LOCATING LEAKS IN WATER MAINS BY MEANS OF THE WATER HAMMER DIAGRAM.*

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WHEN the valve at the end of a long pipe line is closed suddenly, great pressures may be caused. The term water hammer has been applied to this phenomenon. If the valve could be closed instantly all of the water in the pipe would not be stopped at the same instant. The layer nearest the valve would stop first, then the next layer and so on until the impulse has travelled through the entire pipe line. As each layer of water is brought to rest its pressure will, of course, be increased. The velocity of the transmission of the pressure wave will be the same as the velocity of transmission of sound in the water in the pipe, and will vary between 3,400 and 4,700 ft. per sec., depending upon the material of the pipe and upon the ratio of the thickness to the diameter of the pipe.

It has been found that for any given pipe, the amount of the water hammer pressure is a constant times the extinguished velocity. The value of this constant (also called the water hammer coefficient) varies directly with the velocity of transmission of the pressure wave, and for cast-iron pipe used for water supplies has values between 45 and 63. For cast-iron pipe between 6 and 16 inches in diameter, the average value of the constant is about 55. That is, the water hammer pressure caused by the sudden closure of a valve at the end of a long pipe line, in pounds

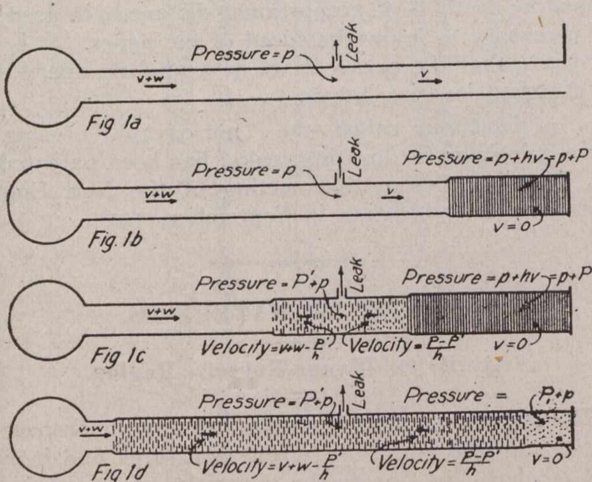

Fig. 1.—Condition of Pressure and Velocity at Various Times After Closing the Valve.

per square inch, is 55 times the velocity of the water in the pipe before the valve was closed, in feet per second.

Fig. 1a represents a pipe line in which there is a leak. The flow between the source (reservoir or large pipe) and the leak is $v - w$ feet per second, and between the leak and the valve is v feet per second. Fig. 1b shows the conditions in the pipe line a short time after the valve at the end is suddenly closed. The velocity of the water near the valve has been extinguished and its pressure increased hv lb. per sq. in. (h being the water hammer coefficient). If the distance from the valve to the leak is l feet and the velocity of propagation of the pressure wave is Z ft. per sec., the pressure wave will reach the leak l/Z seconds after the valve closed. Since the original pressure at the leak allowed a quantity of water equal to Aw cu. ft. per sec. to escape, it is evident that a higher pressure will cause a greater quantity to flow. The extinguished velocity between the leak and the source will, therefore, be less than v ft. per sec. Hence the water hammer pressure generated in this part of the pipe line will be less than hv lb. per sq. in. A wave of reduced pressure will therefore travel from the leak toward the valve. Fig. 1c shows the conditions a short time after the pressure wave has passed the leak. The wave of reduced pressure will reach the valve $2l/Z$ seconds after the valve closed. Fig. 1d shows the conditions a short time after the wave of reduced pressure has reached the valve.

*From paper read before the Illinois Water Supply Association, March, 1914.

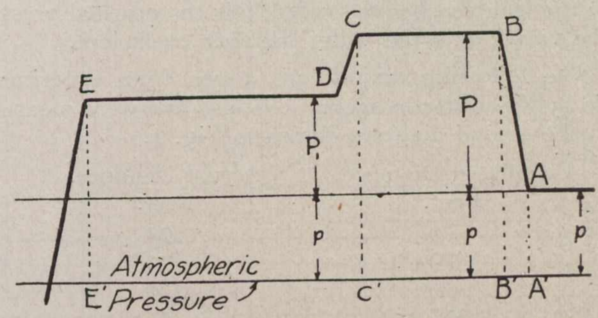

Fig. 2.—Typical Water Hammer Diagram Showing Effect of a Leak.

The water hammer diagram is a graphical representation of the pressure in the pipe line near the valve for a time after the valve is closed. In the experiments made by the writer the diagram is obtained by having the pencil of an indicator trace on a sheet of paper wrapped around a drum driven at a uniform rate by an electric motor. Another pencil attached to an electro-magnet makes a time record.

Fig. 2 shows the characteristic features of a water hammer diagram taken at the end of a pipe line in which there is a leak. The first rise of pressure as the valve begins to close is shown at A. The indicator pencil reaches B when the valve is fully closed. The pressure then remains practically constant until the effect of the leak is registered at C. The distance A′C′ represents the time required for the pressure wave to travel from the valve to the leak and back to the valve. If the velocity of transmission of the pressure wave is known, the distance from the valve to the leak is easily computed. The difficulty in the use of this method is in the determination of the velocity of transmission (Z) of the pressure valve. The velocity of the pressure wave will vary somewhat, according to the amount of air in the water. Another method which avoids the necessity of determining the value of Z is as follows: When the indicator pencil reaches E, the first relief of pressure due to the source is felt. The distance A′E′, therefore, represents the time required for the pressure wave to travel from the valve to the source and back to the valve. If the length of the pipe line from the valve to the source is L, the distance from the valve to the leak can be determined by proportion.

$$l : L :: A'C' : A'E'$$

In the writer's experiments, much more consistent results were obtained by this method than by the use of the velocity of transmission of the pressure wave and the time required for the pressure wave to go from the valve to the leak and return, as scaled from the diagram.

The quantity of water discharged from the leak can also be determined from the water hammer diagram. The