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FEASIBILITY OF COMPUTER MODELS FOR MILITARY SOIL STABILIZATION RESEARCH

By

J. B. Forrest

November 1971

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Port Hueneme, California 93043

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This report considers the feasibility of using computer models for developing expedient soil stabilization techniques. Of major importance is the increase in soil strength necessary to provide specified degrees of vehicle mobility and dust or erosion control.

The merits of pursuing this task at the molecular level are considered and it is decided that application of electro-chemical theory is not warrented at this time. A mechanistic approach, based upon finite element technology is suggested.

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INTRODUCTION

The objective of this study is to evaluate the fe sibility of computer models for more efficient development of military-oriented soil stabilization techniques. The work unit under which this study has been accomplished is part of a broader task concerned with the total spectrum of military mission-oriented soil improvement. The stabilization procedures of interest are primarily concerned with providing the soil strength required for equipment mobility and dust or erosion control. The developed techniques must be compatible with the tactical, financial, time, manpower and logistic restraints placed upon military operations as carried out by the USMC, and should be coordinated with and complement work of the Army and Air Force.

The feasibility of utilizing computer models to economically study reactions between theoretically possible formulations of stabilization agents and soils having various physical and electrochemical characteristics is the topic of this study. The specific goal is to determine if computer techniques could be used to limit the number of possible alternatives to the solution of soil stabilization problems, to provide the most promising avenues of approach, and possibly to fill gaps in the current status of soil technology as applied to Marine Corps requirements.

BACKGROUND

The physico-chemical characteristics of soils have been of interest to the soil mechanics engineer ever since a study of clay mineralogy showed at least a qualitative explanation of the response of fine grained soil material to additives. The term fine grained as used here refers to particles small enough for the electro-molecular surface forces to dominate the inertia or gravity forces. Soils falling into this category are primarily organic and inorganic silts and clays, since these particles have very large surface area to volume ratios. This is not to say that coarse aggregates cannot be stabilized by the application of additives, but this is primarily a cementing or a waterproofing phenomenon and does not result in fundamental changes in the mass of the soil constituents.

Attempts to correlate the physical performance of soils with their chemical and mineralogical characteristics have been pursued by various agencies for more than 25 years with limited success. However, two recent developments utilizing computer technology suggested a new avenue of attack upon the problem. These developments were:

a. Use of computers to model chemical reactions and,

b. Mathematical description of the physico-chemical characteristics of soils utilized in computer programs to predict response.

Most physico-chemical studies of soil behavior have dealt with the clay mineralogical aspects of the involved materials. Although some workers[1] define the term physico-chemical as including both physical and chemical phenomena, these studies were more within the realm of soil physics than chemistry, per se. The mechanisms which were invoked at the atomic level were not true chemical reactions wherein new compounds were formed, but were concerned with such transient effects as cation exchange and the behavior of the water within various electromagnetic fields generated by charges on the clay particles.

To understand the interrelationship between microscopic characteristics and engineering behavior, one should consider a typical arrangement of clay-size particles. These particles are plate-like in shape (composed of layers of molecules) and have an excess negative charge on their flat surfaces due to broken bonds and due to replacement of positive cations within the crystalline lattice. Acidic clays, having a low pH and consequently an excess of positive hydrogen ions, may have positive charges at the broken plate edges, resulting in a flocculated or card house structure due to the attraction of the positively charged edges for the negatively charged surfaces. Basic clays having high pH and excess negative hydroxyl ions have negatively charged edges, resulting in a dispersed or parallel orientation of particles (structure) due to the mutual repulsion of the clay particles.

The excess negative charge on a clay particle surface is referred to as the Zeta potential and is equalized by a layer of positive ions which are adsorbed to the outside of the clay particle. The two oppositely charged layers are referred to as the diffuse double layer. The Zeta potential is related to the total excess charge on the clay particle, the double layer thickness, the dielectric constant of the pore fluid and the surface area of the particle. The thickness of this double layer changes in accordance with the availability of the adsorbed positive ions and the nature of these ions.

