can be counted on. This water, amounting to one-sixth of the whole volume of core material, must be expelled. The computed rate of flow through material with an effective size of 0.002 mm. is very slow. The rate depends on, and is proportional to, the hydraulic slope. With a slope of 10% (which is as steep as is usually found) the computed rate of flow as a solid column of the full area of the section is 0.32 mm. daily. At this rate, 80 days are required for the water to move 1 in. and 2.6 years for it to move 1 ft. This calculation cannot be used with assurance as establishing the exact rate of flow, but it is the writer's judgment that the actual rate is as likely to be below as above the result given. It is clear that, for a large dam, complete drainage and consolidation may be a matter of many years.

From a practical standpoint, it may be recorded that a 6-in. well driven 60 ft. in saturated core material having voids averaging 50%, with the casing perforated freely to admit water, stood empty for weeks. Not enough water drained from this material to raise the water in the well. This may represent the effect of capillarity. With such a degree of tightness, it is clearly useless to attempt to secure consolidation by any method depending on additional drainage outlets.

Measuring Core Pressures

An interesting method of measuring the pressures actually existing in core materials has been suggested by A. T. Goldbeck. By this method, small test cells are built into the core material. Some are placed with horizontal and some with vertical faces, arranged to indicate pressures on the faces during construction and afterward. Such devices are reported to have been placed in hydraulic-fill dams now building by the Miami Conservancy District. The results of observation through a certain period have already been recorded. These observations indicate, as would be expected, that the horizontal and vertical pressures are the same at first and until the material has become somewhat consolidated. Afterward, horizontal pressure increases less rapidly than vertical pressure, and the inference may be drawn that this represents solidification of the material in which the cells are placed to a point where the full horizontal pressure is no longer produced.

This is certainly an interesting method of test and one that may throw light on the conditions of core material.

It reminds the writer of one of his early experiences, which related to different circumstances, but possibly the same underlying principles are involved. It was proposed to build large and heavy structures in which the weight would be well distributed on a foundation of stiff silt. The question was presented as to whether the foundation was sufficient to carry the weight. An apparatus was provided by which test areas of 1 sq. ft. at the level of the proposed foundation were loaded. The results of the tests were most satisfactory. The material carried more than the expected loads with only insignificant settlements. When the actual structure was built, however, there was considerable settlement. The actual settlement was many times greater than had been indicated by the tests.

Pyramid Effect

The explanation is simple enough. The single square foot that was loaded distributed the weight applied to it to a much larger area a short distance below. What was loaded was in effect a pyramid with a flat top of 1 sq. ft. The full applied weight per square foot was carried only at the top, and the unit stress rapidly became less going downward as the area of the pyramid increased. A thin layer of material just below the footing actually got the pressure and was compressed accordingly, and in this way the slight observed settlement was produced. Lower down, however, the unit pressure was lower and there was no appreciable compression.

When the structure was built there was no chance for a corresponding distribution of pressure. The whole area underneath was loaded, and the weight had to be carried through the full depth of silt and the silt was compressed. A corresponding settlement would no doubt have taken place in the test apparatus if the material loaded had been a column 1 ft. square all the way down to rock. The writer thinks that because of this dispersion of load it is generally true that a small test area will carry more per unit than a larger one, and it may be that the same conditions will be found to apply to the test cells built into the core of a dam.

In view of all the information now available, the only safe course to follow, so long as the core material is like that here described, is to assume that it will produce the full horizontal pressure corresponding to its weight and height; and the toes must be made large enough to resist that pressure with ample safety.

Resisting Core Material Pressure

The first point to be considered is the coefficient of friction of the material in the toe, sliding either upon the foundation or upon itself. With hard, clean gravel a coefficient of 0.7 or 0.8 might reasonably be expected, although the data for establishing this coefficient are not as convincing as could be desired. No such coefficient was found, however, in accounting for the Calaveras slip. Instead, it was estimated that the weight of the material pushed forward in the upstream toe was five times as great as the pressure of core material against it. In estimating that pressure the whole height and weight of core material was included, assuming that it acted as a heavy liquid. This indicated a coefficient of friction of only 0.20. This is to be taken as an average for the whole area on which the slip occurred. It may be recorded, however, that a similar calculation for the lower toe which did not slip indicated a coefficient of 0.22. No one can tell how much more it would have held.

The Calaveras material is softer and perhaps more slippery than the hard particles of glacial drift of the eastern states; and it would not be reasonable to expect as high a coefficient of friction. It may be, also, that the coefficient of friction under such heavy pressures as are found in the lower part of a high dam will be less than under the small pressures of moderate depths.

San Pablo Dam Experiments

Some experiments were authorized by George Wilhelm, and made by G. W. Hawley, resident engineer at the San Pablo Dam, near Berkeley, Cal., following suggestions of the writer. A 14-in. cast-iron pipe was cut into two short parts, one of which was fixed and the other attached securely to a steel frame which swung freely on an axis about 8 ft. above. Another steel frame securely connected the ends of this axis with the fixed part of the 14-in. pipe and with other parts of the apparatus. Two hydraulic jacks were used and the pressures were computed from the measured pressures on the pistons.

The two pieces of 14-in. pipe were placed in line and the frames held them so that the ends would just clear.

A sample of the material to be tested was placed in the pipe, filling the lower or fixed part and extending some distance into the movable part. Oak planks, cut to fit as a loose piston, were then placed above. One of the hydraulic jacks was placed above it. Pressure was then applied to compress the material in the pipe to any desired extent. Experiments were made with various pressures, the greatest corresponding to a depth of fill of 200 ft. While the material was held under this pressure, the other jack was placed horizontally against the side of the 14-in. pipe with suitable blocking, and pressure applied until there was movement. The ratio of pressures on the two jacks then gave the coefficient of friction.

The steel frame and the pivot at the top was built so that there was no appreciable friction in the apparatus. A slight correction was necessary because the lever arm to the slipping plane was longer than the lever arm to the point on the 14-in. pipe where there pressure was applied.

The form of the experimental apparatus was suggested to the writer by a paper by A. L. Bell on clay pressures. The apparatus as worked out was more like that used by E. P. Goodrich in his experiments on soil pressures.

The apparatus used differed from both of its predecessors in that tests were made at very much higher pressures. The results may be compared, but it must be remembered