

IMPORTANCE OF CLAY IN APPLIED SOIL MECHANICS

BY FRANCIS N. HUEM *

ABSTRACT

Interparticle friction is the principal property which permits soils and granular materials to resist load without formation. Dry soils of virtually all types are highly stable. The suitability of soils for engineering purposes depends largely upon their ability to remain in place and support whatever loads may be placed upon them, either by a permanent engineering structure or by transient vehicle loads. A study of the properties which distinguish the more satisfactory from the less satisfactory soils indicates that in the majority of cases clays are detrimental to stability. It is apparent that wet clay has the effect of a lubricant in diminishing the natural resistance due to friction that would otherwise exist. It is necessary that the civil engineer responsible for construction of any form of earth work should be informed not only concerning the quantity of clay minerals that are present but also about their nature and their potential influence on the engineering properties of the soil.

Civil engineering covers many activities; as a result, with the advancement in construction techniques and accumulation of knowledge, a continuous subdivision into specialties becomes necessary. Highway engineering is one specialized branch of civil engineering; but it too is now being subdivided into specialized fields. If there is such a thing as an "average engineer" he is likely to feel that having spent a number of years in studying the strengths of materials, struggling with the necessary courses in the basic sciences, et cetera, it is asking too much for anyone to expect him to also become an expert in soil mechanics and conversant with all of the ramifications of that extensive subject.

Indeed, not many years ago, most construction engineers felt that they were making adequate distinctions when earth work or excavation materials were classified as either rock or dirt; they were somewhat inclined to feel that life was getting altogether too complicated when certain specialists with nothing better to do began to classify soils and to draw distinctions between various kinds of sand, silts, and loams, to say nothing of the cabalistic signs and symbols involved in the various soil classification schemes. However, few engineering and technical problems retain the appearance of simplicity if one delves very far into the factors which influence performance under service conditions.

Most civil engineers are faced with the necessity of dealing with soil problems in some phase of their work and the field of soil mechanics covers a variety of applications. Time will not permit even a brief discussion of these numerous fields even if my knowledge were adequate; therefore it should be understood that this discussion is primarily concerned with the effects of clay in highway pavements, bases, and foundations.

In order to establish a relationship between the effects or influence of clay and over-all performance, a chart, figure 1, is offered, which attempts to break down the over-all problem into its primary, secondary, and even more remote contributory factors. While it may appear from this chart that the position of clay is rather remote from the main point of interest, such is not the case; however, in order to establish the importance of the

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clay content in soils and granular base materials, it is first necessary to outline the important properties of such material and to describe the means or mechanism which enables soil masses to support loads and resist deformation.

The immediate surface of a highway or airfield pavement is subjected to a variety of destructive influences. Among these are the thrusts which result from the tractive effort of vehicles either in accelerating or decelerating, which may be described as a combination of abrasive action and rolling friction. The surface of the pavement must also withstand the effects of wind, variation in temperature, and moisture, in addition to supporting the weight of the vehicle. The material beneath the pavement is also subjected to several influences, among which are the effects of pressures resulting from vertical loading and the effects of moisture. It may be argued that low temperatures are also damaging to subgrades, but the effect is an indirect one as there is no reason to think that any damage would result from freezing or thawing

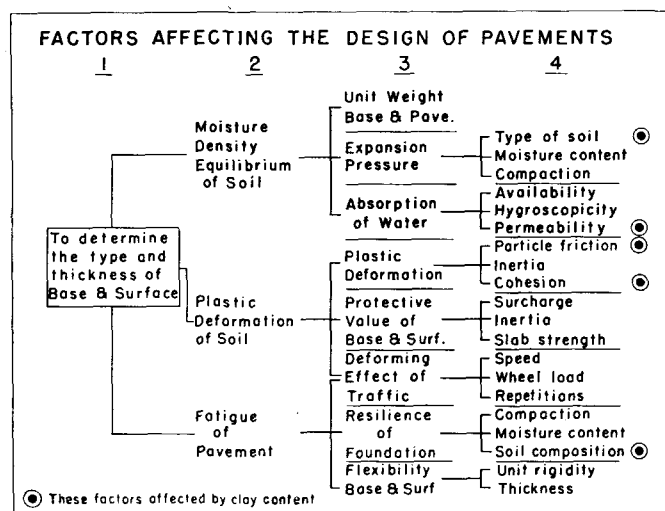


FIGURE 1.

