Influence of Minerals on the Elastic Behaviour of Cohesive Soil

Influence des minéraux sur le comportement élastique des sols cohésifs

Sarma D., Sarma M.D
M-AGS, M-ISSMGE, Independent Consultant (Southern Africa)

ABSTRACT: The trend of predicting the design parameters of soil from the index properties is continuing since decades, however, those correlations do not focus much on the prediction of elastic behaviour of cohesive soils. Moreover, the influence of mineral(s) for the validation of such correlations is either ignored or presumed to be covered by the Atterberg's limits. As the outcomes of the research, pertaining to the title of the paper, influence of a prime constituent mineral has been identified and the extent of its influence is derived. The constitutive modelling, an outcome of the correlative study, is analysed based on its typical pattern. The model thus derived within the set scope of the investigation has led to the conclusion that the pattern is unique for cohesive soils and is under the possible domination of the existence of a common mineral and extent of its weathering process. It leads to the indication of the profound influence of the mineral and its weathering state upon elastic behaviour of cohesive soils. The model pointed out that some of the engineering and geological properties are interdependent. The model has been calibrated with other available empirical correlations and its civil engineering applications and limitations are derived. Outlines of subsequent research areas are also indicated.

RÉSUMÉ : La tendance de prédire les paramètres de conception du sol des propriétés de l'index se poursuit depuis des décennies, cependant, ces corrélations ne se concentrent pas autant sur la prédiction du comportement élastique des sols cohésifs. En outre, l'influence de minéraux (s) pour la validation de ces corrélations est soit ignorée, soit présumée être couverte par des limites d'Atterberg . Comme les résultats de la recherche, portant sur le titre du document, l'influence d'un minéral constituant principal a été identifiée et l'étendue de son influence en découle. La modélisation constitutive, le résultat de l'étude corrélative sont analysés en fonction de son modèle typique. Le modèle ainsi obtenu dans le cadre d'ensemble de l'enquête a conduit à la conclusion que le modèle qui est unique pour les sols cohésifs et est sous la domination possible de l'existence d'un minéral commun et l'étendue de son processus de vieillissement. Elle conduit à l'indication de l'influence profonde de la matière minérale et de son état intempéries sur le comportement élastique des sols cohésifs. Le modèle a fait remarquer que certaines des propriétés techniques et géologiques sont interdépendants. Le modèle a été calibré avec d'autres corrélations empiriques disponibles et ses applications en génie civil et les limites sont dérivées. Les contours des domaines de recherche sont également indiqués.

KEYWORDS: Index properties, elastic behaviour, influence of minerals, cohesive soil, constitutive modelling, weathering process.

1 INTRODUCTION

The trend for prediction of design parameters of soil from the index properties is continuing since decades for avoiding complex, time-consuming, and relatively costly tests. Many empirical correlations are already published and some are being used in practice. Preliminary literature survey indicates that those correlations do not focus much on the prediction of elastic behaviour of cohesive soil. Moreover, the influence of mineral(s) for the validation of such correlations is either ignored or presumed to be covered by the Atterberg's limits. In a postgraduate research of engineering geology, formulated by the Author[1], it was intended to establish the empirical correlation for the prediction of elastic behaviour of cohesive soil from the index properties and any influence of mineral(s). Subsequent development was to use the correlation for fast-track design of road and airport pavements, foundation of structure, and for slope stability analysis within restricted deformation based on known geological formations.

In this research, a detailed literature study and its inference was drawn for the prevailing empirical correlations with particular emphasis on the coverage of elastic property, directly or indirectly. Further, this research included brief methodologies of samplings collected from various locations to the extent necessary for common civil engineering structures, schedule of laboratory investigations on index properties, stress-strain responses of shear tests, and relevant geological studies. Laboratory investigations for civil engineering properties and geological studies were carried out at state Road Research Laboratory and Geological Science Laboratory of the state Public Works Department and University respectively. Based on the outcomes of these studies the inference of all such investigations has been drawn. Furthermore, constitutive modelling for the empirical correlation and influence of minerals has been investigated.

