a water-temperature at the surface of 56.5° and at 2.5 ft. of 58°.

Comparisons were made between the U.S. Weather Bureau standard evaporation-pan, which is 4 ft. diam., 10 ins. deep, and is set on a wooden platform resting on a low mound, and the 12-ft. tank set in the ground 2.75 ft., as already described. Readings taken during a period of one year, showed that the rate of evaporation from the

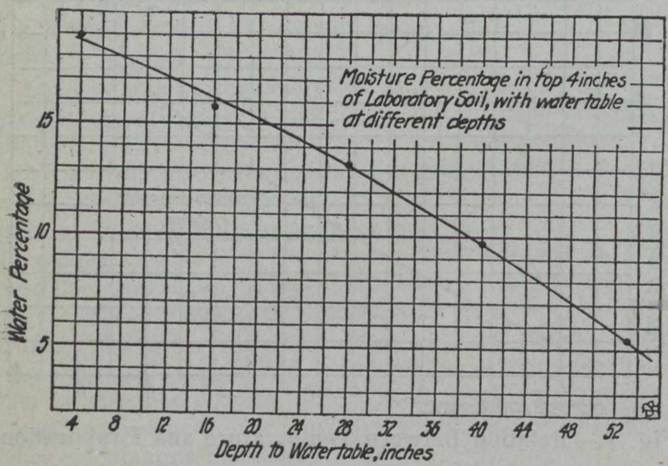

Fig. 3.—Relation Between Depth to Water-Table and Moisture in Top Soil

pan ranged from 131 to 178 per cent. of that from the tank, with an average of 150 per cent.

Experiments with the Piche evaporimeter showed that this instrument was relatively unreliable. Individual readings varied as much as 42 per cent. from the mean computed from comparison with the 12-ft. tank.

A U.S. Geological Survey standard floating-tank, 3 ft. diam. and 3 ft. deep, was placed on an artificial lake

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PULSATIONS IN PIPE-LINES*

By H. C. Vensano

THE conclusions given below are based on a series of experiments on the penstock at the Drum power house of the Pacific Gas & Electric Co. in Placer county, California. This penstock is 6,282 ft. long and has a diameter of 72 ins. at the upper end and 52 ins. at the power house. The following nomenclature is used in the formulas:

a = velocity of wave-propagation in a pipe of uniform diameter.
b = thickness of pipe-wall in inches.
D = diameter of pipe in inches.
E = coefficient of elasticity of steel, taken as 30,000,000 lbs. per square inch.
g = acceleration from gravity in feet per pound.
h = pressure rise or fall from normal, resulting from pulsations, measured in feet of head at any point.
K = voluminal modulus of elasticity of water, taken as 294,000 lbs. per square inch.
L_1, etc. = length, in feet, of sections of pipe of varying diameter, between the point at which the pressure is desired and the reservoir, L being the first section, starting at the point at which the pressure is desired.
T = time of gate-closure or gate-opening, in seconds.
V_1, etc. = velocity of flow in feet per second at beginning of gate-motion.
v_1, etc. = velocity of flow in feet per second at end of gate-motion.
W = weight of water per cubic foot, taken as 62.4 pounds.

1. The general formula for pressure-variation from normal at any point in a pipe-line, with uniformly varying gate-opening, should be

$$h = \frac{2\,(L_1\,V_1 + L_2\,V_2 + \;.\;.\; L_{x-1}\,V_{x-1} + L_x\,V_x)}{g\;T}$$

This formula applies to a pipe with varying diameter.

2. For slow gate-closure, this formula reduces to

$$h = \frac{2(L_1V_1 + L_2V_2 + L_3V_3 + \text{, etc., for the full length of pipe})}{g\,T}$$

and, further, reduces to

$$h = \frac{2L_1\,V_1}{g\;T}.$$

for slow gate-closure with a pipe of uniform diameter. The above formulas are limited to a maximum value of

$$h = \frac{a_1\,v_1}{g}$$

3. As this formula indicates, the velocity of flow at the gate, or at the point where the pressure is to be ascertained, does not necessarily (of itself alone) fix the magnitude of the pressure-wave at such point, but the magnitude of the pressure-wave is influenced by the varying velocities of the moving water-column in all portions of the line between the point at which the pressure is to be ascertained and the reservoir.

4. Under ordinary conditions, the water-hammer effect may, and does, produce as great a fall in pressure below the normal as it produces a rise above normal after the gate has been closed completely. In other words, the pressure vibrates back and forth above and below normal after gate-closure.

5. In pipes of uniform diameter, the magnitude of pressure variation along the pipe-line will vary directly as the time required for the wave to travel from any point in question to the reservoir and return to the same point, provided the time of gate-closure is greater than the half-period of the pipe.

6. The effect of accelerating the water-column by gate-opening is analogous to the effect of retardation in gate-closing, except that the pressure-variations have the opposite sign. The period of pulsation is the same. The chief difference is that the wave-effects die out more rapidly with opening than with closing. This seems to affect the vibration so that the full magnitude is obtained only for a short time.

7. The velocity of wave-propagation in water, for riveted-steel pipe, can be calculated approximately by the recognized formula:

$$a = \frac{12}{\sqrt{\frac{W}{g}\left(\frac{1}{K} + \frac{D}{E\,b}\right)}}$$

if proper allowance is made for the effect of joint-details.

*Abstract from Proceedings of the American Society of Civil Engineers, October, 1917, page 1593.