THE DESIGN OF EARTH DAMS.

The following discussion of the principles governing the design of earth dams has been furnished to the "Michigan Technic" by Prof. Clarence T. Johnston:

The dimensions of a typical form of earth dam, given in cross-section, may be represented in terms of the height of the dam, h (Fig. 1). The up-stream, or water slope may be $3h$, the lower, down-stream or dry slope may be $2h$ and the top width may be $h/5$. The area of the cross-section of this dam is $2.7h^2$. If h is reduced to yards, then the volume of material in the dam per running yard of length is $2.7h^2$ cu. yd. In making estimates, following preliminary surveys, it is often convenient to employ some such expression. Fig. 2 indicates graphically how the volume varies with the height and it is well for the engineer to have this curve in his mind while he is designing an earth dam.

The cost of constructing an earth dam varies with the volume of material and it is also influenced by the height of the dam independent of the volume. The increase in cost with the height is due to many small factors that can only be briefly referred to. The average haul is greater for high dams. The immediate shrinkage of earth work is greater. Time occupied in going to and from work and the time that is employed in raising machinery all go to increase the unit cost. If we assume that earth can be placed in a low dam for 20 cents per cubic yard, we might employ the following formula for obtaining the approximate cost of higher dams:

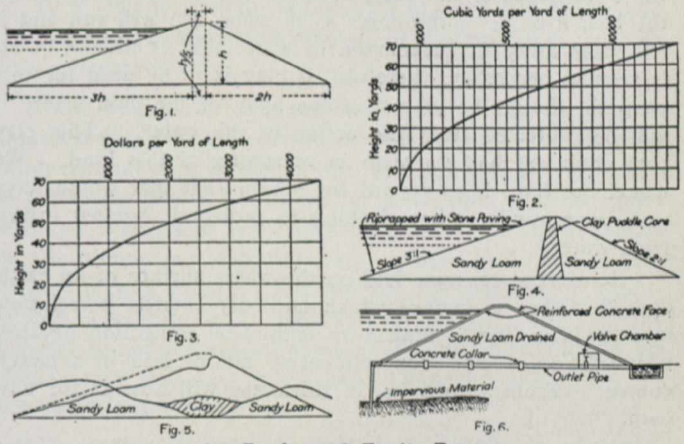
Cost per cubic yard equals $2.7h^2$ (20c plus $0.2h$c).

This formula would place the unit cost of a dam 30 ft. high at 22 cents while the unit cost for a dam 150 ft. high would be 35 cents. It should be remembered that h in the formula is in yards. Fig. 3 shows graphically the relation of the height of a dam and the cost per yard of length.

After we know what the form of the cross-section of the dam is to be and when we have made estimates to determine whether or not the proposed structure is feasible, we can consider some of the important details of the construction of the dam. The design of earth dams has not changed greatly until within the past few years. For a long time engineers have recommended and used cores in earth dams. A core is provided by placing within the dam a wall of material such as clay, which is more impervious to water than is any other material used in the construction of earth dams. This wall runs throughout the length of the dam and from the natural ground surface to an elevation well above high water. Many different kinds of cores have been devised aside from the clay wall. Timber has been employed for this purpose. Concrete and masonry walls have been built along the center lines of dams. When we study the nature and purpose of a core we must be excused for a little speculation. We must assume that the core is provided for the purpose of making the dam stronger. It is manifestly designed to reduce or prevent percolation through the dam. In other kinds of construction the mind of man has evolved plans that have led to something that is water resisting where such a condition is essential. For instance, our houses are built with the water resisting surfaces on the outside. We wear rain coats over our other clothing and not between our coats and our shirts. It does not seem reasonable that all of our ideas based on common sense should be discarded when we are called upon to design an earth dam. To place the water resisting material in a dam at a place where we know it only protects a part of the structure and where its beneficial function, if it has such, is not visible, does not appeal to one who has studied other kinds of construction. Considerations of this kind led the writer to make some experiments a few years ago. Of the twenty-nine model dams built and tested but one can be briefly described.

The dimensions we have already assumed for the cross-section of an earth dam are common in practice. Fig 4 shows the cross-section of the model dam to be described. This model was built for the purpose of determining the value of a clay core. The dam, aside from the core, was constructed of a sandy loam. It was finished early in April, the water turned in, and it remained unmolested until late in October. The water standing against the dam was kept at a uniform level, as nearly as possible, throughout this time. When the water was turned out of the small reservoir formed by the dam, the water slope of the dam was found to have settled as shown in Fig. 5. Beyond this the dam seemed in good condition. There was practically no water leaving the dam through seepage. To the casual observer the dam would have been pronounced a success. It had held water for nearly seven months.

The sandy loam on both sides of the core was removed so that the condition of the interior of the dam might be ascertained. The material between the core and the water face was completely saturated. This was to have been anticipated because the face was not protected and it was known that the core would prevent percolation to a large extent. The material on the other side of the core was in good condition. The core itself had absorbed water to such an



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extent that when the sandy loam was removed on both sides it settled to the base and had the appearance of mortar as it is deposited by a hodcarrier. The location and appearance of the core and the other material of the dam after investigation is also shown in Fig. 5. Great care was exercised to remove the sandy loam without disturbing the core any more than necessary. If the model had been left undisturbed a few months longer it would have failed. The dam was gradually absorbing water and the clay core simply retarded operation.

It is plain that this kind of construction is not good. The writer was called soon after this to examine a dam in actual use which had been replaced several times. It was never overtopped by the water. It would simply absorb water until the saturation had reached a certain point when it would apparently float away. The slopes of the dam as it stood after replacement were too steep. The principal trouble, however, was in the construction of the dam as it stood. The material was of such character that water was slowly absorbed and there was sufficient clay in the interior of the dam to make drainage very difficult. By installing a few tile drains running from the lower toe of the dam to a point slightly more than half way through the structure and by flattening the slopes a little the dam has given good satisfaction and has been used continuously for the past eight or ten years. This experiment in draining a dam was very conclusive in its results. It is apparent that it is better to elim-