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# NATURAL CONDITIONS AFFECTING PERFORMANCE OF SOILS

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Soil, in a very general sense, is the mantle of comparatively loose or unconsolidated material formed by the disintegration and decomposition of the earth's crust by numerous natural processes. Soil, as an engineering material is extremely complex as its character varies materially with ordinary changes in the numerous factors and conditions associated with it. From the standpoint of the engineer, it becomes essential to consider each particular soil as an individual entity, the behaviour of which is the reflection of its own characteristic properties and environment.

In the study of soils, there are two extreme positions to take in such consideration, that of the geologist who is primarily interested in the origin of soils and that of the civil engineer who has no direct interest in origins but is vitally interested in types of soils, the properties peculiar to each type and the properties as influenced by its particular environment. The study of origins of soils particularly in regards to Michigan has been treated in an earlier lecture. Methods or systems for classifying soils has likewise been treated. The study of origin and classification enables us now to better understand the reasons why a further knowledge and technique for use of soils as an engineering material is necessary. In the strict sense of considering soil as engineering material, we might be led to consider it as we do the better known engineering materials such as metals, wood, concrete, etc. But, as we all must realize by this time, soils cannot be treated in this manner. The economics of its use together with the fact that it is a material which is "in situ" requires that we must consider it as it is found in its natural environment, in place, at the site of the engineering structure. As a matter of fact, it is this special peculiarity, or stipulation, which makes it necessary to develop the science of soils engineering somewhat apart from the science of the strength of materials.

More specifically it is the variation in performance of soils as influenced by natural environments and the economics in relation to its use in engineering structures which determines or establishes the problems encountered under the subject of soils engineering. Therefore, the study of the problem divides highway engineering itself into two phases. First, what conditions, natural and economic, make it necessary to improve the properties of soils "in situ" and secondly, what to do in order to improve these properties.

We will deal with only the first phase in the discussion today, while the other phase will be discussed in the following sessions of this school.

Physiographic Environment

Usually, the general location of an engineering stmucture is predetermined by the economic needs; the most suitable, specific location will usually be definitely determined by consideration of natural or physiographic environment. As we all know, the general location might be described by a relatively large area as in the case of a preliminary or reconnaissance survey for a railroad or highway, or to a specific location such as the site of an office building. The selection of the final site, therefore, may be determined wholly, or in part, by the natural environment. But, in any case, the engineer in utilizing the soil material in place must have a thorough knowledge of the affect of the natural conditions upon its performance as a foundation or as a part of the structure, or in a more general sense as an engineering material.

As has been previously discussed under soils classification, the soil may be classified subjectively or objectively. By the subjective method, the soil is considered under the conventional procedure in which study of certain fundamental properties such as elasticity and other physical properties is made. In the objective system, the soil itself as a natural material is the basis of its classification. In this method its characteristics in relation to the parent material and its environmental factors are considered. Therefore, in studying soil as an engineering material, we are interested in how the natural environment not only affects its performance but also as a part of a method for classifying various types of soil.

The performance of soils and the soils problems encountered are influenced, in a large measure, by the several physiographic environmental conditions which may be considered under the following headings:

1. Climatic conditions
2. Topography
3. Drainage
4. Physical state of soil

Climatic Conditions

The various phases of climate is one of the most important physiographic conditions which influence the character of our soil problem. This is particularly true when these phases are considered as agencies in the formation of soils. They also have a marked influence upon performance of soils and necessary subsequent treatment of soils. The various aspects of climate related to this influence includes temperature, rainfall and humidity.

The temperature range in any given locality controls the character of plant and animal life, together with its destruction and also furnishes forces which disintegrate rock. The amount of weathering due to temperature change is not of such great importance however, unless associated with water.

The mechanical process of freezing water is one of the important processes of weathering. Water is also important in other ways, for instance; running water, an important factor in erosion, will also act as a weathering agent if it is carrying solid matter in suspension.

The impurities usually found in water give to it chemical properties which result in other weathering processes. The mineral constituents of the soil particles depend largely upon the chemical composition of the parent rock and the conditions under which the soils are developed. And, as will be seen later, the chemical composition may affect the use of the soil. In humid northern climates the iron and aluminum oxides are removed by leaching whereas in the humid tropical climes, we find the silica leached out leaving the iron and aluminum oxides. In arid or semi-arid climates the alkalies are not completely leached out causing a soil to be neutral or alkaline.