For example, ions of aluminum have a higher valency than sodium ions and thus would result in a thinner adsorbed layer under similar circumstances. Potassium ions have the same valency as sodium, however they are different in size and result in different adsorbed layer thicknesses when used to replace one another. On the other hand, replacement of the pore fluid by deionized water, resulting in the water attempting to satisfy the excess negative charges purely by means of its dipolar structure, would result in marked adsorbed layer growth with attendant soil swelling, etc. Other forces are in attendence at the crystalline level such as the Van der Waals attractive forces but these are now thought to be insignificant in normal engineering applications.

DISCUSSION

Although a great deal of qualitative information is available for particular soils, it is still very difficult to quantify soil behavior. With regard to the exchangeable cations, there is an order of preference wherein one type of ion will replace another type, but this order may vary with different mineral compositions and is very sensitive to the concentration of the various ions available.

A very small organic content in a soil may still provide organic ions which will generally replace inorganic ones and mask exchange capacity.

The different clay minerals behave differently under similar circumstances; for example a clay containing illite will be expected to react significantly differently from one containing montmorillonite. However, the extent of this difference cannot be predicted with certainty. Trace elements or compounds may be very hard to detect experimentally but may exert a profound influence upon material reaction to a particular treatment. Insufficient respect for such factors as temperature following the addition of a stabilizing chemical to a soil has led to disputes in the past even over the results to be expected from a particular additive.

Soils of different geographic regions may be expected to behave markedly differently with respect to a particular parameter. For example, U. S. soils having a low pH (<5.5) show a limited reaction to pozzolanic additives, whereas Australian soils of similar pH levels show a strong reaction.[2] The experimental trial-and-error approach, which has traditionally been used in soil stabilization studies, is extremely costly and time consuming when applied at the field trial stage. However, the fact that field trial evaluations are necessary only serves to emphasize the point that all the significant parameters are not known even to the stage that they can always be incorporated reliably into laboratory scale investigations. Since the state of knowledge makes laboratory simulations of service conditions questionable, little credibility can be attached to purely theoretical considerations of this nature. Even in classical structural chemistry, mathematical approaches such as those utilizing solutions to the Schrodinger Wave equation have only served to suggest new ideas which still had to be investigated by the usual empirical methods.[3]

The testing required to thoroughly define the constituents of a typical fine grained soil material can be very difficult to perform and to interpret. For example, X-ray diffraction techniques to investigate saturation by magnesium ions can be largely influenced by the montmorillonite content[4]. In many cases it would be simpler to experimentally investigate the effects of various additives rather than conduct a quantified experimental analysis at the molecular level, even if a theoretically derived analytical model were available. Of course, the experimental approach will require an improved classification system based upon a standardized technique.

The whole process is further complicated by the fact that it is not clear whether or not some phenomena are electrochemically derived or are purely physical or mechanical in behavior. Yong and Warkentin[5] point out that it is not clear whether irreversible cements (carbonates, aluminum oxides, etc., which do not regain their original properties thixotropically) affect clay surface forces or act as a bond between individual particles. Other anomalies may occur. For example, a Wyoming bentonite was observed[6] to have a liquid limit of 450% when approached from the dry side but 700% when arrived at by drying from a slurry. Obviously a detailed understanding of soils is currently lacking, and appears to be too complex to offer extensive immediate gains even to concentrated molecular-level research efforts.

Computer procedures for analyzing chemical reactions appear to be capable of handling only idealized situations wherein known quantities of a limited number of "pure" chemicals are involved. Unfortunately natural soils contain, in addition to their major constituents an exhaustive number of trace elements, minerals, chemicals, etc. all of which can exert varying influences upon chemical reactions. Computer programs utilizing user oriented languages, such as the ICES[7] system developed at MIT, while providing mathematical descriptions of the performance characteristics of engineering soils, cannot as yet be used to relate in a quantitative way the response of a soil to its physicochemical properties.

