Practical Soil Mechanics at Muskingum—I

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THE END of empirical methods in earth-dam design is predicted by the record of the soils-laboratory work described in the series of articles begun in this issue.

By analyses and model tests the engineers of the $40,000,000 Muskingum River flood-control works are adapting soils of widely different geological character to earth-dam construction with a close approach to predetermined exactness. This is the most notable advance in the practical application of soils mechanics in dam building since the remarkable work of R. R. Proctor described in *Engineering News-Record*, Aug. 31 and Sept. 7, 21 and 28, 1933.

With the work done at the laboratory of the Muskingum project, empiricism has been further pushed from a dominating position, and the design of earth dams is brought near to the realm of rational determination.

In this and three succeeding issues the story of the laboratory is told by the engineers who put their faith in the helpfulness of soils mechanics and whose efforts have been rewarded by increased certainty and economy in design and construction.

Groundwork for a Rational Study

THE PROBLEM of earth-dam design for flood control in the Muskingum River Valley roots deeply in the geology of the drainage area. In the north and west there is a glaciated zone of moraine deposits; and a middle zone of glacial outwash materials follows to the Allegheny plateau in the southeast, where residual soils are dissected by deeply eroded valleys that have been filled with poorly consolidated silts, clays and sands. These different geologic sources give a large variety of soils both in suitability for dam embankment and for embankment foundations. The dams are located in all zones, each of which presents a general soil condition with a specific soil condition at each location. Referring to Fig. 2, a survey shows situations as follows:

1.—The Mohicanville, Charles Mill, and Pleasant Hill dams are founded on materials that were laid down by the glaciers, to a large extent, and have foundations that are both reasonably strong and reasonably impervious. There is one exception to this, where a recent fill of unconsolidated silt had to be removed from the foundations at Charles Mill. These three dams are located in the glacial region. Although the main structures from a soils standpoint are relatively simple, several smaller structures had to be founded on recent deposits of peat some 20 ft. thick and were among the most difficult of our problems.

2.—The Bolivar, Beach City, and Mohawk dams are located in the glacial outwash region, a band along the southeastern boundary of the glaciated region. The characteristics of these foundations are very pervious clean sands and gravels some 100 to 120 ft. deep in the valley floor, overlain by a very thin and in places quite pervious layer of sandy silt. The planning of these embankments was controlled by the magnitude and effect of the seepage, which had to be determined, with provision made to protect the fill against its destabilizing influence.

3.—The other earth dams in the project are located in the Allegheny plateau country and have foundations consisting of unconsolidated silts and clays of depths varying from 5 to 70 ft., in most cases underlain by fine sand or other stable deposits. These conditions, generally speaking, presented the problem of the stability of these foundations under the embankment loads, although some consideration had to be given to effect of seepage where the overlying silts and clays were comparatively shallow. Leesville, Tappan and Clendening dams are in this class, while the Piedmont dam and also the Senecaville dam presented problems in stability alone. Wills Creek dam presented both problems, in that one portion of the embankment rested upon a pervious sand and gravel terrace, while the remainder rested upon secondary fill of silt and clay filling the present stream channel.

With conditions as described, a preliminary soils reconnaissance was indicated as the first operation in dam planning after general location determined by degree of effectiveness for

FIG. 1—IN THE SOILS-MECHANICS LABORATORY of the Muskigum flood-control project, different sizes of hydrometers are used to assure accurate determinations at different densities. Soil classification is determined by both sieves and hydrometers.

flood control had been decided. The reconnaissance very soon made it apparent that diverse problems of extreme gravity would be presented for decision. It was apparent that the unconsolidated silt and clay foundations could fail from resulting excessive shear stresses induced by the proposed embankment loads, such as developed in the construction of the Lafayette Dam (*ENR*, Sept. 27, 1928 and such as are a familiar occurrence in the construction of the high levees on the lower Mississippi River. Should a failure of this type occur, it was realized that it would probably mean the abandonment of the site, resulting in a tremendous money loss. On the other hand, unless a definite basis for design could be developed and applied, the cost of the structure, if designed to be unquestionably safe, might be unnecessarily high.