in the absence of water. Of all the factors or influences which affect the supporting power and load-carrying capacity of soils, moisture is by far the most important variable. In the absence of water, virtually all soil materials, whether crushed stone, sand, loam, or adobe, will support any vehicle load that can be carried on pneumatic tires; therefore, if the soils beneath highway pavements could be prevented from becoming wet, soil mechanics would have little meaning and would not be of much concern to the highway engineer. Actually, so far as practical applications are concerned, the very title "soil mechanics" is misleading, as the term makes no reference to the most important and influential element: namely, water. When engineers mix as little as 5 percent of liquid asphalt with mineral aggregate, the resulting combination is called an asphaltic mixture; if 15 percent of portland cement and water is combined with sand and gravel, the combination is called portland-

cement concrete; but when faced with the necessity of predicting the behavior and supporting power of soil which may contain as much as 25 percent of water, the engineer still tends to delude himself by thinking that he is concerned only with soil mechanics.

As stated before, it was not many years ago that engineers generally paid very little attention to differences in soil types. Most railroad and highway engineers learned long ago that classified excavation is usually a source of trouble and controversy between the contractor and the engineer; and agencies in many states—including the California Division of Highways—do not classify excavation materials. In other words, the contractor is paid on the basis of his bid price whether he is moving loose soil or solid rock. In spite of these simplifications, engineers began to realize some 25 years ago that materials encountered along the highway routes were not always giving equally satisfactory performance and one of the first factors to receive consideration was compaction. The California Division of Highways pioneered in setting up requirements to control the compaction of soils during construction.

It did not take long to discover that in order to secure the maximum efficiency with field-compaction equipment, careful control of the moisture content was necessary. However, with the passage of time and increasing study of the problem, it was evident that thorough compaction alone was not enough to guarantee satisfactory support in all types of soils; it also became apparent that there was need for some laboratory-test procedure that would evaluate the capacity of the soil to sustain loads when in its most vulnerable condition of density and moisture content. Dating from Coulomb's time (1736-1806, most theoretical discussions on soil mechanics recognize that the entire structural strength of soils rests upon two distinct properties: namely, internal friction and cohesion. The stability of slopes and embankments, the pressures against retaining walls, and the ability to sustain vertical loads, all depend upon a combination of these properties—friction between the rock or soil particles and any cohesive forces which may exist. The laws governing the frictional resistance between solid particles are probably very complex and it is to be doubted whether the nature of this phenomenon is clearly understood, even today; but for practical purposes variations in frictional resistance may be well enough defined in the terms used by Amontons, who was one of the first to investigate frictional phenomena. Amontons' law states that the resistance to sliding between adjacent particles in contact varies with the nature of the surfaces, directly with the pressure which holds the surfaces together, and is independent of the speed and the apparent area of contact. The common definition of cohesion as used in soil-mechanics texts does not correspond to the dictionary definition; it is generally stated that the cohesive resistance in soils is that part of the resistance which does not vary with the pressure. This is a rather negative definition, but it agrees with the observed behavior of viscous liquids. The internal friction of liquids is virtually independent of the pressure; the resistance developed by a film of viscous material between two solid bodies varies directly with the area and with the speed of action, but is largely independent of the pressure.

While the civil engineer considers that the term "soil" includes all materials of the earth's mantle, including gravel and sand, as well as the silt and loam, it is true that virtually all such materials contain a greater or less percentage of extremely fine particles having the special properties of plasticity and mobility that are characteristic of the clay minerals. If there is a complete absence of the clay fraction, the material finer than a No. 4 sieve is to all intents and purposes a sand, even though some of the particles are very small. Of course, most clays possess properties that are not solely attributable to small particle size alone. It is not the purpose of this paper to attempt any discussion of the intimate shape and composition of the clay particles. From the standpoint of the highway engineer who is attempting to evaluate the behavior of soils as an engineering material, it is sufficient to recognize that when combined with sufficient water most clays are very effective lubricants and when a sufficient quantity of clay is intermixed with the coarser granular portion of a soil, lubrication will develop whenever enough water is added. As the ability of soils to resist deformation depends very largely on the internal friction, wet clay has the effect of reducing or canceling out the frictional resistance. It may also be pointed out that the so-called cohesive resistance is induced almost entirely by the clay fractions, and therefore that clean sands are noncohesive. Again we must note the important part played by water, as finely ground dry clay particles exhibit no cohesive properties. If water is added to a dry soil, the cohesive resistance will normally increase with the addition of moisture and in most cases the frictional resistance will not be greatly impaired until a certain amount of moisture is added. Beyond this point, the friction will diminish but the cohesive resistance may continue to increase up to some point of higher moisture content, after which both values will diminish as the soil approaches a completely fluid state.

