

some heavy clay soils of the A6 and A7 types with tar emulsions and cutbacks on an experimental subgrade stabilization during the summer of 1937, we found that this type of soil stabilization presents some very different problems from those of soil-aggregate stabilization.

Soil-cement stabilization, as described by Mr. Myers, also presents some interesting problems. According to its claims, the Portland Cement Association can satisfactorily treat any soil, free from organic or other objectionable matter, that has a liquid limit below 40 and a plasticity index below 20. Although the addition of cement changes the physical characteristics of the soil, the compaction in this type of stabilization is quite important.

Any of these various forms of stabilization may become somewhat complex and warrant laboratory and field studies of the materials available before the recommended method of treatment is suggested.

### HIGHWAY EMBANKMENT CONSTRUCTION PROCEDURE

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The handling of embankments depends upon a knowledge of the material types that will be encountered in cuts or borrow and the construction control that may be exercised. This paper gives briefly a description of embankment material types which are often encountered. A method of presentation by the use of the soil profile is included. Specifications for the placing of these materials as well as tests employed in construction control are also mentioned.

Since the summer of 1935 many states have adopted specifications for the control of moisture and compaction of the soil used in embankments. Numerous failures had been occurring for several years in the higher regions where deep cuts and high fills were being used as a result of the evolution of modern grades and eliminations, and these construction requirements were intended to prevent similar failures in the future.

Such specifications have since been found to be adaptable for use in level-to-rolling country where only slight fills are necessary. Some states are even using a density specification for control of the compaction of subgrades so that new pavements may be placed on well-compacted grades.

Common materials encountered and used in embankment may be classified as soil, shale, granular material, random material, and rock. When materials are classified as such, they must be defined. The following definitions will probably suffice for them.

Soil may be considered as layers or deposits of disintegrated rock lying on or near the surface of the earth which

have resulted from natural processes such as weathering, decay, and chemical action, in which at least 40 per cent by weight of the grains or particles are smaller than a No. 200 mesh sieve.

Shale may be defined as finely laminated rock formed by the consolidation of soil including clay, silt, and fine sand.

Granular material includes natural or synthetic mineral aggregate—such as broken or crushed rock, gravel, sand, cinders, or slag—which can readily be incorporated in an 8-inch layer, and which, after being placed in embankment, contains insufficient material to fill the interstices between the stone particles.

Soil is a variable and complex material, with different kinds performing differently under a given set of conditions. As a result, it is essential that soil be subdivided into types or classifications.

Various classifications are in use throughout the country, those of the Bureau of Public Roads probably being most common. However, with the adoption of the density specification for compaction and moisture control, a new method of classification has been developed. This classification is based essentially on maximum obtainable laboratory densities, as performed in accordance with the requirements for the Proctor test.

It has been observed that materials weighing about 120 pounds per cubic foot, dry weight, normally are sands and gravels containing rather small quantities of silt and clay. These materials are known to serve entirely satisfactorily in embankments as well as in subgrades and are usually considered good or excellent for use in embankment.

Likewise, materials with maximum dry weights of 110 to 120 pounds are normally silts of the Bureau of Public Roads A-4 and A-5 classification. These types make good embankments and subgrades when used at a moisture content below the optimum, but they are subject to frost heaving and are particularly unstable when placed in embankments at a moisture content above the optimum. It can be seen then that such materials can be considered only fair for use in embankment and may even be unsatisfactory if used at an excessive moisture content.

Materials weighing from 100 to 110 pounds per cubic foot are usually clays of the Bureau of Public Roads A-6 and A-7 classification and make satisfactory embankments when placed under reasonable control. Such materials require more rigid control during construction than do the better types.

Materials weighing less than 100 pounds per cubic foot are likely to be organic silts or very poor types of clays. Such types are many times wasted, or if used they must be placed under very rigid field control.

The following table shows the range of soil types by maximum laboratory dry weights and the compaction requirement for each type for two conditions of use which was recently adopted by the Ohio Department of Highways as one part of their new embankment specification.

