Effect of compaction and water content on swell of clays
by Stam H Fistedis

A THESIS Submitted to the Graduate Committee in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering
Montana State University

Abstract:
If clay is heavily compacted under an initial water content, some swell tendencies are locked up by the forces of capillarity. When such capillarity is destroyed by saturation, the material swells somewhat, unless the swell pressure is resisted vertically by the weight above it and horizontally by shearing resistance of the foundation.

Swell tests were carried out, maintaining a constant original volume of soil, as the soil in the proper apparatus was submerged in water. Small volume changes were measured in percent of total volume by a dial indicator.

It was difficult to obtain very accurate results from tests of this kind. However, information obtained indicates conclusively that the greatest swell occurs with the greatest compaction and the smallest original water contents. Good results were obtained with moisture contents in the wet side of the optimum.

Soils heavily rolled in a dan may result in a very serious condition, so compaction method may be considered as a governing factor in an earthdam design.

The vertical compressive stresses available to resist vertical expansion are not equal to the weight directly above. Moreover, the great danger is the tendency for horizontal expansion, the building up of expansive forces, and the sudden release of those forces due to failure along some nearly horizontal plane in the dam or at the surface of a weak foundation.

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Approved:

R. C. De Hart
In Charge of Major Work

R. C. De Hart
Chairman, Examining Committee

J. A. Nelson
Chairman, Graduate Committee

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A - Forward

The need for a precise procedure for the design of earthfills still exists. It would be desirable to find a method of determining the softening of clay that may occur when it is completely saturated with water. This is a problem which involves a determination of the compaction required to produce a clay embankment of a density sufficient to obtain the watertightness sought.

The moisture content under which compaction is to be carried out, the degree of compaction, and the method of compaction must be determined in such a way that settlement, softening, swell or other undesirable conditions be kept to a minimum. It should be understood that the advantages gained must justify the cost of the compaction method used.

The failure of a few earthdams makes immediate investigation of the causes demanding. The failure of an earthdam at Lebanon, Pennsylvania, was due to a slip on the outer slope. The creep was apparently due to the softening by rain of the material of which the dam was composed, presumably of the prevailing plastic soil characteristic of southeastern Pennsylvania.

Another failure at Colorado Springs was of a similar nature, but more serious. Strong seepage through the dam was followed by swell, caving and slipping of the outer slope, the slips reaching within a foot or two of the crest and necessitating the lowering of the water.

Research on the behavior of soils used in embankments and its successful application for construction purposes will improve a great deal the safety of the earthdams to be built in the near future.

The foregoing study is limited in the observation of the swell of clay soil with different moisture contents and methods of compaction.

In closing, the writer wishes to express his deep gratitude to Professor R. DeHart for his expert advices that made the execution of the present research possible.