2 INFERENCES

This research was carried out with an objective of correlating geological nature of soil and engineering properties, with particular emphasis on the prediction of elastic behaviour of cohesive soils vis-à-vis the elastic settlement of structures. Significant outcome of the research is the constitutive model (Ref Figure-1), which is based on some sensitive parameters, namely, dry density (γ_d), Plasticity Index (PI), and initial tangent modulus (tan ψ), where ψ is the angle between initial tangent modulus and abscissa and presented in graphical form. The graphical model has been obtained by plotting two factors, as shown in the abscissa and ordinates, based on the results from about 8 sites in northeast India, which is famous for highest rainfall, flood, earthquake, and complex geological formations. The result yields two curves that intersect at nearly 90 degree depicting two classified characteristics of the model. Hence, it was found necessary to verify whether the graphical model holds good for the parameters of other sites of the region. Accordingly, supplementary test-data were obtained from the samples of various sites, where investigations were undertaken by the Road Research Laboratory (RRL). Based on the data, so obtained from RRL, values of the two distinguished factors as shown in the abscissa and ordinates of Fig 1 were plotted and were found corroborating with the model. This simulation exercise had encouraged further investigations on the interpretation of data and development of correlation, exploring various geochemical and other technical evidences in context to the two classified characteristics of the model.

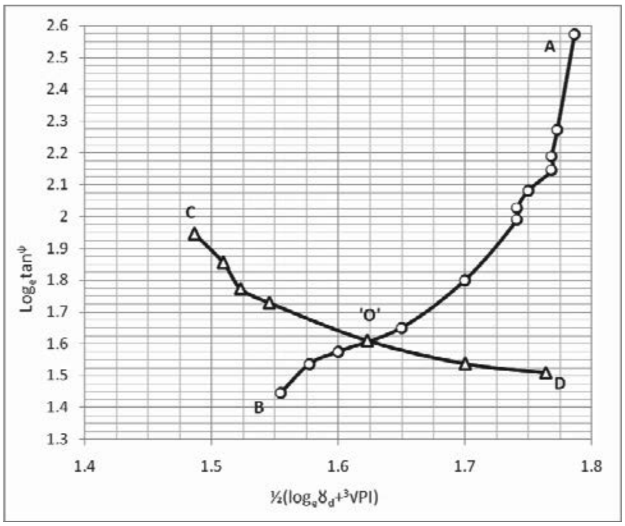

Figure 1. The constitutive model of elastic and index properties of cohesive soil distinguished by geological characteristics

3 INTERPRETATION

The constitutive model, as shown in Fig 1, was required to be interpreted with severe setbacks invading it. However, the expectation that the engineering characteristics of soil depend on the geological properties was given due attention. Accordingly, for clayey soil it had been the expectation that the values of PI, $\gamma_{d,}$ and ψ were under the profound influence of the texture, structure, composition, and other geological parameters.

A most common form of geo-chemical test was carried out and found to be of much help in interpretation of the parameters that influence the nature of the graphical model.

The ultimate extent of interpretation was to investigate how the engineering properties of the clays of the study area have the bearing on physical, chemical, and biological weathering processes of rock and how such information on geological variations of the soil samples could be correlated for estimation of the elastic settlement of structures.

4 CORRELATION

Correlation among the various geological and engineering properties was found to be a complex process, which nonetheless was attempted within the limited scope of this research through geochemical analysis. The samples were identified as medium to highly plastic inorganic clay of semi-pervious to impervious nature. This identification process was based on the results obtained from the laboratory tests carried out to investigate the engineering properties of the samples under study.

The study samples were predominantly Kaolinite and Illite (formed by decomposition of Potash Feldspar), Biotite (mostly altered to Chlorite and Serpentinite), partly weathered Quartz, and possibly Montmorillonite. Although the exact crystal structure of clay minerals could not be known in thin slides, nonetheless, geochemical and other indirect evidences proved these to be clays obtained predominantly by the decomposition of Feldspar.

5 GEOCHEMICAL EVIDENCE

The mineralogy of sedimentary rocks were characterised by two distinct types of minerals, first, the resistant mineral obtained from the mechanical breakdown of the parent rock, and, second, the minerals newly formed from the products of chemical decomposition. The latter minerals were generally hydrated compounds. *"Goldich (1938) pointed out that the order of the stability of minerals of igneous rock towards weathering is the reverse of their order in the reaction series of Bowen (1915 a & b)"* - Mason and Moore 1991. The identity of arrangement between Bowen's reaction series and Goldich's stability series indicates that the last-formed minerals of igneous rock are more stable in subtropical temperature than the minerals formed at an early stage of crystallisation. In other words, the difference between the conditions at the time of formation and those existing at the surface reflects the order of stability of common silicate of igneous rocks.

Quartz and Feldspar are the abundant and dominant minerals. Whereas Quartz is very resistant to the chemical attack, feldspar is less resistant under identical scenario. Although Feldspar may persist indefinitely in sedimentary rocks, they are chemically decomposed by prolonged weathering. In particular, Feldspars give rise to clays with Potash Feldspar reacting in the presence of water to give Illite and Plagioclase Feldspar reacting in a similar manner to give Montmorillonite.

