of division was made in order to facilitate the computation of the mean observed velocities at any given section.

In traverses at the different positions along the pipe the tube was inserted at various angles with the vertical in the plane perpendicular to the axis of the pipe. As no indication of unsymmetrical distribution of velocities was observed, these angles were not recorded.

Reading the Gauge.—At every position of the tube in a traverse the columns of the gauge were read simultaneously three times at intervals of from 20 to 30 seconds. Before beginning the readings at any point from two to three minutes were allowed for the gauge to settle. In case the second reading differed greatly from the first in any given position, the first was rejected and more time allowed for the gauge to come to rest. This happened only a very few times throughout the entire series of traverses.

The differences of the means of the three readings in each column were taken as giving the correct observed differences of head.

Tube at Centre of Pipe.—At the end of the traverse, which was made continuous across the pipe, the tube was

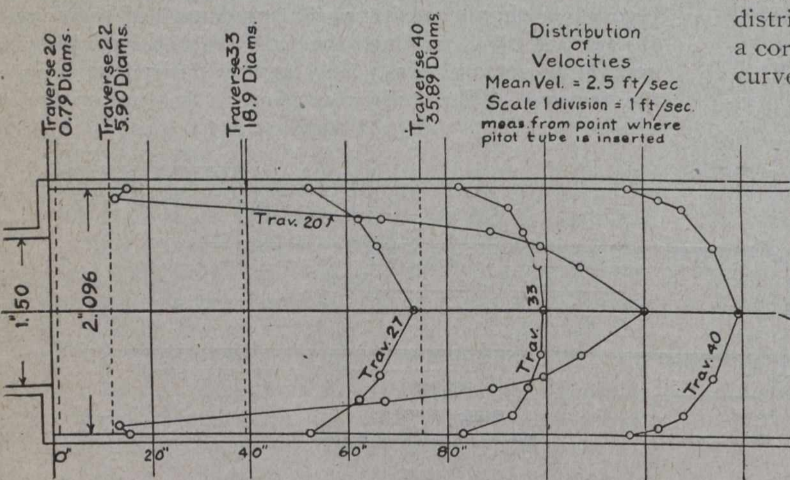

Fig. 2.

brought back to centre and the gauge readings observed as at the beginning of the traverse. This then gave three observations in each traverse with the tube on centre, at the beginning, middle and end. The mean of these three observations was taken at the true reading at the centre during the traverse.

Weighing the Water.—Weights were taken at the middle and end of each traverse as at the beginning, so that three weights were taken for every traverse. The mean of the three weights was considered as the true one from which the mean velocity in the pipe could be determined.

Time.—The time occupied for a complete traverse was about one and one-half hours.

Hydraulic Gradient.—Gradient lines have been plotted showing the observed difference of head between the different positions along the pipe below expansion for a distance of 36 diameters, Fig. 3. These curves are for velocities of one, two, three and four feet per second. The datum level or origin is the pressure at the point of expansion, and in the smaller pipe immediately above the plane of enlargement, and designated in the drawing by "E."

It will be seen that the pressure drops suddenly upon entering the large pipe, remains nearly constant for the short distance of 0.86 diameters, then begins to rise rapidly for a distance of about six diameters (12 inches). From this point the pressure begins to fall and the gradients have a slope slightly exceeding that under normal conditions, but gradually decreasing in rate of descent until at about 36 diameters below the expansion they approach very nearly the hydraulic slope of normal flow for these velocities in two-inch pipe.

It is interesting to study these curves of hydraulic slope in connection with the curves of distribution of velocities taken at the various points below the enlargement. The pressure is seen to rise most rapidly in the region where the eddies occur. There seems to be a rise in the gradient line corresponding to the amount of distortion in the curves of velocity distribution due to combined eddy formation and a retardation of the mean velocity. As the jet passes from the smaller to the larger pipe the velocity curves show first a maximum distribution at the walls and here it is that the rate of rise in the gradient is a maximum. The jet issuing from the smaller pipe is rapidly expanding with a consequent decrease in mean velocity. Farther down the pipe the velocity curves are adjusting themselves rapidly toward a more uniform distribution and in consequence the gradient line takes on a corresponding downward slope. Finally, as the velocity curves assume the form of normal distribution the hydraulic slope approaches the gradient of normal conditions of flow.

Readjustment of Velocity Distribution.—A curve of the ratios of $\frac{V_m}{V_c}$ for the various positions below enlargements was plotted in order to determine, if possible, at what position below the expansion the flow becomes normal. It is interesting to note that the conditions of velocity distribution adjust themselves to the form of normal flow in straight pipe at approximately the same distance below the disturbance in the case of sudden enlargement as in that of contraction, in the neighborhood of 35 to 40 diameters below the enlargement.

Loss of Head Due to Sudden Enlargement.—The theoretical loss of head due to sudden enlargement of section may be expressed by the equation, $H_b = \left(\frac{A_c}{A_1} - 1\right)\frac{V_2^2}{2g}$ known as Borda's formula. A_2 and A_1 are the areas of the larger and smaller pipes, V_2 is the mean velocity in feet per second in the larger pipe, $g = 32.2$, and h the loss of head in feet.

The *observed* loss of head due to sudden enlargement of section may be expressed by the aid of Bernoulli's Theorem for steady flow between any two positions in a level line as follows: $h_1 + \frac{V_1^2}{2g} = h_2 + \frac{V_2^2}{2g} + H_f + H_e$, where $h_1 + \frac{V_1^2}{2g}$ is the total effective head, the sum of the pressure and velocity heads, at any definite point in the up-stream section, $h_2 + \frac{V_2^2}{2g}$ the total effective head at any point in the down-stream section, H_f the frictional loss between the two points, and H_e the loss, indirectly observed, due to sudden enlargement.

Since $h_1 - h_2$ may be observed, the expression may be written, $h_1 - h_2 + \frac{V_1^2 - V_2^2}{2g} - H_f = H_e$, where H_e