BOUNDARIES DOWNSTREAM FROM OUTLET WORKS CONTROL GATES

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Subject: Importance of Smooth Surfaces on Flow Boundaries Downstream from Outlet Works Control Gates

This report discusses recent laboratory and field tests which clearly show that small irregularities in flow surfaces subjected to high velocity flow may trigger severe cavitation which will damage these surfaces. Examples of damage resulting from cavitation caused by such irregularities and the size of abrupt into-the-flow offsets which induce incipient cavitation are also discussed. Recommendations are made on how to treat the flow surfaces just downstream of control gates where the boundary layer redevelops after being disrupted by acceleration through the gate.

Information obtained recently from laboratory and field studies indicates that more attention should be given to assure smooth surfaces on flow boundaries immediately downstream of outlet works control gates than has been given in the past. The requirement for smooth surfaces in this region is brought about by the disruption, or partial destruction, of the turbulent boundary layer as the flow accelerates and discharges from the gates.

When a turbulent boundary layer is nearly destroyed, the flow velocities close to the boundary become about the same as that of the main stream and much higher than when the boundary layer is fully developed (Figure 1). These higher velocities at the boundaries below gates make a rough boundary more conductive to cavitation than the same roughness on a spillway or other surface where the head or the amount of fall are the same. It is in this region where the boundary layer is being reestablished below a gate that small surface irregularities, particularly abrupt offsets, are troublesome.

Laboratory tests on small abrupt 90°, sharp-cornered offsets into and perpendicular to the stream show that cavitation may occur downstream from a 5/16-inch offset at stream velocities of 29 feet per second when the pressure at the offset is approximately atmospheric or 30 feet of water absolute (Figure 2). The velocities below outlet works gates are usually much higher than those shown in the figure for incipient cavitation. This means that cavitation and destructive erosion of the surfaces will occur if surface irregularities of the offset-into-the-flow type are of any appreciable magnitude. Such erosion took place at Palisades and Wanship Dams during the past season's operation.

At Palisades Dam, where velocities just downstream from the gates were in the range of 100 to 115 feet per second, cavitation pitting occurred downstream of an abrupt offset of 1/8 inch (Figure 3). Similar offsets in the left passage below the Wanship outlet gates, where the velocities were about 93 feet per second, caused severe damage (Figure 4). Apparently, these offsets produced local cavitation that in turn increased the roughness of the surface so that damage progressed to that shown in the photograph. There was no cavitation damage below the right gate where no offsets into the flow were reported.

Pitting was also noted at the downstream end of a bevel of about 10:1 which had been formed by grinding an into-the-flow offset at the end of the Palisades gate frame (Figure 5). The probability of this damage has been indicated in model tests which show that low pressures form downstream of lines of intersection for bevels of 12:1 and 24:1 (Figure 6). When high velocity flows pass the abrupt changes in alinement of these surfaces, the pressures are reduced to vapor pressure and cavitation and cavitation pitting takes place. Typical pitting downstream of a 12:1 bevel at a stop log slot is shown in Figure 7.

Offsets away from the flow do not appear critical if the offsets are small. This is not true of large offsets as evidenced by the erosion shown in Figures 8 and 9. The offset of about 1-1/4 inches, in this case, occurred between the curved corner of the gate frame and the square corner of the downstream flow channel. Actually, a fillet about 10 inches long was placed in the corner at the end of the gate frame. The damage at this offset on August 15, 1957, is shown in Figure 8. The increase in damage incurred during a month's operation at small openings is shown in Figure 9.

The magnitude of away-from-the-flow offsets which would be permissible for given velocities is uncertain at this time. However, laboratory tests on this type of offset are now in progress and tests on other common surface irregularities are planned. Conclusions concerning these offset types must await the results of current and future investigations.

In view of the laboratory tests and the field information from Palisades and Wanship Dams, it is considered imperative that specifications for outlet works include instructions that permit no abrupt into-the-flow offsets not parallel to the direction of flow for finite distances downstream of control gates where velocities exceed about 40 feet per second.

Since the corners of offsets in the field are seldom sharp and cavitation near the incipient range is very mild, it is believed that there is no need for special consideration of surface finishes and tolerances for velocities less than 40 feet per second.