Two of the dams proposed for construction on pervious foundations were very high structures; one, the Mohawk Dam, 115 ft. high, is probably the highest ever proposed on a sand and gravel foundation. To proceed, therefore, without a previous knowledge of the foundation behavior of such structures after completion would be unwarranted. Again the embankments themselves were to be constructed of diverse materials. The excavations for spillways, outlet structures, etc., at various sites ran into millions of yards, and (for economy) had to be utilized wherever possible. A thorough knowledge of the behavior of all the materials available for use in the embankment was essential to the proper planning of the work and the preparation of specifications for its execution.

It was apparent then in the very first stages of the project that only by a thorough-going application of the latest developments in soil mechanics and by conducting additional necessary research to amplify the results so obtained could the dams be designed safely and economically. This called for a soils laboratory and made it clear that it must be equipped: (1) for the rapid analysis and classification of soils, to lay the basis for the determination of further investigations; (2) for the determination of permeabilities of undisturbed and remolded samples of foundation and embankment materials respectively, with proper facilities to apply this information to the specific problem at hand, principally by the use of model studies; (3) for the determination of the consolidation and shearing characteristics of undisturbed samples of foundation materials and, to some extent, of remolded samples of proposed embankment materials; and (4) for the investigation of the consolidation characteristics of embankment materials and the moisture requirements necessary for control in placing them.

With the laboratory in service, preliminary soil studies were begun in field and laboratory to obtain sufficient information to determine the feasibility of constructing a dam at a particular site and to determine the probable design requirements to insure stability of the embankments, including sufficient information about excavations and foundations for all proposed structures to permit the preparation of a preliminary design for estimating purposes.

Field sampling first task

Contracts were let for obtaining drive samples of the overburden and core borings at the various sites. The number of borings was such as to permit the general development of a geologic section. Usually two or three borings were undertaken across the valley floor and about the same number in each abutment. The samples of the overburden were obtained by drive tubes driven below the bottom of the casing between the operations of driving the casing and washing out the excess material. Core borings were taken in rock with a double-barreled drill equipped with diamond or metal alloy bits. As the characteristics of the site, developed by detail studies of these preliminary borings, indicated its probable inclusion in the final plan, the scope of the investigation was widened to include further borings to develop spillway locations, detailed data on outlet structures, more exact information on possible borrow-pits and further data on the valley-fill materials.

Numerous borings were taken by hand augers in the excavation and borrowpit areas under consideration. Samples in 5-lb. sacks as well as 1-lb. samples in sealed jars were secured from these excavations for later use in remolded tests, in addition to classification work, to fix the general characteristics of such borrow-pits. Hand-auger borings were also used to investigate, in detail, the extent, depth and general characteristics of natural blankets in the valley bottoms which help to seal off the more pervious layers below. The samples placed in sealed jars were to provide specimens for water-content determination.

