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WATER HAMMER PROBLEMS SOLVED BY THE USE OF ALIGNMENT CHARTS

WATER HAMMER PHENOMENA REVIEWED WITH CHARTS FOR GRAPHICAL SOLUTION OF JOUKOVSKY'S AND ALLIEVI'S FORMULAE.

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THE use of alignment charts for the solution of problems in engineering has received considerable attention recently. Several articles showing the application of the alignment chart to problems in reinforced concrete, structural, machine design, hydraulics, etc., have appeared in the technical press, but as far as the writer knows, this is the first time the following formulæ for water hammer have been charted by this method. It is hoped that they may prove to be of some value to the engineer who has to deal with water hammer problems.

In order to make the curves more intelligible to those who are not well acquainted with the phenomena of water hammer and to whom the scattered literature on this subject is not immediately available a brief discussion of this phenomena will be given, followed by the generally accepted formulæ upon which the charts are based.

A bibliography of the important papers on this subject will be found at the end of this article.

When water is flowing through a pipe it contains a certain amount of kinetic energy in virtue of its velocity. If the velocity is changed the kinetic energy of the water must also change. If the flow of water is stopped by the quick closing of a gate, the kinetic energy of the water due to its velocity is changed to potential energy with a resulting increase in pressure in the pipe. This in turn is used up in stretching the walls of the pipe and in compressing the water. This increase in pressure is termed "water hammer."

"Maximum water hammer" and "ordinary water hammer" are both covered by the accompanying charts. Chart No. 1 for maximum water hammer, Chart No. 2 for ordinary water hammer respectively.

In order to obtain the conditions for maximum water hammer it is necessary that the time of gate closure be less than the critical time $\frac{2L}{a}$, that is, the time necessary for the pressure wave to travel from the gate to the reservoir and back. It might also be well to note that the excess head in the formula for maximum water hammer $(h = \frac{Va}{g})$ is independent of the length of the pipe, but directly proportional to the extinguished velocity and to the velocity of propagation of the pressure wave.

Maximum Water Hammer.—The only complete analysis of maximum water hammer is to be found in a paper by Prof. Joukovsky, published in 1897. The following description of this phenomena is taken bodily from O. Simin's translation of Prof. Joukovsky's paper, which was published in the proceedings of the American Waterworks Association, 1904.

In Fig. 1 let A B be a pipe, in which water flows with velocity, V, from the origin, A, past the gate, B. If, now, the flow is suddenly stopped by a rapid shutting of the gate, B, the kinetic energy of the water column A B will cause an increase of pressure in the pipe.

Let us consider the column of water, A B, as divided into n, very small, equal sections, 1, 2, 3—$(n-1)$ and n.

The phenomena of water hammer takes place in a series of cycles, each consisting of four processes, as follows:—

(1) Section 1, meeting in the gate, an obstacle to its movement, will be compressed and will stretch the pipe wall surrounding it. All the kinetic energy of this section

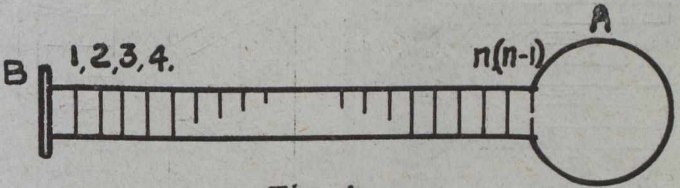

Fig. 1

of water will be used up (a) in its own compression, resulting in the increase of pressure by an increment, P, and (b) in the corresponding stretching of the walls in section 1 of the pipe. As a result of this action, section 1 of the water column has left vacant behind itself a small space, to be occupied by a part of the next arriving section 2. Consequently it is only after section 1 has been stopped and compressed, and after the small space thus left has been filled, that section 2 can be arrested and compressed.

Now the kinetic energy of section 2 must be expended in some way. Will it increase the pressure upon the gate, which has already been caused by the arrest of section 1? No, and for the following reason:

The pressure upon the gate depends entirely upon the pressure, P, sustained by section 1 which is now in static condition.

The pressure upon the gate could therefore be increased only if section 1 could be further compressed, and this could take place only if the pressure upon the surface between it and section 2 (which we may imagine to be a thin piston) could be greater from the side of section 2 than it is from the side of section 1; and this is impossible because section 2 has only the same kinetic energy as section 1, and this energy will (as in the case of section 1) be used entirely in compressing the water of the section (section 2) only to the same additional pressure, P, and in stretching that part of the walls surrounding section 2.