As the wet clay fraction reduces the internal resistance by lubrication but may increase the resistance by improving the cohesion, it is necessary to determine something of the relative importance of these two properties. From a practical view point, both field and laboratory experience demonstrate that of the two basic properties, resistance resulting from friction is greater in magnitude and therefore the most important when dealing with typical soils or granular materials. Beds of clean sand, even when wet, have long been known to furnish excellent foundation support provided a reasonable thickness of surfacing material is placed above them. Crushed stone or gravel with no measurable cohesion is excellent for base course construction and is able to withstand virtually any vehicle load if covered with relatively thin surfaces having the requisite tensile strength. On the other hand, plastic soils or asphaltic mixtures having high cohesive values but little internal friction are rarely adequate to sustain vehicle loads. It is realized, of course, that if the cohesive or tensile strength could be made sufficiently high, internal friction would not be necessary. Metals are typical substances having little or no internal friction; in them, resistance values are almost entirely a result of the cohesive or tensile strength. However, natural soils con-

taining appreciable amounts of water are not capable of developing such high cohesive values and therefore the internal friction is the most important property. This conclusion is in accord with the observation that an excessive amount of clay is detrimental and soils or gravel containing high percentages of clay invariably become unstable and lack supporting power when wet.

Having recognized the generally adverse influence of clays, it is pertinent to inquire whether there are differences in performance which result from the type of clay, as it is well known that there are numerous types and classes among the clay minerals. While specialists and experts in clay technology must perforce recognize many of the variants and peculiarities of clays, the highway engineer has gone a long way if he recognizes three main groups: namely, kaolinite, illite, and montmorillonite. Again he is only concerned with their physical properties and it is well known that most clays of the montmorillonite class possess a very high affinity for water, typically showing considerable expansion or swelling; when wet they are very effective lubricants. Kaolinite is at the other end of the scale, having in general a much lower capacity for water, and retaining a greater internal resistance from friction than does bentonite, for example. Illite clays appear to be somewhat intermediate. In addition to the particle shape or structural differences that are characteristic of each of these types of clays, it is also evident that the physical properties may be markedly affected by small additions of water-soluble salts or other organic or inorganic compounds. A knowledge of these behavior patterns and the effect of such elements on the fluidity and plasticity of clays is, of course, one of the essential branches of clay technology, and requires specialized knowledge which the average highway engineer or even a well equipped highway materials department can hardly hope to command.

The engineer's interest, however, is primarily involved in the question of the over-all effect of the particular clay when the soil becomes wet and the primary question is the effect on the structural stability which, as stated above, really involves the possible reduction of internal friction.

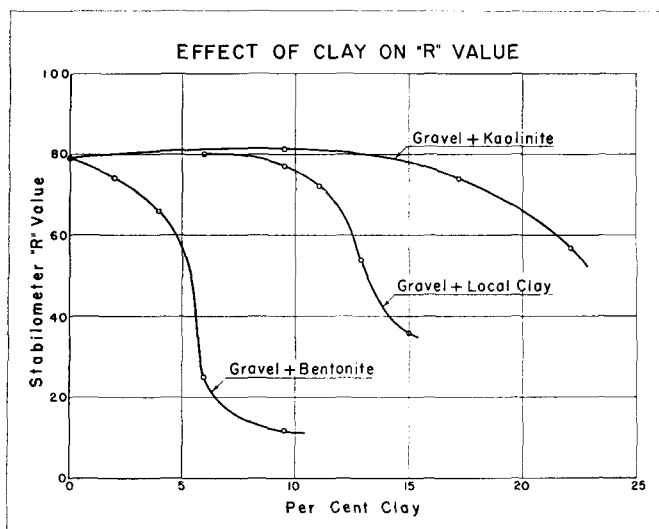


FIGURE 2.