As the studies on any site progressed,

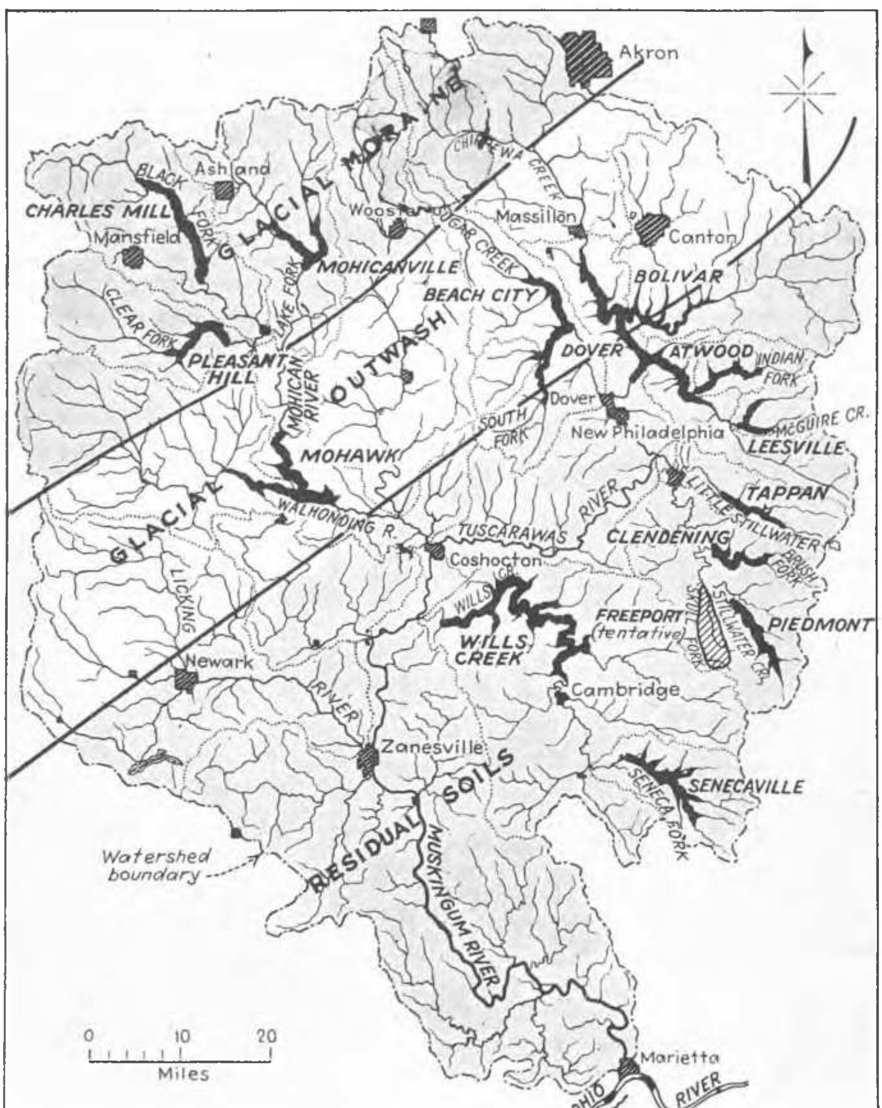

FIG. 2—DETENTION DAM LOCATIONS are fairly evenly divided between the glacial morain, glacial outwash and residual soil zones into which the Muskingum Valley drainage area is divided.

it became necessary to obtain undisturbed samples of the foundation materials. These samples were of two general types: those obtained for permeability studies, and those obtained for consolidation and shearing tests. In the first class, it is not necessary to get the sample to the laboratory with its original moisture content, but it is necessary to get the sample in an undisturbed condition. With the second class of sample, the material has to be undisturbed and its water content unchanged when it reaches the laboratory. This made it necessary to seal these samples in paraffin immediately upon taking them on the job. Both of these types of samples were taken by excavating test pits in the foundation of the proposed embankment.

Soils classified in laboratory

Preliminary soil classification in the Zanesville laboratory consisted of moisture-content determination and grain-size analysis. These two factors taken together give a rough picture of the type of material and its probable behavior. The grain-size analysis alone does not give any information on the probable degree of consolidation of the material, but in a saturated material, knowing the grain size, the water content gives an excellent indication of the stability of the material. Water content is, of course, also valuable to determine the suitability of the material for direct use in embankment.

As soon as a sample was received in the laboratory, it was taken to the classification desk, where a soil technician took a small sample from the sealed jar and placed it in a watch-glass set. This sample was then weighed, dried in an electric oven at a temperature of 98 deg. C. and weighed again. From these, knowing the weight of the glass, the weight of the water content and the dry weight of the sample can be determined and the moisture content in terms of per cent of the dry weight computed.

The next step was to determine the grain-size classification for the material. A well-trained technician can generally classify the soil closely, but frequent analyses (about one sample in ten) are necessary as checks and to provide representative curves for further study.

Soil classification is handled by sieve analysis, by hydrometer analysis or by a combination of the two. Fig. 1 shows the hydrometer table and various sizes of hydrometers for accurate determinaations at different densities. The grain-size distribution often requires a determination by a combined method of analysis. The soil to be so tested is first washed through a 200-mesh sieve; that portion retained is analyzed by sieves and the porion washed through by hydrometer. It is not necessary to make the wash thoroughly, but only to remove fines enough to prevent caking of the sieve sample while drying and allowing the sieves to complete the separation, taking care to add to the hydrometer test the remainder passing the 200-mesh sieve. The combined analysis is a check on both methods of analysis, for the resulting grain-size curve plotted characteristically on semi-log paper should result in a smooth curve joining at the break of method. The soil classifications used are illustrated by the diagram Fig. 3.