DENSITY SOIL CLASSIFICATION

| Condition I<br>Fills 10 feet or less in height and not subject to extensive floods |   | Condition II<br>Fills exceeding 10 feet in height, or subject to long periods of flooding |   |
|--|---|---|---|
| Maximum Laboratory Dry Weight*<br>(Pounds per cubic foot)                          | Minimum Field Compaction Requirements<br>(Percentage of dry weight) | Maximum Laboratory Dry Weight*<br>(Pounds per cubic foot)                                 | Minimum Field Compaction Requirements<br>(Percentage of dry weight) |
| 89.9 and less  | **  | 94.9 and less   | ***   |
| 90.0 - 99.9  | 95  | 95.0 - 99.9   | 100.0   |
| 100.0 - 109.9  | 95  | 100.0 - 109.9   | 100.0   |
| 110.0 - 119.9  | 90  | 110.0 - 119.9   | 95.0  |
| 120.0 - 129.9  | 90  | 120.0 - 129.9   | 90.0  |
| 130.0 and more   | 90  | 130.0 and more  | 90.0  |

\* Maximum laboratory dry weight is obtained as described in Bulletin No. 99, Ohio State University Engineering Experiment Station.

\*\* Soils having maximum dry weights of less than 89.9 pounds per cubic foot shall be considered unsatisfactory and shall not be used in embankment.

\*\*\* Soils having maximum dry weights of less than 94.9 pounds per cubic foot shall be considered unsatisfactory and shall not be used in embankment under Condition II requirements.

An inspection of the requirements in the table will show that the poorer the soil, the higher the compaction requirement. In addition, the conditions for use of the soils are recognized by the arbitrary line of demarcation, by height of fill, and by the probability of flooding.

Common embankment failures include :

1. Slipping of an inclined surface used as the embankment foundation.
2. Slipping of the side slope of the entire embankment.
3. Settlement.
4. Erosion.

The side-hill type of failure is quite common in areas where the foundation is poorly compacted or where it is made of a very plastic clay in which proper construction precautions were not taken—such as benching to insure an adequate and stable base.

Sloughing is a prevalent type of failure and may be attributed to a variety of causes, among the most important of which are improper compaction and construction control. Clays are

particularly dangerous when placed in an embankment in a poorly compacted state, since water percolation from rains, snow, or floods causes saturation. This water content, according to actual tests, has often been noted as being equal to the liquid limit. The outer slopes of many embankments slough because modern compacting equipment cannot always be used to best advantage near the edges of the side slope.

Settlement is common in materials normally used in construction. Granular material placed dry may settle after becoming wet; rock fills may settle when proper keying has not been obtained in construction. Shale is particularly dangerous since it is often rock-like in nature when excavated and placed, but upon exposure to air, water, and temperature changes, it slakes down to its natural constituents of sand, silt, or clay.

Erosion occurs commonly in silts and granular material when improper protection is afforded the side slopes.

#### CONSTRUCTION CONTROL

The most logical method of correcting embankment failures is to improve the original design. Obviously such a procedure cannot be followed unless all available types of materials have been located, tested, and classified. This is commonly taken care of in the soil profile which is made before the design and contract.

Laying out the soil profile is the largest single contribution that the soil laboratory can make to a highway department. It involves mapping and classifying all types of soil encountered, showing all geological formations and classifying them by material types—such as shale, sandstone, limestone, clay, coal, etc.—investigating areas susceptible to slides, and



Fig. 1. Embankment failure after a severe flood, Washington County.