The relation between temperature and water is thus seen to be closely associated and weathering action cannot be completely described without consideration of both phases inter-dependently.

The action of water and changes in temperature add further to our problem in certain incidental phenomena such as differential and frost heaving which will be discussed later.

The importance of climatic conditions then in relation to the natural soil depends upon the amount of water present and upon the variation and range of temperature. The type of soil problems which are encountered, as caused by these conditions, will be discussed under topography, drainage and physical state of soil.

## Topography

The topography, or relief of the land surface is closely associated with many soil engineering problems. The topography and its associated problems will vary for different localities and areas. The topography of a given area, of course, is determined by the manner of origin of its surface. The topography of a mountainous area being decidedly different from that of glaciated areas. Since we are interested in Michigan, a glaciated area, specific attention will be given to problems encountered under such conditions. Most of the problems here discussed will deal primarily with building of railroads and bridges, but certain information may be useful in the construction of other types of engineering structures.

The topography may be considered for our purposes, according to the amount of difference of elevation or inequalities of the land surface and may be divided into three groups namely -

1. Hilly
2. Undulating
3. Level

Hilly Topography: Hilly topography in the glaciated areas of Michigan presents a number of associated soil problems as determined by the natural contours, geological characteristics of the body of material in place and subsequent treatment in construction.

Natural Contours: In this type of topography arise problems concerned with deep cuts and high fills. The establishment of the line and grade, of course, will be determined by many other factors, yet some consideration must be given to natural conditions as influenced by the topography. The selection of grade line will be determined by the importance of safety and convenience, drainage and financial considerations. Safety and convenience are not within the province of this paper, drainage will be discussed later, but the character of the soil will influence very much the financial consideration.

The location economics will be affected by the topographical features and in addition, the nature of necessary cuts and fills, the availability of suitable material for embankment fills, the stability of sloping ground above and below a selected route, and the availability of suitable construction material will all influence the final selection of line and grade.

Since the character of the soil in hilly topography is essentially morainic in character, it is subject to a wide range of soil materials from a fine clay to large boulders. This non-uniformity requires a thorough study of soil types and a specific knowledge of their properties in order to determine their suitability as fill material or the economics of proper treatment for satisfactory use, such as control of compaction by Proctor method, introduction of stabilizing agents, etc.

Sudden variations in soil structure in hilly glacial topography present many soil problems and necessary treatment. The character of these problems and their specific treatment will be covered in "Practical Use of Soil Information in Highway Design." It is suffice to point out that these variations are associated with frost heaves with which we are all familiar. Also, in this type of topography is found soil types containing deposits of nested, large boulders, a source of trouble to the contractor in excavation. In this type of topography is found conditions of interrupted drainage, old stream beds which have been blocked by deposition of later deposits. It is seen that this type of topography does not exhibit uniformity as a leading feature, which, of course, requires that greatest possible care be taken in the preliminary investigation and study.

During design and construction thought must be given to possibilities of erosion and revegetation in hilly topography. This type is subject to erosion, particularly from surface run-off and adequate erosion control must be provided and protection afforded by plant growth peculiar to the soil type. This is particularly important too, because of the scars in cut and new slopes in fill which must be provided in such types of topography.

Undulating Topography: In undulating topography the problems encountered are similar to those of hilly topography except that they are of lesser degree.

In this type there is more need of selected materials in construction due to the more level topography and the fact that the existent soil is heavier in its characteristics, being of the ground moraine type or till plain material, which type provides conditions conducive to differential heaving. However, in this type of topography, frost heaves are less prevalent.

From an economic standpoint these types of soil are the valuable agricultural soils and our location and type of highway is effected to some extent by this consideration.

Level Topography: On a whole, the level topography provides fewer problems than do the hilly or undulating types. The material usually is the floor of extinct glacial lake beds or extensive outwash plains or delta waters. This resultant material provides the most ideal foundation soils and is the source for excellent selected materials. In this case, nature has done the job of crushing, grinding, washing and grading of aggregates. However, in some cases serious problems are obtained where wind shifted sands, not very thick in bed, lie upon clay soils. Careful examination must be made to determine necessity of thickening such beds in order to eliminate poor drainage.