Tentative design now possible

The completion of the soil classification from the available samples, determination of the water contents for each, along with the informaion on the rock determined by the geologists from the study of the rock cores, permits the preparation of a geological cross-section along the center line of the proposed embankment. In addition to this, in some cases it was found necessary to prepare geological sections normal to the axis of the dam at various locations and also sections along proposed spillway and outlet routes.

As the next step, a preliminary design of the embankment is prepared. The preliminary design of the embankment will ordinarily contemplate he use of all suitable materials available in required excavations and will supplement these with the best available borrowpit materials for the embankment design indicated at the site. At this stage the proposed embankment section can be added to the geological sections, and since the final stability of the structure is being investigated the foundations and embankment must be considered from now on as a unit. All investigations are directed to determination of stability from the standpoint of seepage and strength, with this in mind.

These studies may show that it is necessary to change the design of the embankment by providing flatter slopes or more adequate drainage, or that it may be necessary to change the condition of the foundation by providing a blanket to connect with the impervious section of the embankment and extending upstream from it to insure an adequate ratio between path of percolation and head. It may be necessary to alter the condition of the foundation by removing certain materials, under all or part of the embankment, which are too impervious or too weak to permit of economical treatment by any other method. The foundation condition may be altered by the inclusion of concrete, steel sheetpiles or earth cutoff provisions. But from now on, the embankment and its foundations together must be considered as a unit for study.

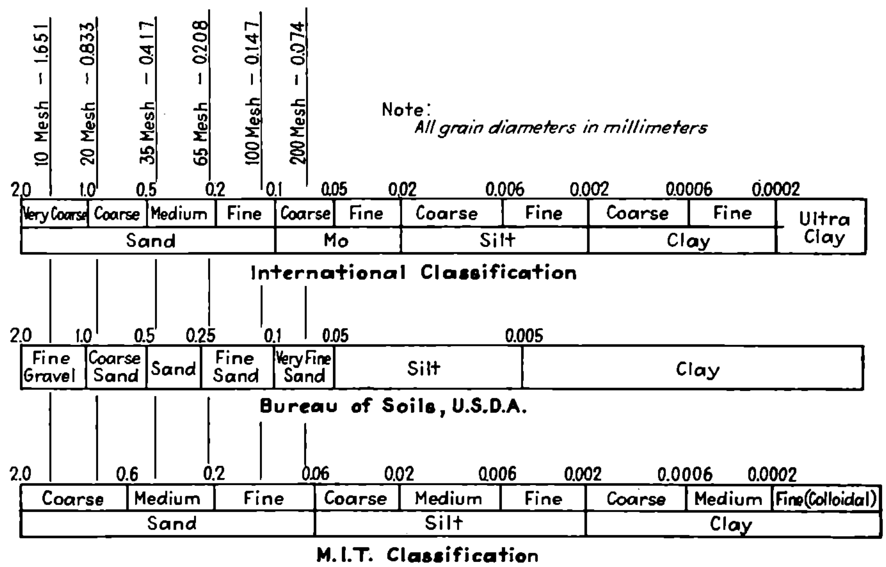

FIG. 3—THE THREE SOIL CLASSIFICATIONS in general use; comparison of the results of a soil test are shown by the grain-size figures.

Further studies may develop the need for additional field explorations to provide all the required data, the purpose being to determine:

1. The characteristics of the proposed dams and foundations as to permeability and seepage and their safe design to resist piping and sloughing.

2. The characteristics of the foundation material as to amount and rate of consolidation, shearing stresses induced by embankment load and resistance strength of the foundations.

3. The suitability and use for embankments of materials from excavation and borrowpits.

The development of equipment and methods for making these determinations is described in three following articles.

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The next article, to appear April 9, describes methods of conducting the permeability and seepage studies, which brought out the important fact that an upstream blanket was often more effective and economical than a corewall in reducing seepage.