Computations using available literature show that once the turbulent boundary layer is completely eliminated, a considerable length of continuous surface contact is required for it to be reestablished. For example, for a stream velocity of 100 feet per second, about 360 feet of continuous flow contact is required to reestablish a velocity distribution in which the velocity at a point 1/8 inch from a concrete flow boundary will be 50 feet per second. About 150 feet of continuous flow contact is required to obtain a velocity of 50 feet per second at a point 1/16 inch from the flow boundary. These distances will, of course, vary with the stream velocity and the roughness of the surfaces.

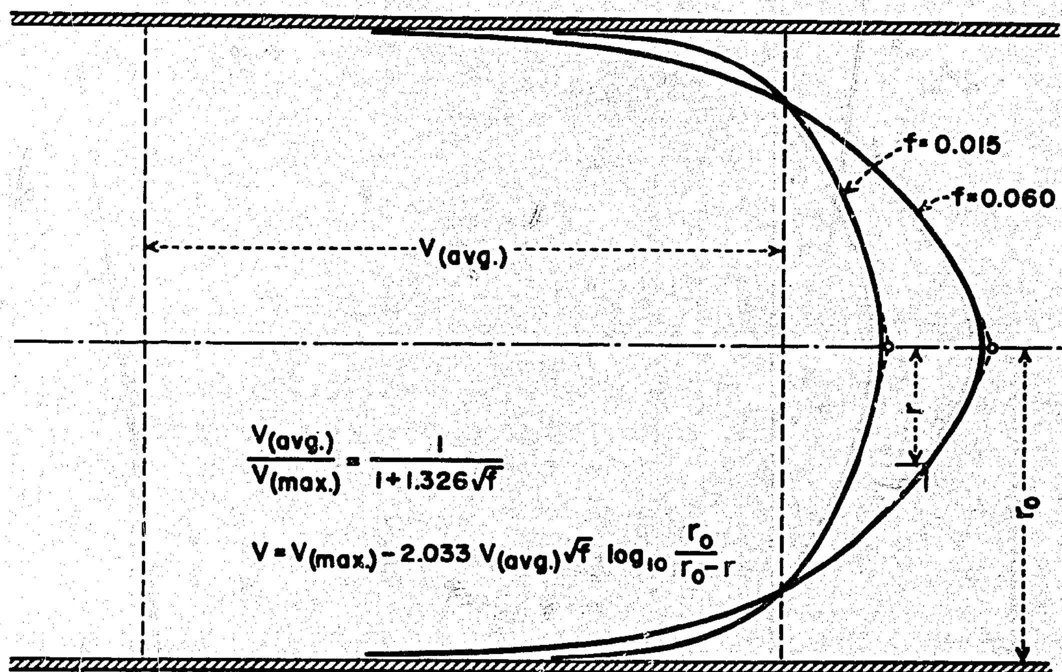
This analysis does not account for friction or consider the fact that some boundary layer exists at the gate. Both tend to reduce the distance required to reestablish the boundary layer.

Because of these factors and because the corners of field offsets are likely to be somewhat rounded, rather than sharp, it is believed that special treatment need not be applied to more than the first 15, 30, and 50 feet downstream of gate frames when stream velocities exceed about 40, 90, and 120 feet per second, respectively.

It is suggested that some provision be made to eliminate such offsets when they do occur. This might be accomplished by requiring the offsets to be ground on bevels of 20:1, 50:1, or 100:1, depending on whether the velocities exceed about 40, 90, or 120 feet per second. These treatments would be similar to those now specified for tunnel spillways. Surfaces downstream from the 15, 30, and 50-foot distances could have the same finishes and tolerances now specified for tunnel spillways.

At present, there are no data to indicate the desirability of changing specifications covering abrupt or gradual irregularities away from the stream, or abrupt or gradual irregularities into the stream where the boundary layer is fully developed, as would be the case in overfall or tunnel spillways. Future tests will indicate whether or not further changes in specifications are desirable.

Figure 1



COMPUTED VELOCITY PROFILES IN TURBULENT FLOW

Computed velocity profiles for smooth and rough surfaces in turbulent flow.