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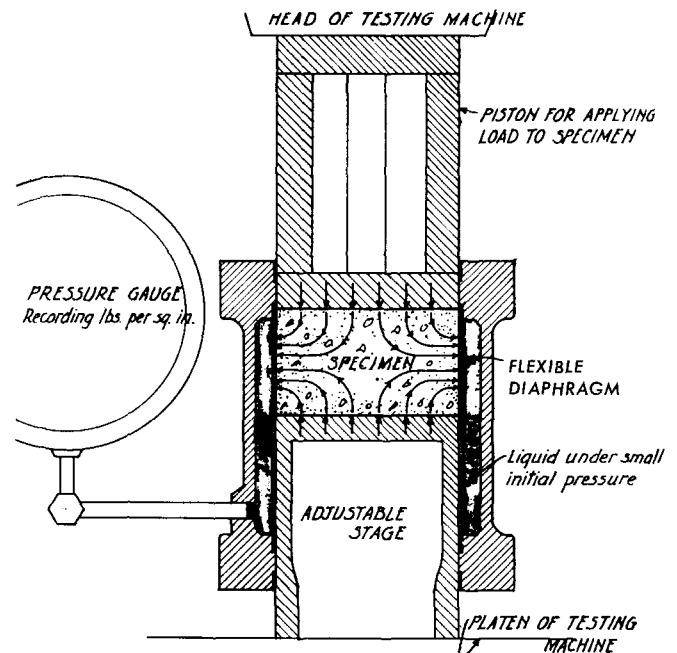


FIGURE 3.

In order to measure the ability of soils and granular materials to sustain loads, many tests have been devised; one employs an instrument called the "stabilometer," which is used in the laboratory of the California Division of Highways. This testing procedure makes it possible to prepare soil specimens by introducing sufficient water to fill the void space, compacting to a state of density comparable to that developed in most highway bases and basement soil layers, and then by measuring the resistance to deformation. Basically, the stabilometer is a form of plastometer. The test reflects primarily the internal friction or degree of lubrication; cohesive resistance plays a minor part. A compacted sample being tested in this instrument, is subjected to a vertical load which may be varied at will. For highway purposes it is typically 160 psi. The instrument makes it possible to measure the lateral pressure transmitted by the specimen (see fig. 3). Figure 2 is a chart showing characteristic curves illustrating loss in stability or internal resistance of a crushed sandy gravel due to the addition of increments of plastic clay. This test is used as a basis for calculating the supporting value of the soil; by use of suitable formulas it is possible to compute the thickness of cover courses of bases and pavement which will be necessary to support vehicle loads of a given magnitude and number of repetitions. These test procedures have been reported in considerable detail elsewhere and will not be discussed further here. The stabilometer test and the elaborate compaction equipment required to produce specimens that are characteristic of soils in place in the roadbed mean that this test procedure is virtually restricted to a fairly large, well-equipped laboratory.

It is essential however, that the engineers in charge of construction should have some ready and convenient means for detecting the presence of excessive amounts of adverse clay or fine material. In view of the fact that the lubricating effect of clay or of any other material is

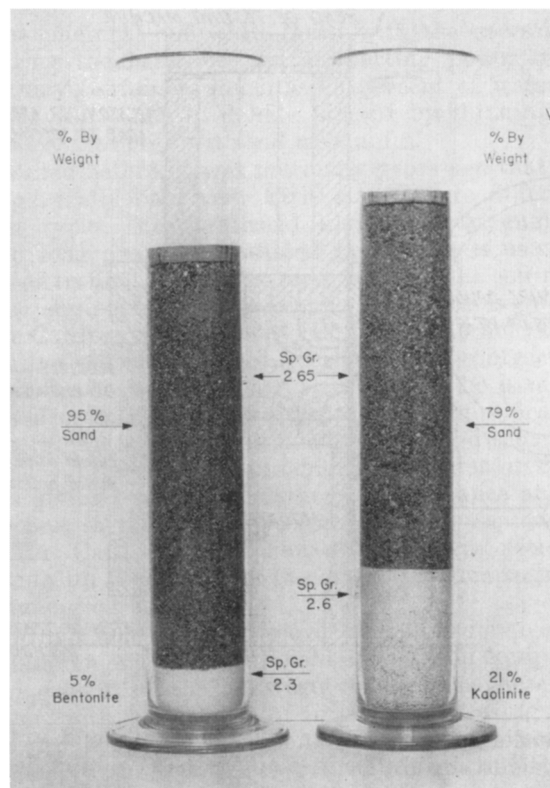


FIGURE 4.