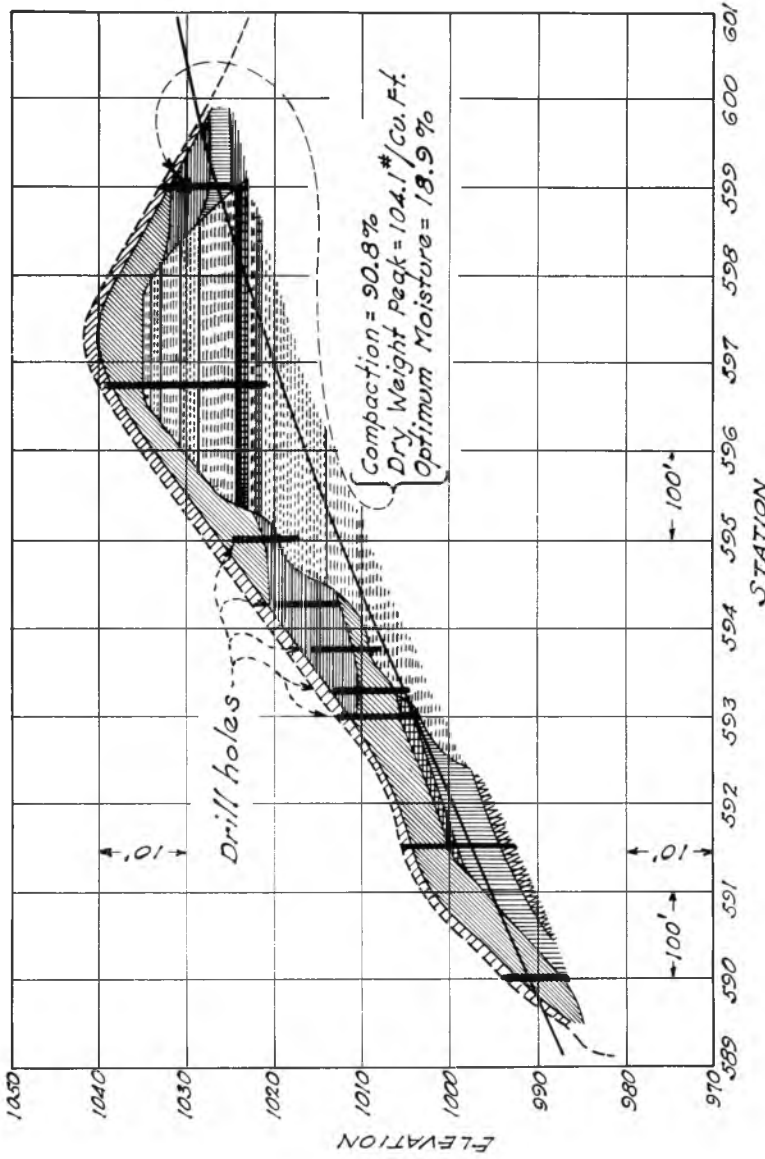


Fig. 2. Typical soil profile.



Fig. 3. Field equipment used in obtaining soil profiles by the Bureau of Tests, Ohio Department of Highways.

inspecting foundations to determine their fitness for the proposed loading. Such a survey is essential to insure embankment stability, so that poorer material types will be used only after the proper design has been produced and the necessary changes made before construction.

The second item in insuring embankment stability consists of construction control. Such control in several states involves the use of the so-called Proctor test for determining the maximum weight per cubic foot and the optimum moisture content. Proctor curves are made from all types of material found on the project and from those submitted to the field for use in the construction control. See density test described in "Soil Mechanics Applied to Highway Engineering in Ohio," by K. B. Woods and R. R. Litehiser, *Ohio State University Engineering Experiment Station Bulletin No. 99*.

Field control is effected by making wet-weight determinations of the compacted fill. In comparing these with the laboratory Proctor curve, the percentage of compaction is calculated by dividing the dry weight per cubic foot of the compacted embankment soil by the peak weight of the laboratory dry-weight Proctor curve.

A major development in construction control has been offered recently in the use of typical curves for embankment control. It has been found that similar soil types give similar curves in the Proctor test. After the averaging of several thousand samples in specified ranges of weights per cubic foot, curves were made representing these weight ranges. On one set, the curves showed a range of dry weights normally encountered in embankment construction.

Such curves are easily used in the field by making a weight-per-cubic-foot determination in the Proctor cylinder and obtaining a penetration reading of this compacted material. These two readings are superimposed upon a set of typical