CONCLUSIONS

On the basis of available data it would appear that insufficient soil data exists to enable recent computer advances to handle soil stabilization from the point of view of simulating the electrochemical behavior. The status of soil stabilization research at present is such that difficulty is sometimes experienced in recognizing what the pertinent parameters are, let alone quantifying them in detail. In addition, the testing required to fully characterize a natural soil is apt to be greater than that involved in an empirical evaluation of some of the more promising stabilization possibilities.

This does not mean that a growing appreciation of the physicochemical or mineralogical properties of soils will not be very helpful. It merely means that the science is not quantified to the point where numerical calculations can offer further reliable advances at this time.

FUTURE WORK

While the application of computer models to the simulation of chemical or physicochemical reactions occurring within soils does not appear feasible at this time, the use of computer codes to determine the physical response of expedient surfacings to imposed environments on a purely mechanistic basis appears to be highly promising.

As the requirements of the USMC for rapid soil stabilization appear to be limited primarily to landing mats, membranes and dust palliatives, and are almost exclusively limited to surface treatments, a computer-based structural or mechanistic approach to analysis of these techniques seems desirable. Development will be attempted of a computer program that will, by inputting a nominal amount of data, return answers regarding the practicability of candidate treatments with as much detail as deemed necessary for Marine Corps requirements. For example, where heavy wheel loads are involved, the computer could provide an analysis based upon a large-deflection finite element program (for the case of a membrane over a soft soil), or based upon a layered system analysis (for the situation where a surface soil layer has been stabilized). Computer output could reveal the maximum stresses and displacements occurring under specific types of loadings for comparison with allowable values; or could, with a slight additional refinement, point out whether the proposed treatment is suitable for the intended purpose; and could even suggest better alternatives.

The first requirement will be to adapt existing finite element programs to the specific situation represented by thin overlays, such as expedient surfacings, placed over natural soil profiles. Next, literature research combined with some supporting laboratory measurements will be necessary to quantify basic parametric values of the surfacing materials. The resulting analytical system can be further refined by comparison with actual prototype response.

At this stage, two different approaches will be possible: (1) the computer-based analytical model can be maintained for solving specific Marine Corps soil stabilization problems; and (2) various hypothetical situations can be solved and curves or nomographs prepared that will provide a measure of system performance in terms of the geometric and material properties of various expedient surfacing systems.

As an example of utilization of the latter approach, if the need existed to carry a specified number of repetitions of a particular wheel load over some specified soil, a previously-constructed graph could be consulted that would indicate the required thickness of any one or a combination of several available surface treatments. Various situations covering expected types of loadings or environments, typical soil types, and available surfacing treatments will be investigated for consolidation into one manual.

This work will be complementary to that of two other NCEL work units sponsored by USMC. One of these others is "Systems Analysis of Mission-Oriented Soil Technology Problems" (Work Unit YF 53.536.002.01.001). The basic objective of the systems analysis work unit is to provide a systematic organization of soil stabilization procedures that will permit military commanders to make selections based primarily upon military tactical and logistic considerations. When the system is established, the various stabilization procedures will be assigned relative degrees of merit. Those that have a low ranking will be candidates for improvement or replacement under the second of the complementary work units mentioned above.

The second complementary work unit "Soil Stabilization Analysis and Testing in a Military Context" (Work Unit YF 53.536.002.01.003) provides for laboratory and field testing of candidate soil stabilization procedures for applicability to USMC needs. The work provides for improvement of existing procedures that, while the best available, may not be completely satisfactory solutions to USMC problems.

The computer-based techniques proposed in this report (the third USMC-sponsored work unit) will provide analytical models for interpolating and extrapolating the results obtained from experimental testing. Use of the computer models will permit an economical examination of a wide range of load-stabilizer-soil combinations.

In summary, the "computer" and "testing" work units together will improve and add to the list of soil stabilization procedures that are acceptable both from a military and an engineering standpoint. Partly, these two work units will receive direction from the "systems" work unit through the revelation by that work unit of gaps in soil stabilization technology. In turn, the "systems" work unit will provide a framework for codifying the technology in a form readily useful to the Marine Corps.

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