dependent upon the volume or the thickness of film between the particles, the most fundamental relationship depends upon the effective volume of clay that exists in each soil. In order to speed up the testing operation by avoiding the need for weighing the sample and drying it in an oven, a test called the "sand equivalent determination" has been developed. This test is applied to a sample of soil passing a No. 4 sieve. The relationship between the quantity of clay present and the amount of coarser sand particles in the soil is developed on a volume basis, and the test results indicate whether the volume of sand is high or low—hence the name "sand equivalent" (S. E.).

Essentially, the sand equivalent test is performed by shaking a sample of the fine aggregate vigorously in a transparent cylinder containing a special solution (fig. 5) and noting the relative volumes of sand and partially sedimented clay after standing for 20 minutes. The entire operation can be carried through in less than 40 minutes. In order to speed up the sedimentation of the fine clays or colloidal particles, a flocculating agent was required and a solution of calcium chloride was selected on account of its relatively low cost, stability, and non-irritating properties. As illustrated in figure 4, a small amount of bentonite is in lubricating effect equal to a much greater weight of kaolinite and the strength of the CaCl_2 solution was adjusted to the point where 5 percent of bentonite would give an S.E. reading approximately equal to that produced by 21 percent of kaolinite after a sedimentation period of 20 minutes. This relationship appeared to be best established by using a 0.025N CaCl_2 solution. However, the strength of the solution is not

critical for most natural soils; therefore, a working solution of 0.05N has been adopted and will be used until accumulated experience may warrant a change. After some experience with the calcium chloride solution, it was found that the addition of a small amount of glycerin produced a stabilizing effect and test results were more readily reproducible when made on carefully quartered samples. Finally, it was noted that the calcium-chloride-glycerin solution was not sterile and certain molds tended to grow. In order to sterilize the solution, formaldehyde was added.

When the sand equivalent test was first developed, it was hoped that it would furnish a good indication of the overall resistance value of the soil. A correlation

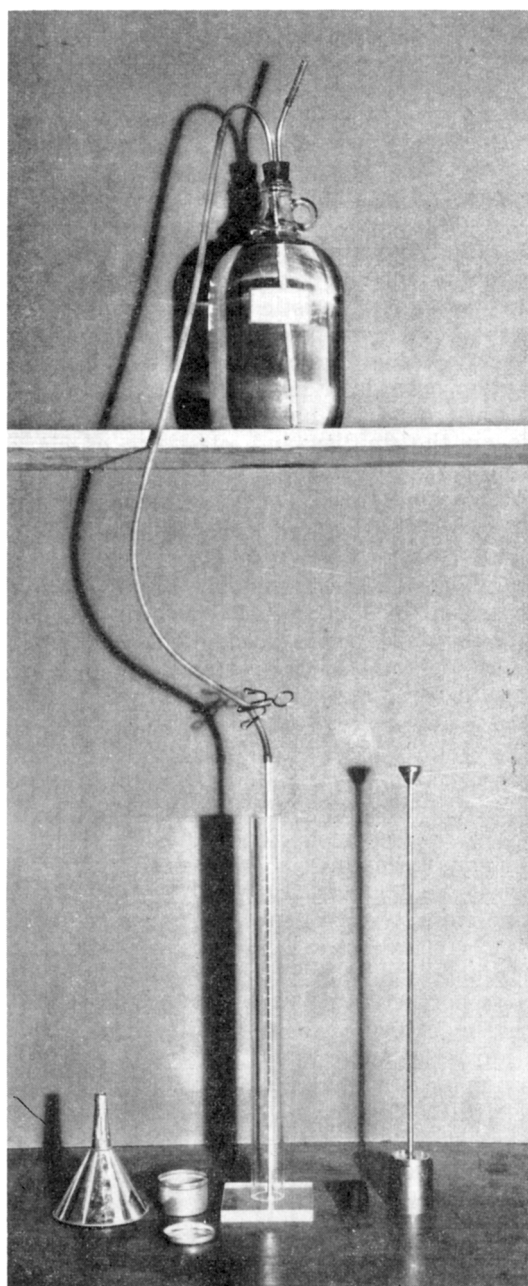


FIGURE 5.