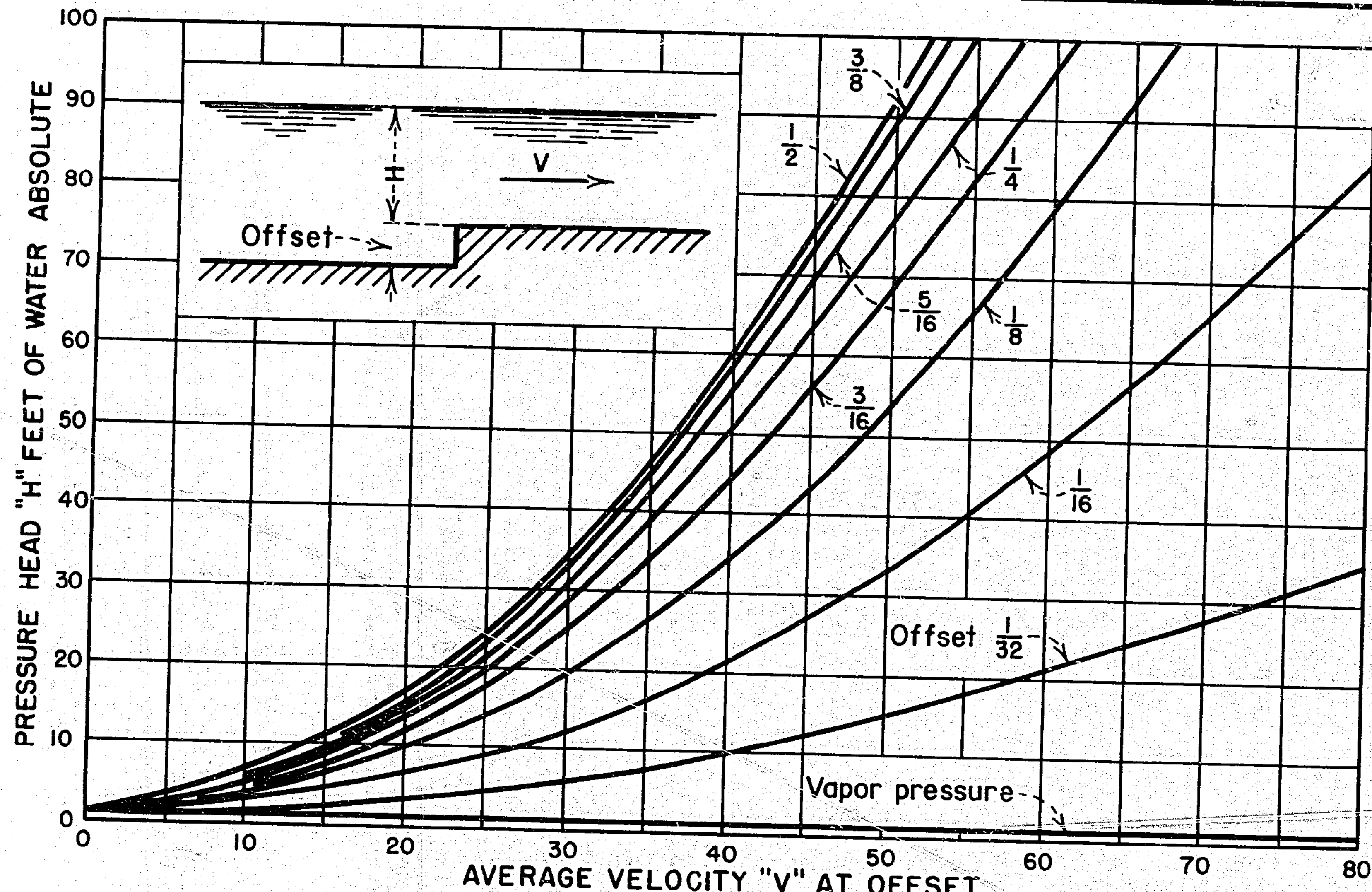


FIGURE 2.- HEAD-VELOCITY RELATIONSHIP FOR INCIPIENT CAVITATION—ABRUPT, INTO-THE-FLOW OFFSETS

606

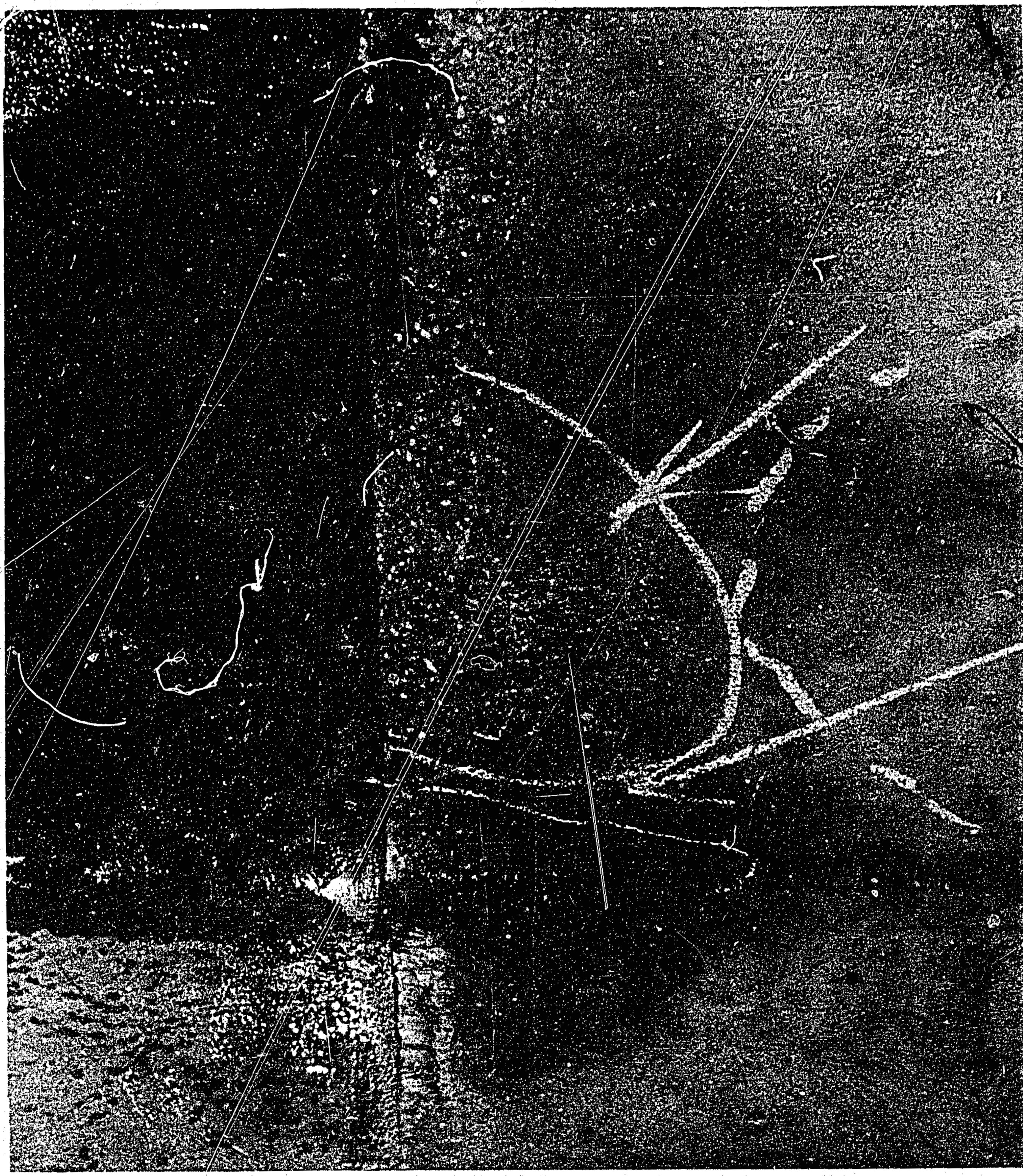
Figure 2

Figure 3

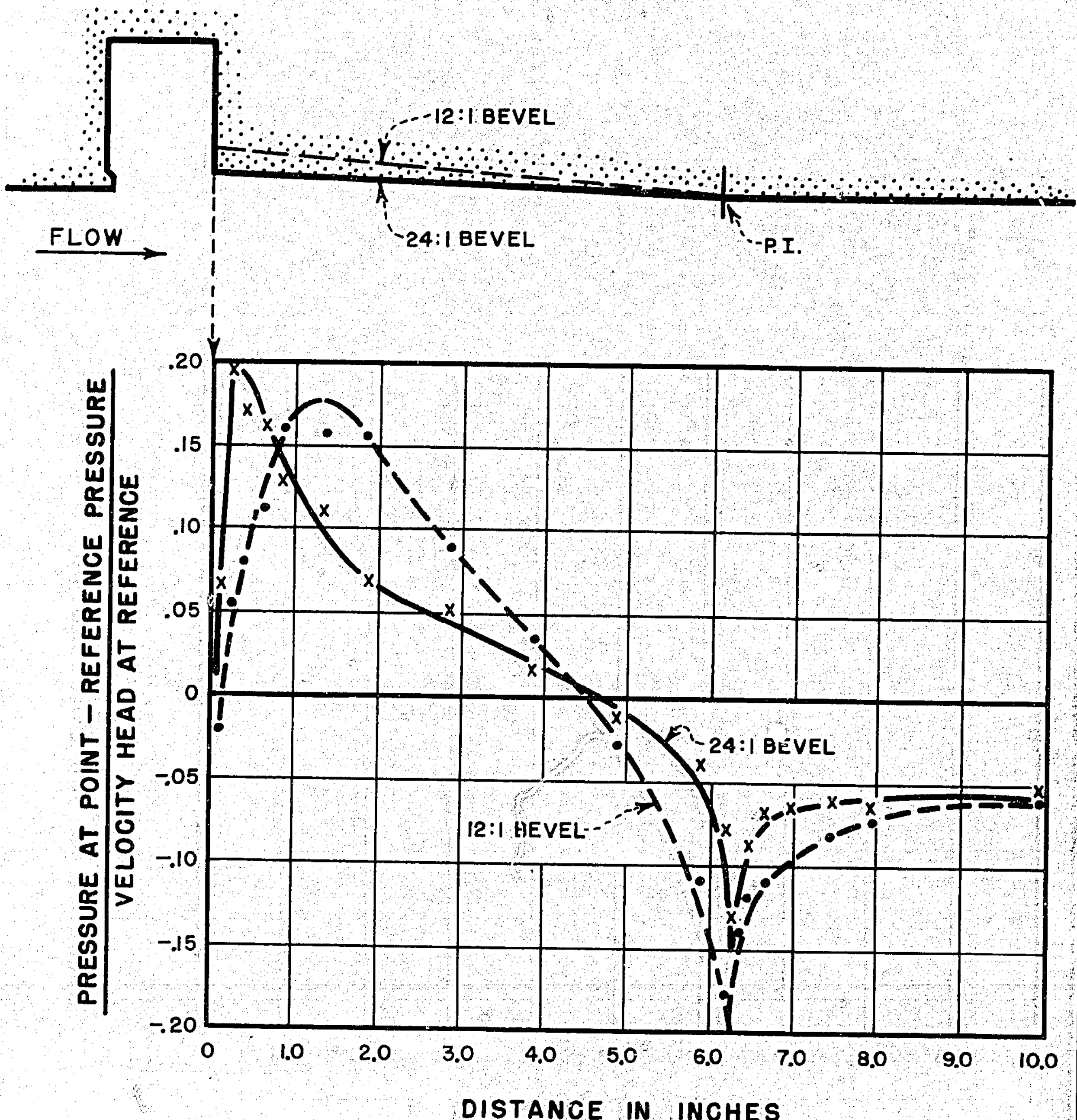
Palisades Project--Outlet No. 7
Cavitation-erosion at 1/8 inch,
abrupt, into-the-flow-offset
H-1340-38 February 1958

Weber Basin Project, Utah--Photograph No. P-526-400-4477 Wanship Dam. This view shows cavitation of the concrete floor just downstream from the left control gate of the outlet works. The dark area in the background is the downstream frame of the 3' - 6" x 3' - 6" gate. The maximum depth of cavitation was about 0.3 feet. 11-6-57

Figure 5



Palisades Project--Photograph No. P-456-108-4320
Outlet Works. Close-up of cavitation below outlet gate No. 7. Note the ground surface upstream of the dotted vertical line.