The samples under study were predominantly a mix structure of Kaolinite and Illite with the presence of Ferro-magnesium minerals and weathered Quartz. However, the presence of Montmorillonite was doubtful as because the studied samples did not show the typical expansive characteristics.

The specific gravity is generally low when rock contains light coloured minerals like Quartz and Feldspar and is high when rocks contain dark coloured minerals, for example, Ferromagnesian. However, clay minerals generally have a mean specific gravity value of about 2.7, but the samples that were studied showed a range of values of specific gravities from 1.99 to 2.65. It was expected that the samples would contain some amount of organic matter and possibly more decomposed Feldspar than decomposed Biotites as they are more resistant than Feldspar or other Ferromagnesian minerals. The only exception being the sample which lies at the point of intersection between two curves of the model.

6 INDIRECT EVIDENCE

The clay sample of the study area typically Quaternary deposits, which were the derivation of the Precambrian Granite and Quartzo Feldspathic Gneisses, had been influenced by all three types of weathering processes, namely, physical, chemical, and biological, of which chemical is dominant.

The Precambrian Granitic rock, which includes the Quartzo Feldspathic Gneisses of the area, are composed of predominantly Quartz, Feldspar, and Biotite as primary minerals. Therefore, it is obvious that decomposition of these minerals have led to the formation of clays. Since Quartz and partly Biotite are resistant to chemical weathering, the role of Feldspar stands out in this regard. The Feldspar easily decomposes in the presence of rain water and in presence of carbon-dioxide in atmosphere. The product of the decomposition is clay which plays an important role in the formation of soil of the study area. Quartz remains unchanged in the process of chemical decay and therefore presence of some amount of silt and also sand at depth greater than 15m is notable. Biotite on decomposition yields yellowish clay, the yellow colour being due to the iron content in Biotite. The decomposition sequence of these minerals is also in agreement with the stability order of minerals by Goldich (1938).

7 INTERFERENCE DRAWN FROM CORRELATION

The correlation between the engineering and geological properties infers the conclusion that the pattern of the curves obtained in the model (Fig 1) is apparently dominated by the content of Feldspar and extent of decomposition of Feldspar in relation to other constituent minerals.

The samples represented by the points along the curve A-B show a continuous decomposition of Feldspar and alteration of Biotite to Chlorite with the increase of the values of $\frac{1}{2}$ ($\log_e \gamma_d$ + $\sqrt[3]{PI}$) and $\log_e \tan\psi$. Therefore it has been inferred that the initial tangent modulus is apparently related to the content and extent of decomposition of Feldspar and hence is expected as a major influential factor in estimating the elastic behaviour of cohesive soil.

The points along the curve C-D shows some exception to the above inference and possibly suggests a reversal of the above, whereby Ferromagnesian minerals are undergoing the process of decomposition with increase in the values of $\log_e \tan\psi$ and decrease in the values of $\frac{1}{2}$ ($\log_e \gamma_d$ + $\sqrt[3]{PI}$). The point number "O" is obviously an intermediate point for both the curves of the model.

Correlation of engineering and geological properties based on specific gravity analysis shows that the point no "O", that is, the intersection point has the highest value of specific gravity being 2.65, thereby suggesting presence of more or less an intermediate composition of light and dark coloured minerals. The bottom point of the curve A-B shows a specific gravity of 1.99 and the upper point of the curve A-B shows 2.19, indicating enhancement of decomposition and alteration of both light and dark coloured minerals with the increase in the values of $\frac{1}{2}$ ($\log_e \gamma_d$ + $\sqrt[3]{PI}$) and $\log_e \tan\psi$. The bottom and top points of the curve C-D shows specific gravity values of 2.19 and 2.4 respectively, thereby indicating that Ferromagnesian minerals have increased with the increase of $\log_e \tan\psi$ and decrease of $\frac{1}{2}$ ($\log_e \gamma_d$ + $\sqrt[3]{PI}$) values.

8 CONCLUSION

As the outcomes of the research, influence of a prime constituent mineral has been identified and the extent of its influence is derived. The constitutive modelling, an outcome of the correlative study, is analysed based on its typical pattern. The model thus derived, within the set scope of investigation, has led to the conclusion that the pattern is unique for cohesive soils and is under the possible domination of a common mineral and extent of its weathering process. It leads to the indication of the profound influence of mineral and its weathering state upon elastic behaviour of cohesive soils. The model pointed out that some of the engineering and geological properties are interdependent. The model has been calibrated with other available empirical correlations and its application in civil engineering and limitations are derived. Outlines of subsequent research areas are also indicated.

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10 NOTATIONS

γ_d: Dry Density
PI: Plasticity Index
Tan ψ: Initial Tangent Modulus
ψ: Angle between initial tangent modulus and abscissa.

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