does exist, but it is not sharply defined throughout the scale. The reasons therefor are not difficult to understand, if it is recognized that the ability of a mass of soil or granular material passing a No. 4 sieve to resist deformation will depend upon the following factors: (1) The amount of lubricant mixed with the sand fraction; i.e., asphalt, clay water, etc.; (2) The effectiveness or efficiency of the lubricating fraction wet bentonite is a better lubricant than kaolinite, for example; (3) The degree of roughness or irregularity of the sand grains or rock particles; (4) The amount of void space in the sand fraction of the soil; and (5) The amount of intermingled coarse rock retained on a No. 4 sieve.

We readily perceive that of these five variables the sand equivalent determination is primarily an indication of no. 1. It attempts to compensate for no. 2 by means of the type of solution used. It cannot indicate the variation caused by item 3, and as presently performed does not make allowance for no. 4, although it seems possible that means for making this correction may be worked out. Allowance for the effects of no. 5 need to be made if the coarse aggregate exceeds 25 or 30 percent of the total. Therefore, in order to evaluate the combined effect of all factors, some test such as the stabilometer test is necessary. However, experience has shown that one of the principal variables is the amount of clay present, and it may readily be determined that when the sand equivalent value is greater than 30, the clay fraction is not sufficiently large to have much influence on the resistance value of an untreated soil.

Very small amounts of clay may be detrimental to the performance of bituminous mixtures, especially when the clay exists as a coating on the surfaces of sand grains. As the sand equivalent determination furnishes a ready means for detecting the presence of such fine materials, a tentative scale of values has been set up to permit rapid testing and quick determination in the field.

A comparison of sand equivalent test values with other test results indicates that the majority of soils showing high expansion under soaking may be identified by means of the sand equivalent. It has been the general practice to consider that any soils showing an expansion

of greater than 5 percent when tested in the California bearing ratio procedure will be unsuitable for placing in the upper levels of a road bed. It appears that the same class of soils could be identified and segregated by stipulating that any soils having a sand equivalent less than 10 should not be placed in the upper layers, as they are also likely to develop excessive expansion when saturated.

In conclusion, it may be stated that the suitability of soils for engineering purposes depends largely upon their ability to remain in place and to support whatever loads may be placed upon them either by a permanent engineering structure or by transient vehicle loads. A study of the properties which distinguish the more satisfactory from the less satisfactory soils indicates that in the majority of cases clays are detrimental to stability and that wet clay has the effect of a lubricant in diminishing the natural resistance due to friction. It is necessary that the civil engineer responsible for construction of any form of earth work should be informed not only concerning the quantity of clay minerals that are present but also should know something of their nature and their potential influence on the engineering properties of the soil.

DISCUSSION

D. P. Krynine:

For those interested in permafrost some Russian books translated into English may be recommended. The Steffenson Library translated for the Army Engineers a book by V. F. Zhukov entitled *Earthwork for Foundations in Permafrost Zones*, Moscow, 1946. The U. S. Geological Survey translated the book by N. A. Tsitovitch and M. I. Soumgin entitled *Principles of the Mechanics of Frozen Grounds*, Moscow, 1937. Neither translation has been printed, however. Russian scientific work on permafrost has been used in engineering practice, but much is still in the experimental stage.

A still unsolved problem in soil mechanics is the shearing resistance of clays, both saturated and non-saturated, especially of the latter. Mineralogists and physicists probably could contribute considerably to this study, as practically nothing is known of the behavior of the lattice during the shear process, particularly in brittle clays and in clays flowing plastically. A phenomenon which is well known to the engineers is the difference in shearing resistance of a clay sample as determined by slow and quick shearing tests. Further clarification of the causes of this difference is needed.