The Necaxa Dam slipped, but was afterwards rebuilt on the original section. The Big Meadows Dam is being raised with an enlarged section.

### Increasing the Grain Size

The second way of increasing stability is to use core material that will consolidate more rapidly and thoroughly. There is only one way to insure this; that is to increase the grain size of the material allowed to remain in the core. With pools and water quantities actually used in the dams known to the writer, particles smaller than 0.001 mm. and perhaps up to 0.002 mm. have been wasted. Everything larger has gone into the dam.

In some cases, an effort has been made to secure completeness of deposition of these fine particles to avoid waste and to increase the yardage accounted for in the dam.

To increase the effective size of core material, it is necessary to increase the limit of size of particles to be wasted. This can be done by narrowing the pool or by increasing the quantity of water passing it. (See Fig. 3.) On one occasion at San Pablo, to test this out, the toes were allowed to increase in height for a time without raising the pool. This was continued until the pool almost disappeared. Hardly more than a muddy creek remained in the middle of the dam. The core became comparatively narrow and much coarser in grain size. The effective size was increased to approximately 0.01 mm. Finer particles were all wasted. In other words, the core material was, say, five times as great in grain size. It had, therefore, twenty-five times as great draining capacity, and only one twenty-fifth of the capacity to hold water by capillarity.

Material placed in this way had a much better chance of drainage; first, because the core was narrower and there was less water to be removed; second, because the water had a shorter distance to go; and third, because, other things being equal, the water would get away twenty-five times as fast. After a few weeks of operation in this manner, the work was stopped temporarily, which gave an opportunity to examine the deposited core material. After only a few days it became hard enough to walk on, many times more solid than ordinary core material.

In one other respect this coarse-grained puddle differed from ordinary puddle. There was a small relative range in its grain sizes. The fine particles were eliminated, and the volume of puddle produced was reduced, but there was no very great change in the quantity and character of the coarser particles. These coarser particles constituted the whole mass of the coarse-grained puddle. With ordinary puddle, they were mixed with a large additional volume of fine-grained stock. The grains in the coarse-grained puddle were thus more nearly of the same size, and it followed that, other things being equal, the percentage of voids was greater. This was found to be the case in the test at San Pablo, and after the material had become hard and stable, it had a percentage of voids that would have indicated lack of stability in ordinary stock. This is an illustration of the fact that voids used as an index of stability can only be properly compared for the same kind of stock.

### Waste of Fine Material

If this method of increasing the grain size of core material were to be followed throughout the construction of a dam, obviously there would be two results. First, a great deal of fine material would be wasted. The quantity would depend upon the quantity of such material in the stock used. In the natural course of events most of this would be reposited harmlessly upon the bottom of the reservoir. Second, a dam built in this way would be much more stable but theoretically not quite water-tight. There would be an appreciable amount of seepage through core material of this grain size.

The amount of seepage loss may be estimated approximately. Assuming that the laws of flow are the same as they are in the finest sand to which experiments have extended, it was estimated that at the San Pablo Dam if the whole core material could be made 0.01 mm. and if the rest of the dam had contributed nothing to tightness, the theoretical rate of seepage would be 280,000 gals. per day. The loss of this quantity of water would not be a serious drain upon the supply, if it adds to stability. Practically, as is known from filter experience, considering the core material as a filter, it would soon silt up and become watertight.

As a practical proposition in dam construction, core material having a grain size of 0.01 mm. is to be accepted as sufficiently fine from the standpoint of water-tightness. This size of 0.01 mm. is not given as a precise limit. It may be that still coarser material would give sufficient tightness or that finer material would drain sufficiently. The size is mentioned because it is the size of material that was actually found possible to produce at the San Pablo Dam by reducing the size of the pool to a minimum, and because other considerations suggest that it may be suitable.

The question remains as to whether a dam in which the pool and water quantities were so adjusted as to hold the effective size of core material at 0.01 mm., or at some other selected limit, and in which the core material was never permitted to become very wide, would consolidate itself as the dam increased in height to an extent that would eliminate lateral pressure of core material.

It is the writer's idea, that a dam built in this way would certainly be more stable and safer than one in which the core material contained an additional quantity of finer particles.

This thought is similar to an idea expressed by D. C. Henny, who stated:—

"Probably the nearest approach to a perfect core of great thickness which can be hydraulicked, is one composed of fine sandy silt, such as is generally found in the arid West, having little cohesiveness, good self-drainage qualities, becoming hard and solid after a short time, and yet being, if not perfectly, at least practically water-tight."

Mr. Henny's description may be taken as an accurate description of the writer's idea of 0.01-mm. material. It certainly does not apply to 0.002-mm. material. Mr. Henny's other propositions in regard to fine core material such as is ordinarily used, are believed to be well founded.

### Use of Rock Fill

In building hydraulic-fill dams, the débris above the solid rock has been most easily worked and extensively used. Such débris is frequently fine in grain size, and its use may result in an excess of core material and a deficiency of toe material. To correct this tendency, rock fill has been added to the toes of a number of dams.

The rock fill has usually been placed as dry fill; that is to say, by blasting, steam shovel, and cars or carts. The cars or carts run on the toes of the dam and deposit material at the same time that the hydraulic process is being used to fill the interior.

At the San Pablo Dam, a similar result has been reached by handling the rock after blasting by the hydraulic method. Open flumes were used with a flow of from 15 to 20 cu. ft. per sec. A 6% slope was necessary as long as wooden flume bottoms were used. With steel flumes, equally favorable results were obtained with a 4% slope. About 3,000 cu. yd. per day were placed, on an average. Pieces of broken rock up to 1 cu. ft. in size were handled under these conditions. By blasting the hardest rock available, it was possible to get material for fill that contained relatively few fine particles, and all of the small quantity of very fine material was wasted. Large additions to the toes of the dam were made in this way.

Working a quarry with a high face, it was possible to throw down great quantities of material in one large blast, and to wash many thousands of yards into the dam from a single position of monitors and flumes. The economy resulting from operating so long in one place, as compared with moving the equipment all over the hillside to pick up scattered and relatively thin deposits of débris above the rock, turned out to be fully equal to the additional cost of rock excavation; and rock fills, built in this way, cost no more per cubic yard than fill made from débris.