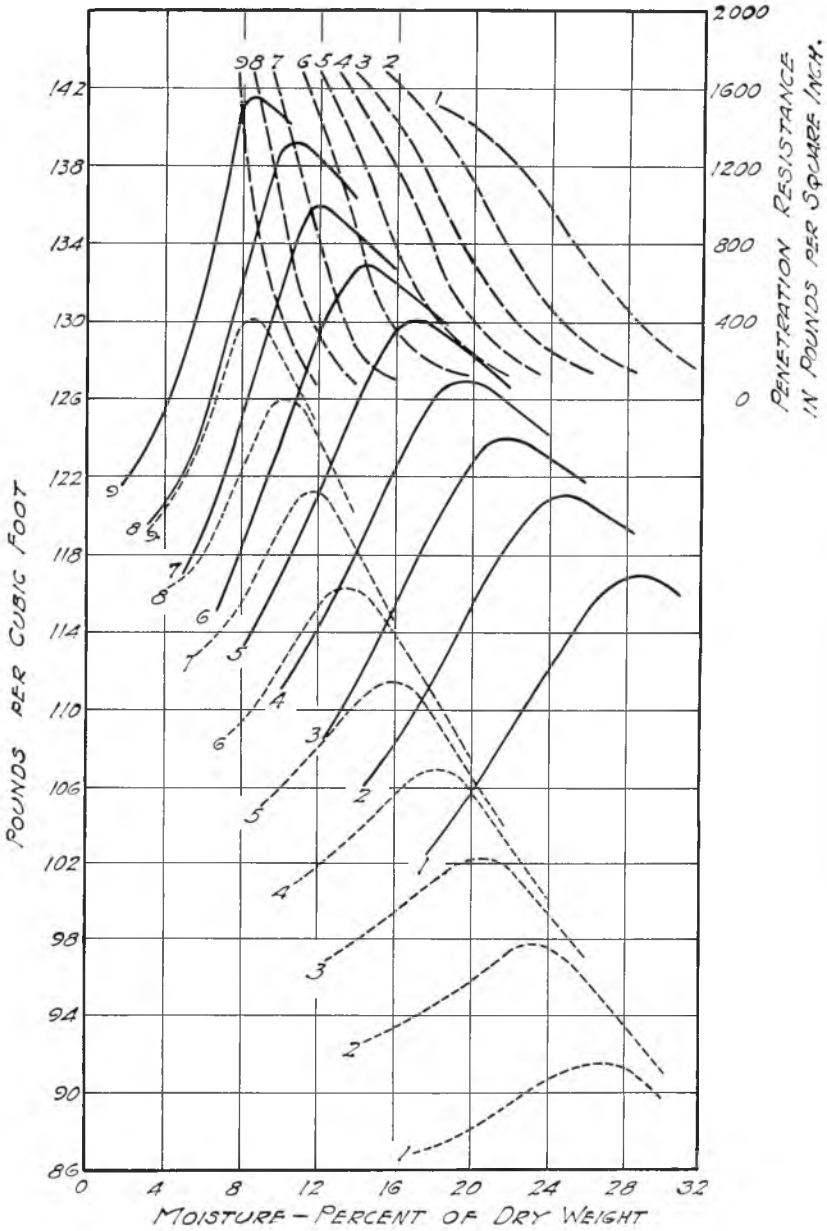


Fig. 4. Typical embankment control curves averaged for each five-pound dry-weight peak range for 1,088 Ohio soil samples received in 1937.

curves and that curve is used in which the readings give the same moisture content. Many jobs in Ohio are now being controlled by this method. Likewise, in the absence of typical curves, curves from other projects can be used as long as the above-mentioned readings give the same moisture content.

After several years of application on large embankment projects, the Proctor test may be considered as a sound engineering method for controlling embankment compaction. Embankment stability is directly dependent upon the mapping of the soil conditions before the writing of the contract and upon providing for adequate design for the weak spots. Embankment materials occur in many variations, and energy must be spent in controlling the poorer materials. The better types of materials are of much less concern.

## FUNDAMENTALS OF SPECIFICATIONS

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There are three distinct steps in the preparation of contracts—the making of preliminary surveys, the preparation of plans, and the writing of specifications. From the survey, information is secured from which the plans are prepared and the specifications are written. The plans show the various details of the work as it is to be constructed. There is no doubt concerning the need for careful surveys and properly prepared plans; but there is still greater need for carefully written and properly prepared specifications, because it is from the specifications that the bidder is able to determine the nature of the work to be done and to draw his conclusions as to the fairness of the persons writing the specifications, how well the engineer knows the details of the work contemplated, and what kind of treatment he may expect from those who will be in direct authority during the progress of the work. With good specifications the contractor can intelligently estimate the cost of the various items of work, and there will be a minimum of arguments as to requirements and therefore small probability of litigation, as well as a minimum of delays during construction, which are always an item of expense to the contractor.

It is through the requirements of the specifications that the engineer is able to exercise control over the work and to secure proper quality of materials and workmanship.

It is thus evident that both the contractor and the engineer derive benefit from good specifications. It is equally true, although less evident, that the public in general derive benefit from good specifications; better results are obtained at less cost than would be secured with poor specifications. Suitable specifications are the first safeguard of public funds.