Similar problems in these various kinds of topography may be encountered in any type of engineering construction. The complexity of problems must be realized and proper information concerning the peculiarities of the local area of foundation site must be obtained and corrections or modifications in design must be made to cope with the situation.

Closely associated with topographical features are the drainage conditions. Most of us are familiar with the affect of moisture and water content upon the performance of soils. In practically all kinds of engineering construction drainage is of supreme importance. It is not necessary to discuss the effect of water on most types of construction, what we are most interested in the study of soils is the types of water encountered, how it affects the performance of soils and methods of treatment for different types of soils.

Types of water associated with the general subject of soils may be divided into three classes, namely -

1. Gravitational water
2. Capillary water
3. Hygroscopic water

Surface water and run-offs may indirectly affect some soil problems, but on a whole only these three types need to be considered as associated with the subject of soils.

Gravitational water may be defined as that portion of the water in the soil that is moved down by gravity. It includes all water which is free to flow through the soil mass under the action of gravity and not intimately associated with the soil particles and soil structure.

The presence and effect of ground water upon foundations, highways and in open excavations is particularly significant. Its importance in the problem is most evident in connection with the construction of structures on unconsolidated material. Methods must be developed to cope with underground water during construction as well as methods for its removal after construction.

The relation of geology to soil deposits has been discussed in a previous lecture. Again, a knowledge of local geological features is necessary to determine information on ground water. Surface observations are not sufficient because of the possibilities of complex underground structures existing beneath relatively simple looking ground surface. This is particularly true in country which has been subjected to glacial action.

Further methods of study and exploratory methods will be discussed under "soil mechanics", but brief mention should be made of geophysical electrical methods in which variations in resistivity provides a clue for the determination of ground water. Satisfactory results have been obtained in various parts of this country and other parts of the world. Further reference should be made to articles upon this subject.

The subject of ground water hydrology is closely related to the performance of soils. This relation has been well treated by several authors including Housel, Tolman and others and is too lengthy for discussion at this time. However, its importance must be stressed and those who would become well informed in soils engineering must acquaint themselves with the subject. Some of the problems of ground water should be touched upon particularly swamps, perched water tables, frost heaves, quick sands and spring break-ups.

One of the effects of the last glaciation was to leave numerous depressions in the surface of the land which have filled with ground water to become lakes. These small lakes are favorable to the formation of peat of which many have become filled. These deposits have caused great trouble in the past because of the instability of the peat of high water content.

Perched water table refers to water trapped by impervious strata in the unsaturated zone above the true water table.

Frost heaves are a result of variations of water movement in the soil affected by variations in temperature above and below freezing, the necessary water being supplied by gravitational water. Several theories have been advanced as to the cause of frost heaves. It is known that frost heaving may occur in a wide range of soil texture. The texture of the soil will usually determine the method used for proper treatment.

Quick sand is sand in which there is an upward flow of water producing instability and, of course, is a serious problem which calls for some treatment. In general, the treatment of all types of ground water problems calls for control of ground water by various methods, but the important fundamental is - keep the water table sufficiently low so that gravity flow can take place away from the structure.

Capillary water as the name implies, is ordinary water which occurs in small voids so that the surface tension of the water becomes an important factor in determining its behavior. The behavior of capillary water in soils is influenced by many factors including variation of texture of soils, mechanical arrangement of soil particles, movement of water table, upward or downward (dependent upon rainfall).

Capillary water acts as a stabilizer of soils in the absence of frost, a property of utmost importance, yet again where sudden change of texture in soil occurs, it can be the cause of differential heaving. It might be pointed out that capillary water is the actual form of water which forms the ice lenses in frost heaves. And, the high capillarity of fine sands and silts is the property which causes their very detrimental character, under conditions favorable to the formation of ice lenses. In the case of clay soil, during spring, the capillary water becomes gravitational water causing consequent spring break-up.

Hygroscopic water may be described as water which surrounds and is very closely associated with the individual grains. It cannot be evaporated by air drying. Hygroscopic water does not enter into soil engineering problems as does gravitational or capillary water. Its importance being probably more closely associated with the test characteristics of soils.

Climatic, topographical and drainage conditions have a definite relationship to soil performance. Another condition which must be studied is that of the physical or natural state of the soil. This condition is closely related to the others - and specifically refers to the characteristics and properties of the soil.

