v = the velocity of wave motion in the pipe.
V = the extinguished velocity of the water.
W = weight of a cubic foot of water.
G = the acceleration due to gravity.

For ordinary conditions this would amount to about 60 lbs. for each foot of velocity extinguished.

Losses Involved in Ram Operation.—During the acceleration period the potential energy in the water supply entering the pipe is being changed into kinetic energy in the form of a moving mass of water, the power being accumulated and concentrated.

Without giving the matter consideration one naturally concludes that since water is running to waste, during the acceleration period, there must be a corresponding sacrifice of power and efficiency. This, however, is not the case, the only loss being the velocity head of discharge, which is usually but a fraction of a foot. The potential energy of this water has been stored in the form of kinetic energy in the moving mass of water in the drive pipe. When water power is used to raise water to a higher level it is self-evident that only a portion of the water can be raised to the higher level, hence, the remainder must be wasted at the lower level. For example, if a theoretically perfect machine were operating with a 10-ft. supply head and lift of 20 ft. ft. above the machine, it is evident that it would require two units of water with 10-ft. head to raise one unit 20 ft. The other unit is running to waste, yet no power whatever would be sacrificed, the machine in that case being 100 per cent. efficient.

The losses involved during the acceleration period are due to entry head, friction in the drive pipe, and the velocity head of the wasting water with the friction of its passage through the waste valve. These are all losses which can be determined definitely, hence the efficiency of the acceleration period is susceptible of accurate calculation when the co-efficients of friction for the design have been established.

In the case of the larger sized rams operating with medium drive head and moderate velocity the efficiency of the acceleration of power accumulating period may exceed 97 per cent.

The two periods of action are independent of each other, The action during the acceleration period is entirely independent of the conditions of delivery or retardation; that is, of the head against which the water is pumped. Likewise the retardation or pumping conditions are independent of the head used or time required in attaining a given velocity in the drive pipe.

The acceleration period ends when the waste valve is partially closed and the retardation period really commences before this valve is fully closed. The interval between this time and the opening of the check valve is really part of the retardation period though no water is pumped. The pressure is being raised in the ram accompanied by the water hammer effect.

A small amount of velocity is sacrificed in water hammer loss, the amount depending upon the head against which the water is pumped, or more directly the rise in pressure. The water pressure strikes the check valve suddenly and, due to its inertia, an increment of time is required to move it. This causes an instantaneous rise in pressure beyond that required to force the water through the valve and a small loss of efficiency is involved. The losses during the retardation period are: water hammer, opening discharge valve, friction through discharge valve, velocity head of discharge and slip of check valve at end of delivery.

Ram Capable of Mathematical Treatment.—Thus it will be seen that the action of the ram is capable of analysis and consequently of mathematical treatment.* When the various co-efficients have been determined by experiment for any given type of ram its performance under given conditions can be determined by calculation. The writer hopes later to acquire sufficient experimental data to be able to determine the proper value of the co-efficients.

Efficiency.—The efficiency of the ram is the product of the efficiency of the acceleration, or power accumulating period, and of the retardation, or pumping period.

There are two different formulas used for computing the efficiency of the hydraulic rams, namely, the D'Aubuisson and the Rankine formulas.

The former is expressed by the equation

$$E = \frac{q(H + h)}{(Q + q)H}$$ and the latter by $$E = \frac{qh}{QH}$$ where:

E equals the efficiency of the ram.
Q equals the water wasted.
q equals the water pumped.
H equals the supply head.
h equals the pumping head above supply.

The D'Aubuisson formula represents the efficiency of the machine itself, as it considers all the water flowing through the drive pipe as the working force and the work done that of raising the water pumped from the ram to this point of delivery. If Q equals the total water supply and h the pumping head above the ram, then the formula takes the simpler form of $E = \frac{qh}{Qh}$.

The Rankine formula represents the useful work accomplished in raising the water from the level of the supply to the point of delivery.

The losses in the supply pipe are included with those in the machine itself in calculating the efficiency of the ram.

The efficiency of the ram depends upon the size of the machine and the conditions under which it is operating. The efficiency, under ordinary circumstances, of small rams varies from 50 per cent. to 70 per cent., and the larger sizes from 70 per cent. to 90 per cent.

With a properly designed ram, operating under favorable conditions, it is possible to obtain as high as 95 per cent. efficiency (D'Aubuisson).

Effect of Varying the Conditions of Operation.—Supply Head.—The effect of the supply head upon the operation of the ram is confined to the acceleration period. Other things being constant, the efficiency is increased by increasing the supply head. However, the same efficiency can be obtained with different heads by proportioning the velocity to the head.

With the higher heads, a greater velocity, with corresponding increase of capacity, can be used without sacrificing efficiency.

Consequently, the effect of increasing the supply head is to increase the capacity of economical operation, or, if the capacity remains constant, to increase the efficiency.

Pumping Head.—The effect of the pumping head is confined to the retardation, or pumping period.

Approximately the same efficiency during the retardation period can be obtained with any pumping head, but the velocity required to obtain this maximum efficiency increases with the pumping head. The efficiency, however, with

* Leroy Francis Harza, in his paper, "An Investigation of the Hydraulic Ram," published bc the University of Wisconsin, as Bulletin No. 205, gives a very complete mathematical treatment of the operation of the ram. He also carried out an elaborate series of experiments to check his theory.