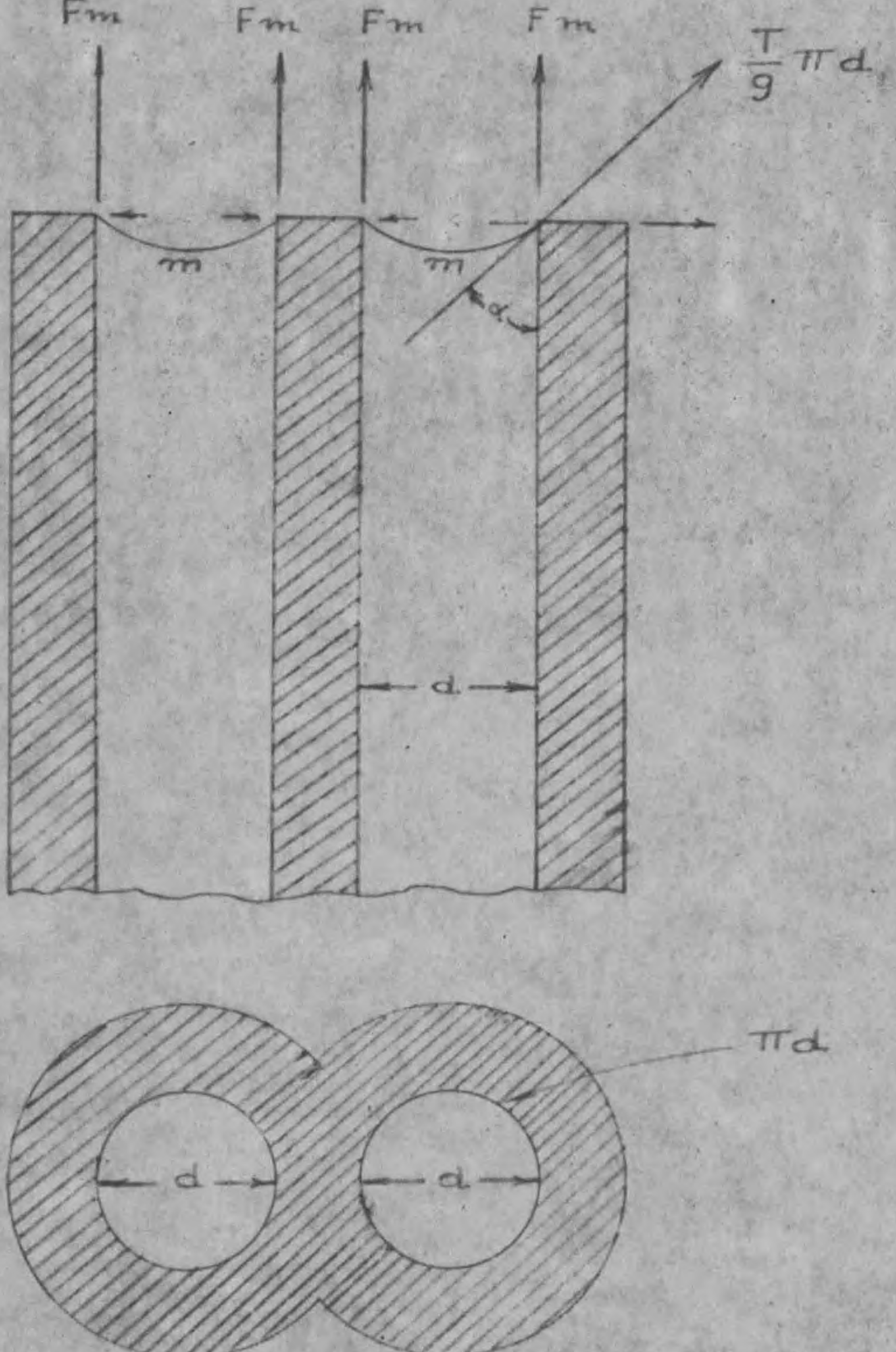
Stam H. Fistedis

Swell in Clay Soils

If the thin pores in a clay soil are considered as forming thin tubes, the water in those tubes will tend to rise up to a certain level that its surface will form a meniscus m. That meniscus would have been semispherical if both water and glass tube were clean.

Suppose that soil powder (in this experiment clay soil) is placed in thin layers in a container with a bottom provided with numerous small holes so that the soil particles cannot fall out and that this bottom is brought into contact with a water level. The soil would then be gradually moistened from below. The level of the rising moisture is practically horizontal at all times, as if the moisture were moving in parallel thin tubes of equal diameter. This diameter d is called the statistical diameter and is characteristic for every soil.

According to the capillary tube hypothesis, the capillary movement is explained by the lifting force of meniscus, or curved surface, at the top of the column of capillary moisture. A hypothetical straight line traced at the surface of a liquid is assumed to be extended by the force of surface tension. The latter is measured by units of force (for instance, grams) per unit of length (for instance, centimeter). The value of surface tension for pure water at the room temperature (about 67° F) is T/g grams per centimeter, the value of T being equal to 72.8 and g to 981. It is assumed that the circumference of the meniscus, as of any other line at the surface of the liquid, is extended by the surface tension. If the meniscus is fully developed, the surface tension at its perimeter acts vertically and upward. When the meniscus is not fully developed, the surface tension at



Meniscus in a capillary tube

its perimeter acts along the tangents to the surface of the meniscus. The angle a formed by these tangents with the walls of the tube is the angle of capillarity.

The force of the surface tension $(T/g)\pi d$ acting at the circumference of the meniscus may be broken into a vertical force $F_m = (T/g)\pi d\cos\alpha$ and a horizontal force. The force F_m is the lifting force of the meniscus, which is supposed to lift a column of water from the surface of the liquid to the level of the meniscus. If the angle of contact α gradually decreases, the lifting force of the meniscus increases to reach maximum when the meniscus is fully developed.

The height h of a water column that can be lifted by the meniscus in a capillary tube can be determined from the conditions of equilibrium. If the cross section of the tube is designated with a, the relation becomes $F_m = hak$, where k is the unit weight of water. Now, if an excess of water comes from above, it will tend to fill the pores of the soil that may have dried near the top layers. In this case, the surface tension will be shifted to the free water surface; thus, the clay particles will be freed from surface tension and hence, from compression. Particles will then expand. That is the cause of swell of the clay when it is saturated with water. The previously acting capillary forces are now removed.