Characteristics of a soil have been defined as those attributes which may identify the soil and which add to the general knowledge of the manner in which they may perform but which do not give a direct measure of soil behavior.

Among characteristics of soil may be listed texture, structure, surface area, density relations, color, chemical composition, mutation and possibly several others.

Texture, as applied to soils, refers to the size, shape and arrangement of the individual particles, the degree of consolidation, and, largely determined by the foregoing, the size and percentage of voids.

Texture as a term is sometimes used to refer only to the particle size while the term structure is used to refer to the other factors mentioned above. In such a method of classification, soil is divided into three textural groups namely sand, silt and clay according to particle size. Soils of coarse texture with particle sizes no finer than sand are called granular.

These types of textures possess many definite properties of practical importance which will be discussed in following papers. And, of course, these properties are directly related to the performance of the soil as found in place.

Soil structure, as has been stated under the previous definition of texture, is a term used to describe the state in which the particles are held together in the soil mass, which includes arrangement of particles and type and extent of bonding. These arrangements and bondings include firmly cemented materials such as hard pan to granular coarse single grained structures.

Surface area, or more accurately the specific area, is an inherent characteristic by which we commonly think of a soil as being heavy or light. The specific area is defined as the surface area per volume, increasing as the particle size decreases. It is a property which plays an important part in colloidal action of which you will hear more later.

Density is defined as the weight of a material per unit volume. It is quite common to use density in expressing the degree of consolidation or compactness of a soil. In this sense, the density is quite closely related to structure as a characteristic.

Most of the characteristics as will be noted are general terms and not capable of measurement except the later two just mentioned. They would almost seem to come in the category of physical properties and perhaps should be so classed when definite measurement is made.

Closely associated with density is the void space in the soil mass or porosity another characteristic which may be indirectly determined but which is used as an identifying attribute or indicator as to the soil performance in a general way.

Soil color as an indicator gives clue to the character and extent of weathering to which the soil has been subjected and identifies the soil chemical constituents. Professor Veatch pointed out how these colors might identify the performance of certain soils.

Another characteristic is the chemical constituent of the soil. Of late, considerable research has been done in the relation of chemical constituents to the performance of soils. These relations may give us the answer to many questions in soil stabilization, explaining the reaction of certain soils to certain chemical soil stabilizers.

It is thus seen that many general characteristics are used in classifying and the study of soils. At times, it is not so apparent how these characteristics affect the performance.

I have listed a few general problems in which characteristics of the soil affect engineering operations. The performance of the soil has been noted by many of you, but you have not necessarily associated them with these characteristics.

Excavation methods and rates of progress are clearly dependent on the material to be encountered together with its geological structure. These two factors also determine the finished cross section of the excavation. Slight change in location may avoid troublesome material.

Texture and structure plus moisture content will indicate the probable angle of repose to adopt for given materials, indicating the necessity of a knowledge of the specific nature of a material in its natural state. Of course, at times, it is necessary to have a more complete knowledge by study in the laboratory of soil samples. The inevitable use of assumed angles of repose in preliminary design may be admitted but thorough study is necessary of definite types of structure to determine the effect of removal of soil material (in situ).

Sands and gravels will usually be found to be unaffected by exposure to atmosphere. Clays are different and special attention must always be paid to the effect of exposure to the atmosphere on any clays that are to be uncovered during excavation. Moisture content of the clay is a critical factor in such determinations.

The ease of working in dried materials in excavation is obvious. Water content alone is the cause of many of the peculiar characteristics described by such names as gumbo (clay) mud (often silt) and quick sand.

Associated with the placing and consolidation in ordinary embankments is the problem of settlement and bulking. The relation of the volume of fill material after deposition to the volume of the same material before excavation. This relation is definitely dependent on the type of material being handled. Bulking will depend principally upon the undisturbed state of the material, moisture content and methods used in construction. Settlement may be the joint result of shrinkage of fill material and actual settlement of the supporting strata. Although a thorough study of the material by soil mechanics may be indicated and necessary a knowledge of the soil characteristics will be a great aid in preliminary considerations.

In conclusion, it cannot be too strongly emphasized that the various environmental phases; climate, topography, drainage and natural characteristics, as described herein is only a very general review of the many complex and inter-related problems.

Experience in the field is the only sure guide in recognizing the surface indications and related conditions, but much can be obtained from experience of others and the printed word.