PRESSURE DISTRIBUTION UPSTREAM FROM END
OF PIPE IN FREE DISCHARGE

(Talk Given at Allenspark Rocky Mountain Hydraulic Laboratory Colorado
by Jack C. Schuster, 1953)

GENTLEMEN: I have assembled a few remarks introducing the situation of flow conditions and pressure distribution at the end of a pipe flowing full of water. No thought had been given to the situation, and we were unprepared to explain negative pressures near the pipe end. Neither I nor my associates could recall seeing the situation discussed in literature, although the flow at the end of a floor has been studied with respect to pressure distribution on floor and its relation to critical depth. The question may resolve to "Where is the end of the pipe?"

In a curvilinear movement of a liquid, depending on whether the stream lines are concave or convex, the centrifugal force will act either in the direction of gravity or opposite to it. As a result, instead of the hydrostatic pressure triangle acd, the pressure will be represented by curve ab.

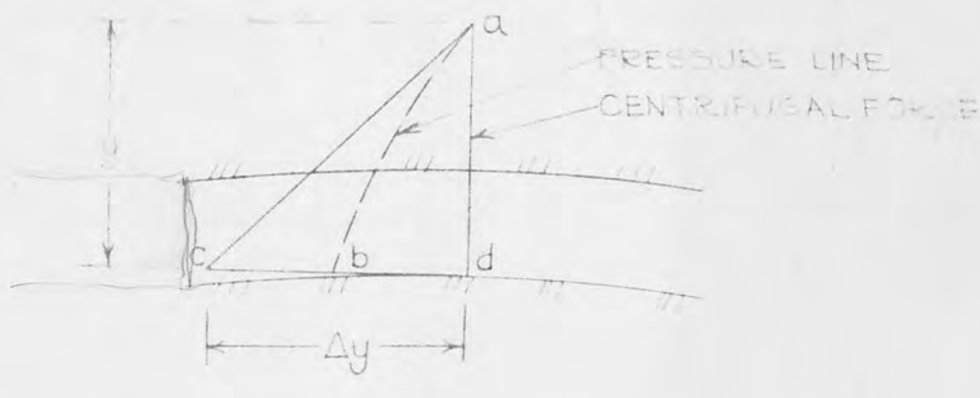


FIGURE 1

Application to Pipe

At the end of the pipe the pressure on the jet is atmospheric. With the weight of water unsupported and a gravitational force acting, indications are that a curvilinear flow occurs within the pipe. The origin and the degree of curvature has not been determined, but it is believed the pattern of flow can be defined according to the Froude number. In the Froude number range of the tests, it was found the position of the origin was rather insensitive.

water has tensile strength

The pressure distribution was found from a limited number of measurements of a 6-inch-inside-diameter brass pipe, Figure 2. The pressure at the top of the pipe for a Froude number of 3.06 (average velocity 12.3 fps) varied from zero at the end of the pipe to a vacuum of 0.185 foot of water approximately 1 pipe diameter upstream of the end. The pressure on the bottom varied from zero at the end to 0.315 foot positive 1 diameter upstream. The pressure reduction extended a considerable distance upstream from the end (approximately 5 to 7 diameters). With an increased Froude number to 6.71 (average velocity 27 fps), all pressures increased in a positive direction. The pressure at the top of the pipe 1/4 diameter upstream from the end was approximately zero and at 1 diameter -0.050 foot. The pressure on the bottom varied from zero at the end to 0.45 foot positive at 1 diameter. The increase in pressure at the top of the pipe, from a vacuum upstream to zero at the end, is probably accomplished by a divergence of the upper stream lines. The decrease in pressure at the bottom of the pipe from a positive value to zero is accomplished by a convergence of stream lines. The figure indicates the curvature origin at approximately 1 diameter for the higher Froude number. The distance upstream of the pipe end to the point where atmospheric pressure again prevails is undoubtedly influenced by boundary resistance; therefore the location of this point will depend upon the pipe roughness.

