ECONOMICAL SECTION OF WATER CONDUIT FOR POWER DEVELOPMENT*

VERY little information has been published regarding methods of determining the economical section of a conduit for supplying water to a power plant. For this reason a paper prepared by Cary T. Hutchinson, consulting engineer, New York, for presentation at the spring meeting of the American Society of Mechanical Engineers is of particular interest.

In what follows a formula for the best slope and size of conduit is deduced, which takes into account in a practical manner the construction costs, the value of the power recovered, and the rate of returns expected on expenditures made, as well as the other physical conditions of the problem. The resulting relation between the best area and the quantity of water is shown in Fig 2, for chosen values of factors entering the problem, and it is pointed out how, by a simple modification of the graphs of this figure, the relation for other costs and unit prices can be easily determined. One interesting result is that for a flume, or for any conduit, for which the increment cost for increasing the capacity by a relatively small amount is proportional to the surface, the best speed of flow of the water is constant, independent of the size of the conduit.

The economical section is evidently that resulting in the greatest net earnings of the power plant under the conditions controlling the market where the power is delivered. Inasmuch, however, as this section must be determined in advance of complete knowledge of market conditions, it is clear that only an approximation can be made, and that a ready method to determine the variation in net earnings for a large range of sections and shapes of water conduit may be useful.

Assuming that a certain shape and slope of water conduit is fixed upon provisionally, the question is whether some change either in the slope or in the shape or size of the section will result in an increase in net earnings. Any increase in the dimensions of the conduit will obviously entail an increase in construction cost, and hence an increase in annual charges. This increase in annual charges is limited, practically speaking, to interest, amortization and profit, inasmuch as only small changes in a quantity which itself is a small part of the total are under consideration. For instance, under ordinary conditions the loss in the water conduit may vary from, say 5 per cent. to 10 per cent. of the total power; it is a variation of possibly 25 per cent. one way or the other in this 5 per cent. or 10 per cent. that is involved.

TABLE 1—VALUES OF SECTION CONSTANT (a) FOR VARIOUS SECTIONS

Shape of Section	Hydraulic Radius	Cross-Section	Section Constant a	Section Constant $\sqrt{a}$
Semicircle, radius = r	$r/2$	$\pi r^2/2$	2π	2.51
Square, side = d	$d/3$	d^2	9	3.00
Half-square, depth = d	$d/2$	$2d^2$	8	2.83
Hexagon, half-full, depth = d	$d/2$	$\sqrt{3}d^2$	$4\sqrt{3}$	2.55
Prism:				
Tan $\alpha = 1/1.5$, $b = 4d$	$0.72d$	$5.5d^2$	10.6	3.26
Tan $\alpha = 1/2$, $b = 10d$	$0.83d$	$12d^2$	16.0	4.00

It is therefore evident that no increase in operating charges, or maintenance or repairs need be considered, and that the changes in design of the conduit should carry charges only for interest, amortization and profit. An allowance for profit on the additional expenditure must be included, since every dollar invested should earn its share of profit as well as its fixed charges.

The increase in power resulting from an increase in the size of the conduit brings in a certain addition to gross earnings. Against this, in theory, should be charged the costs of operation and maintenance on the additional equipment and machinery required to deliver this power to the market; but for the same reasons stated, in considering the water conduit all these charges against the additional gross earnings may be ignored in this analysis, as they are negligible in amount, due to the fact that the increase in the power output is small. There would, in fact, be no increase in operating charges, and under practical conditions there would be no increase in equipment, and therefore no increase in fixed charges on equipment. The matter then reduces to the comparison of the additional gross earnings from the power recovered by an increase in the size of the conduit on the one hand, and the additional interest, amortization and profit on the cost of the enlargement of the conduit on the other.

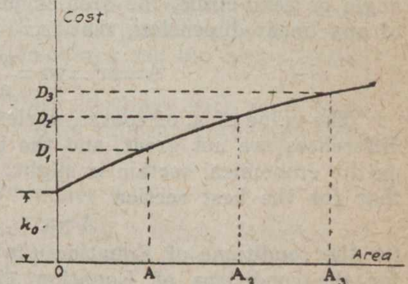

FIG. 1—RELATION BETWEEN SECTIONAL AREA OF CONDUIT AND COST

The determination of additional power is simple, involving merely the overall efficiency from the water to point of delivery. A consideration of the value of this increased power is a matter of judgment on the part of the engineers and executives of the enterprise, giving attention to the market conditions under which the power is sold, and particularly to the load factor.

The determination of the additional cost of the conduit, however, is more difficult, inasmuch as this cost depends in theory not only on the area of the cross-section of the conduit, but also upon its shape; that is, upon the hydraulic radius of the wetted perimeter. The relation between the area and the wetted perimeter differ, for example, for a rectangular, a circular or a hexagonal conduit, and cannot be expressed in a simple equation to cover all shapes of conduit. The practical way to handle the problem is to fix upon one shape of conduit, determine the economical area and slope for this shape and then follow out a similar procedure for such other shapes as may be practicable in the case under consideration. This determination being made for the several possible shapes, the best result is then selected.

The procedure indicated in the foregoing general discussion can be expressed symbolically as follows:—

Let Q=flow in sec. ft., taken as constant.
L=length of conduit, ft.
A=area of conduit, sq. ft.
s=slope of conduit, ft. per ft. of length.
r=hydraulic radius of conduit, ft.
w=wetted perimeter of conduit, ft.
v=speed of flow, ft. per sec.
C=constant in the Chézy formula.
e=efficiency from water to point of delivery $\times 0.085$.

Then the power loss p in the conduit in kilowatts will be

$$p = eQsL \qquad (1)$$

In this equation s is the variable, and any change of p is due to a change of s and is expressed by

$$dp = eQLds \qquad (2)$$

If m is the annual value of one kilowatt under the ruling conditions, then

$$mdp = meQLds \qquad (3)$$

is the added gross (and net) earnings due to the change in s.

As to the cost of increasing the capacity of the conduit, the flow is assumed to be given by the Chézy formula

*Excerpt from paper read before the spring meeting of the American Society of Mechanical Engineers.