of hydraulicking partly fills the voids with fine material, but the process stops itself before they are all filled. The toes readily drain and all the stability naturally inherent in the stock is obtained.

The core may be defined as that part of the dam deposited from water in the central pool. In the writer's experience, core material is homogeneous. At any level there is no appreciable difference in grain size between the middle of the core and its farthest extremities.

Similar to Sedimentation Basin

The principles determining the size of particles deposited in the core, or not deposited, are the same as the ones that apply in a sedimentation basin of a water works plant. The larger the area of the pool in proportion to the quantity of water that goes through it, the more complete will be the subsidence, and the smaller will be the limit of size of particles retained.

Most hydraulic-fill dams have been built with good-sized pools in the centre during construction (see Fig. 2), in which sedimentation has been fairly complete. The writer has examined samples of the core materials from a number of dams. The samples are rather surprisingly alike in grain size. They ordinarily contain particles in large quantities down to a limit between 0.001 and 0.002 mm. (or sometimes 0.003 mm.) in diameter. Generally speaking, all smaller particles have been carried away by the escaping water and have not remained in the core.

It should be said that the determination of the exact size of these small particles is by no means as precise as the determination of the size of grains of filter sand. The results are reached by the microscope with a micrometer and are to be considered as roughly approximate only. It has been the intention to use a basis as nearly as possible comparable to that adopted for the large particles in sand analysis, which is to use as the diameter of any particle the diameter of a sphere of equal volume. Following this rule the width, rather than the length, of small particles is measured.

Core material then, as a matter of observation, consists of particles from this size up to the size of the smallest particles retained in the toes. In a general way, this size may be taken as 0.03 mm., or ten to fifteen times as great as the limit of size of particles that are retained in the core.

Speaking of core materials in the terms that are used in describing sand, it may be said that the effective size of core material is ordinarily about 0.002 mm. This size is so small that one who is not accustomed to microscopic work has little conception of it. For comparison, it may be stated that ordinary filter sand has an effective size of from 0.3 to 0.4 mm., while dune sand, being the finest material usually spoken of as sand, has effective sizes ranging from 0.15 to 0.20 mm.

Drainage of Core Material

Without attempting precision, and using round figures, the core material is one-hundredth of the size of dune sand. This means (assuming that the laws of flow and the laws of capillarity applying to the finest sands apply also to these still finer materials) that, other things being equal, the drainage of core material will take ten thousand times as long as corresponding drainage of fine sand. Fine dune sand would drain as much in an hour as core material in a year. It means, further, that the height to which water can be held by capillarity is ten thousand times as great as the height at which it is held by fine sand. If fine sand will hold water by capillarity to a height of an inch, as it will, then core material like that shown by the samples will hold water by capillarity to much more than the full height of any dam.

The reason why this core material does not drain is, therefore, clear. It seals itself up and becomes practically water-tight.

With the dimensions existing in dams that have been built, assuming that the laws of flow known to apply to the finest sands apply also to the still finer materials, it will take years for the excess of moisture to drain out, as it must do before the solidification of the material is possible.

As a practical proposition, drainage is not possible with such fine materials. By that is meant such prompt and complete drainage as will result in solidification during the construction of the dam.

Construction records and samples show approximately what happens. Core material of the fineness already described goes down first in the form of soft mud in which the voids filled with water are at least 70% of the total volume. Such mud is very soft.

The percentage of voids furnishes, on the whole, the best index of consolidation and stability. In itself, it is not an adequate basis of comparison, because different kinds of core material may have different degrees of stiffness with the same percentage of voids; but, notwithstanding this difference, the percentage of voids is the best index of consolidation so far available.

The material when it goes down contains 70% of voids. Under these conditions, the minute solid particles are held apart by the water contained between them, and the passages through which water can pass are much larger than they would be with a more compact arrangement of the same material. Water drains from this material gradually, and the material consolidates.

Water Moves to Top

The drainage may be horizontal, in which case the surplus water finds its way through the core material to the toes and escapes. There is, however, a shorter way out, and it appears probable that most of the drainage takes place vertically. That is to say, the solid particles settle down and consolidate while the water moves upward between them to the top. This consolidation takes place gradually at rates depending on the dimensions of the dam and also on variations in the effective size of the core material; for while the writer considers all this material broadly as having an effective size of 0.002 mm., there are no doubt considerable variations in size and permeability.

Experience shows that consolidation goes on so that after a period of from a few months to two or three years in the ordinary course of dam construction, it will have been consolidated to a point where the voids are about 50%. As the consolidation increases, the sizes of the passages between the grains become smaller, and the flow becomes less rapid and the process of consolidation goes forward more and more slowly.

Material with 50% of voids when taken out of a boring is described as material having the consistency of stiff putty. It is capable of standing up in a boring driven beyond the casing for several feet, and it offers great resistance to penetration.

One of the best field methods of testing the consolidation of core material has been to find the depth to which a 1½-in. pipe could be forced into it by two men. This method of testing has been used in several dams. It has been possible to co-ordinate the penetration so found with records of the percentage of voids. In a general way, penetration by 1½-in. pipe pushed down by two strong men extends to the point where the voids are about 50%. In other words, the 50% material is so stiff that it can no longer be penetrated to any considerable depth by this method.

Tests of material by letting down cannon balls, etc., are less searching. The penetration does not go as far.

Void Percentage for Stability

Material with 50% of voids in a considerable depth acts essentially as a liquid. It exerts the full lateral pressure corresponding to its height and weight per cubic foot, and when the resistance of the toe is overcome, this material moves forward and flows. Precise limits cannot be set, but this is the general result of observation at Calaveras as a result of determinations of voids in many samples of material that did flow and in other samples of material that did not flow. This refers to the Calaveras Dam near San Francisco, Cal., which slipped as it was approaching completion on