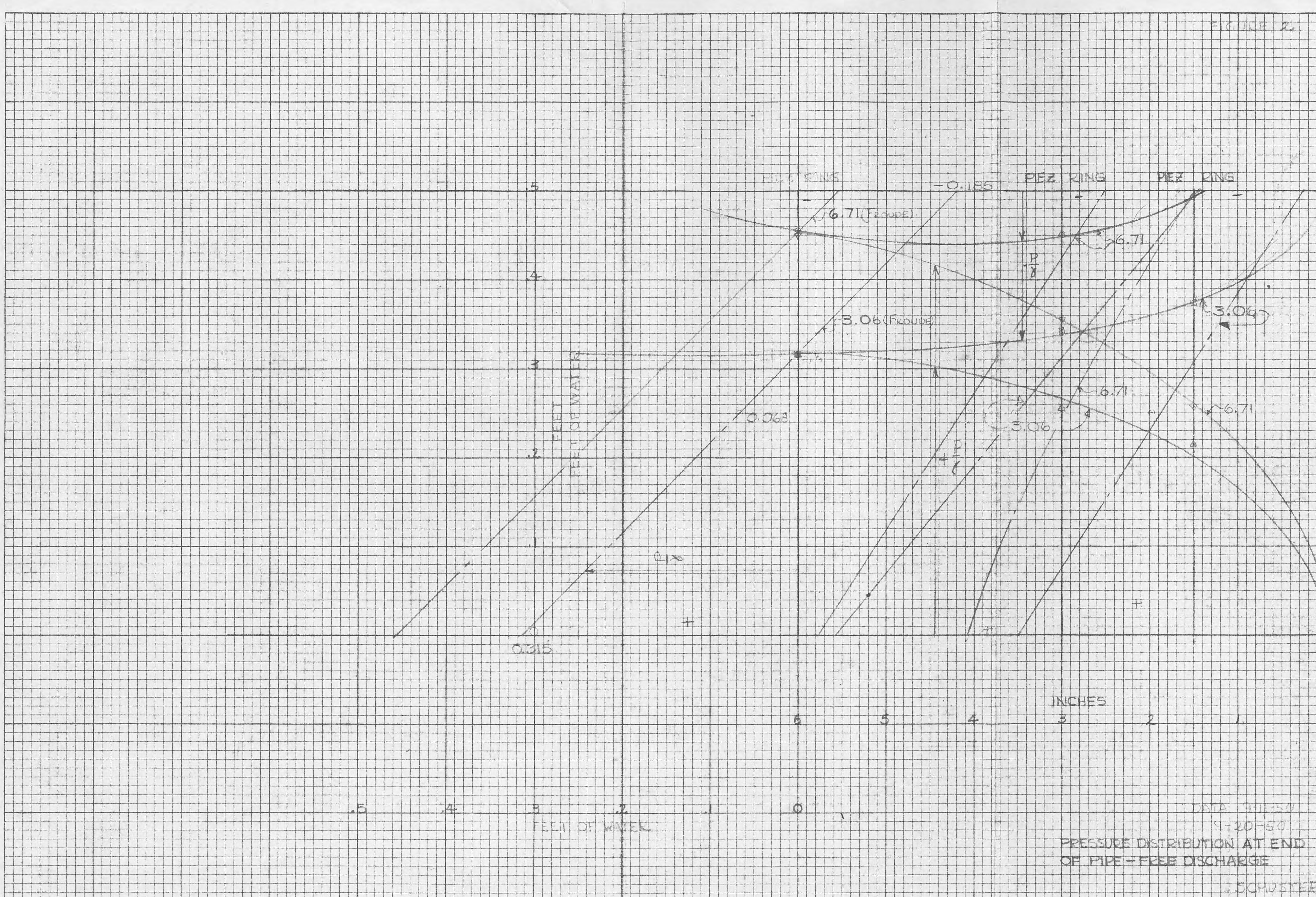
$F = \frac{V}{\sqrt{gd}}$

$F^2 = \frac{V^2}{gd}$

An attempt was made to measure velocities at top and bottom of the issuing jet. The results indicated that the velocity head top and bottom differed by a pipe diameter. No attempt was made to measure the velocity in the plane of the piezometers, which might serve to indicate an adjustment of the velocity profile and thus the pressures.

The situation described here may have very limited application, but some further investigation might extend its usefulness.

Gentlemen: May I leave you with the question "Where is the end of the pipe?"



PRESSURE DISTRIBUTION AT END
OF PIPE - FREE DISCHARGE