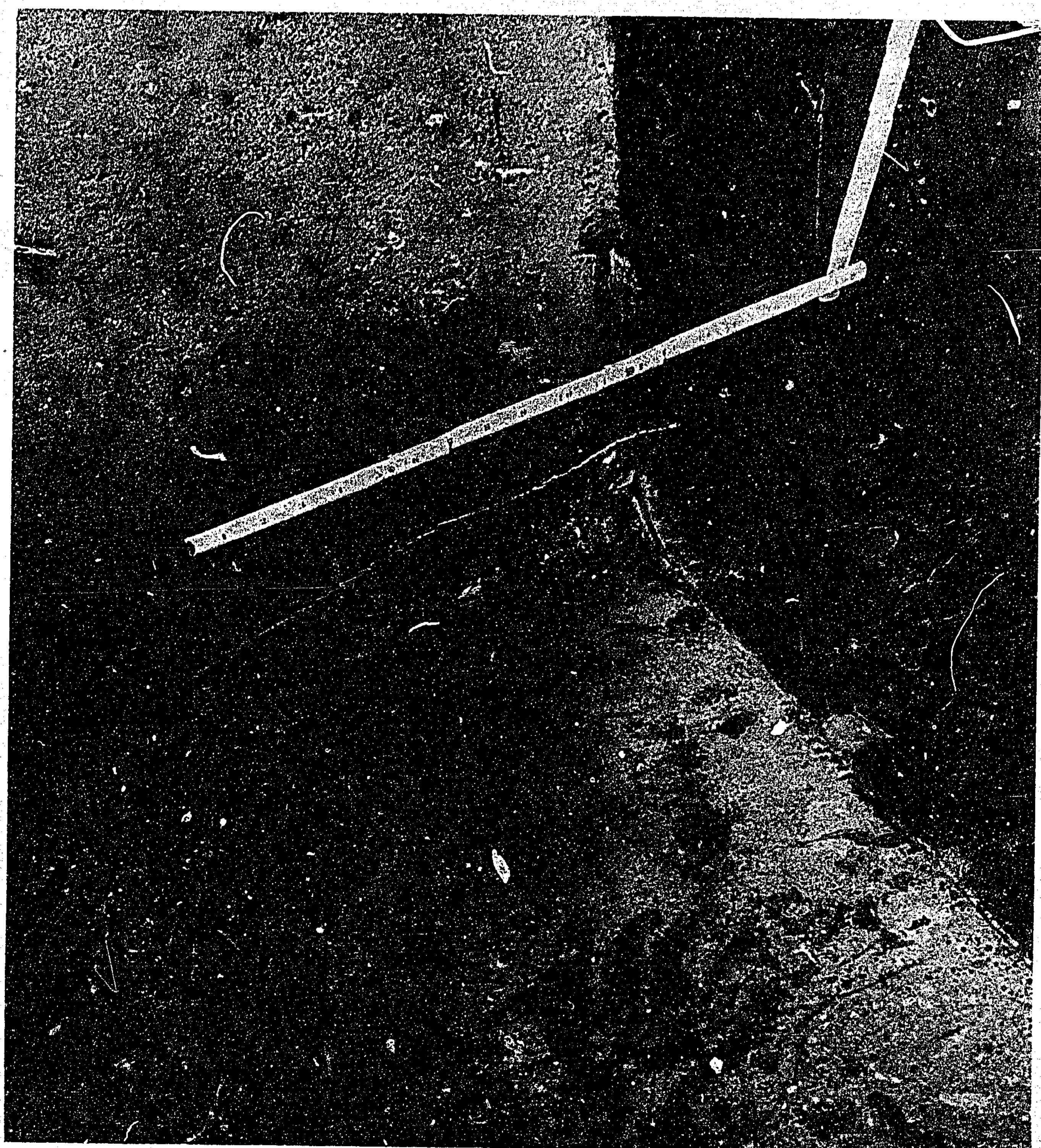
STUDIES OF SURFACE IRREGULARITIES

PRESSURE REDUCTION DOWNSTREAM
FROM 12:1 AND 24:1 BEVELS

Figure 7

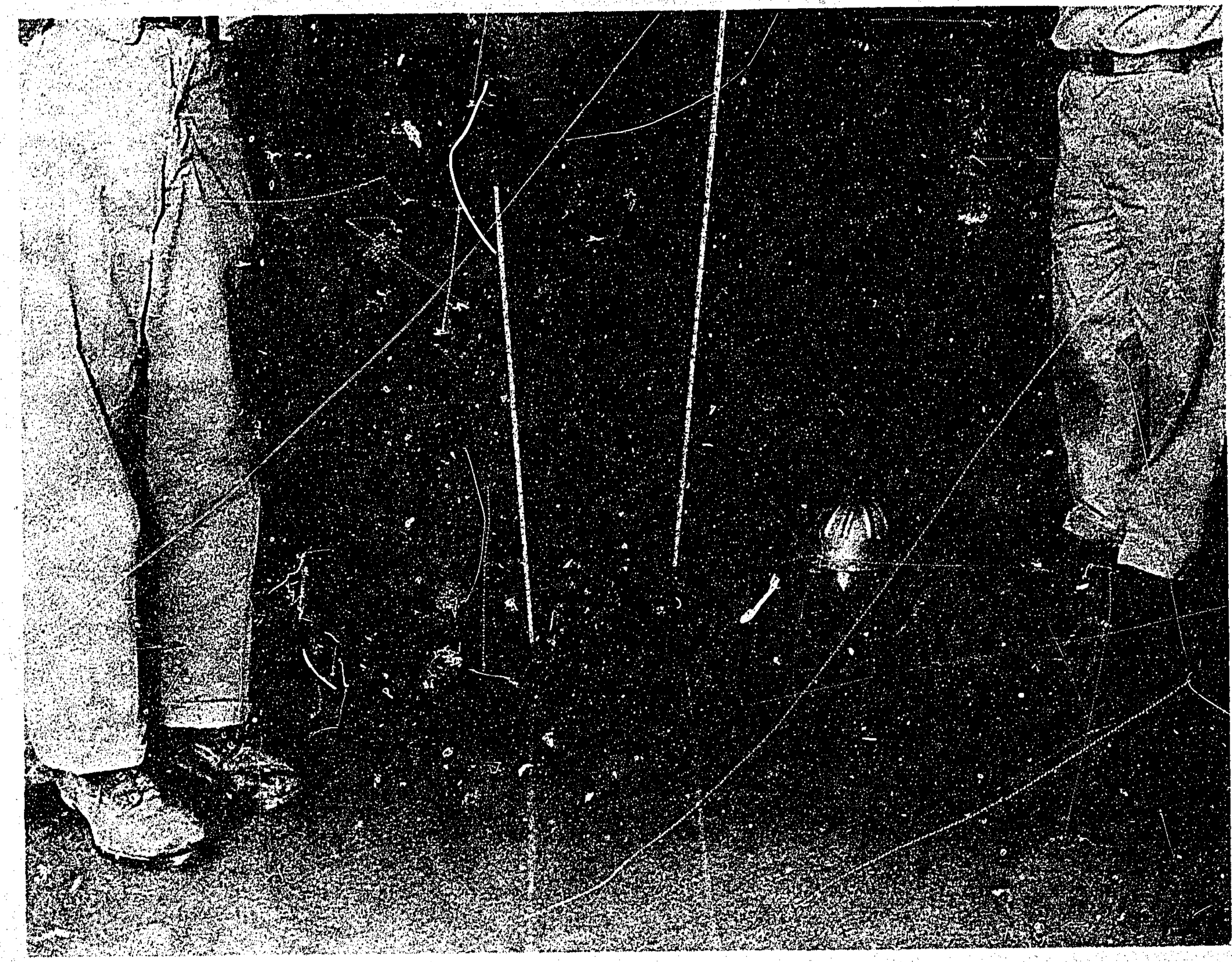
Lucky Peak Dam, Outlet No. 4--Corps of Engineers
Erosion at end of 1:12 bevel at stop log slot.

Figure 8



Palisades Project--Photograph No. P-456-108-4358
Right Bottom corner of concrete-steel joint in Outlet No. 8. 8-15-57

Figure 9



Palisades Project--Photograph No. P-456-108-4411
Cavitation in floor on right side of outlet gate No. 8. Eroded area is about 9 feet long, 20 inches wide, and a maximum of 6 inches deep. Note reinforcing steel.
9-17-57