Limitations of Current Soil Mechanics Theory

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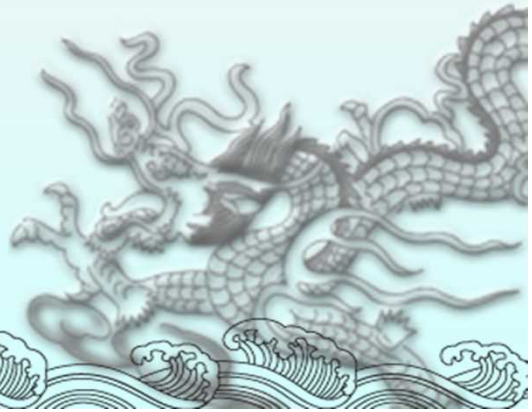
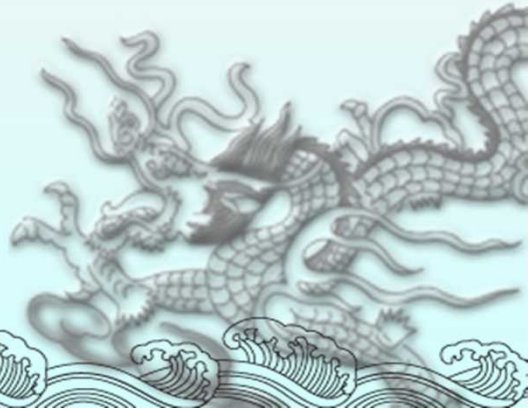
Outline

1. **The reasons for uncertainty in soil mechanics theory**
2. **Discussions on effective stress principle**
3. **To suggest a study method of soil deformation and strength from a multi-field perspective**



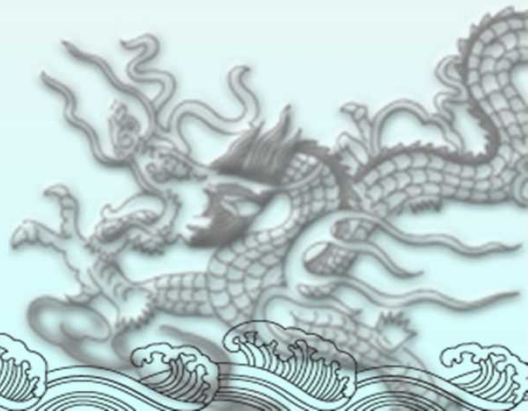
- **We all know that the predicted results from the soil mechanics theory has large uncertainties.**
- **Soil mechanics is a discipline with half theory and half experience.**
- **We found out that the action of engineering experience is inversely proportional to that of scientific theory for any disciplines.**
- **The greater the proportion of science role , the smaller the proportion of engineering experience role. On the contrary, the greater the proportion of engineering experience role, the smaller the proportion of science role.**



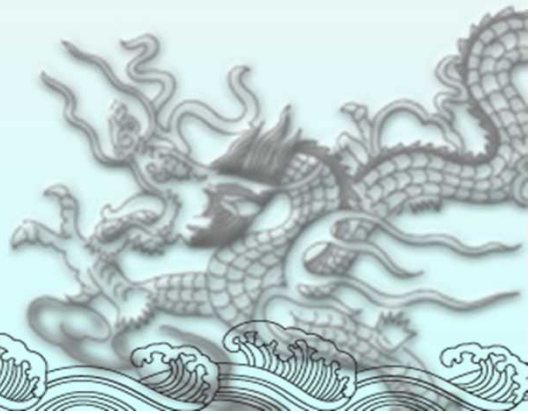
- **if the critical spirit is lacked and the limitations of existing soil mechanics theory are not revealed, It is impossible to change the semi-theoretical and semi-empirical status of soil mechanics.**
- **This report is to discuss the two most important limitations in the current soil mechanics.**

  1）the uncertainty in soil mechanics theory

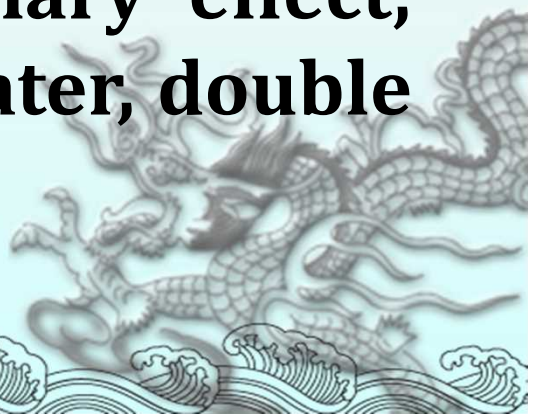
  2）the limitations of effective stress



1. The reasons for uncertainty in soil mechanics theory



- **The soil is sediments of loose and weak cohesive mineral particles, and the liquid and gas are filled in the soil pores.**
- **The cohesion force between the soil particles is weak. Therefore it makes the mechanical behavior of soils to be different from that of other construction materials.**
- **For the weak cohesion, the interaction of the solid-liquid-gas phases can not be neglected, which includes capillary effect, crystallization effect of salt in water, double layer effect.**



- **The soil is sensitive to changes with many factors, especially with the surrounding environments. Therefore, the soil is a kind of easy variable material.**
- **Many factors (such as degree of saturation, temperature, physical - chemical action ...) have important effects on the soil strength and stiffness that is the same order of magnitude as the effect of frictional and cohesion action.**
- **On the other hand, the effect of other factors on the strength and stiffness of construction materials (such as concrete) can be ignored because of its strong cohesion force.**

- **The soil behavior (such as strains and strength) is complex and its influencing factors are numerous.**

$$\varepsilon_{ij} = f(\sigma_{ij}, u_w, u_a, S_r, e, h, h_p, T, S, t, \dot{\varepsilon}_{ij}, c, \ldots) \quad (1)$$

$$\tau_f = f(\sigma_{ij}, u_w, u_a, S_r, \varepsilon_{ij}, e, h, h_p, T, S, t, \dot{\varepsilon}_{ij}, c, \ldots) \quad (2)$$

- **The above factors are not independent, and the specific forms of the above formulas are unknown.**

- **The above factors need to be simplified and the secondary factors should be ignored.**
- **If only one independent variable, i.e., the effective stress is selected, the constitutive relations can be expressed by**

$$\varepsilon_{ij} = f(\sigma'_{ij}) \qquad (3)$$

$$\tau_f = f(\sigma') \qquad (4)$$

- **If two variable, i.e., the effective stress and void ratio are selected, the constitutive relation (Cam-clay model) can be expressed by**

$$\varepsilon_{ij} = f(\sigma'_{ij}, e) \qquad (5)$$

The reasons for uncertainty

- **Soil is a kind of easy variable material, and it is very sensitive to many factors.**
- **For simplify, the influences of many important factors are ignored in current soil mechanics. But it does not mean that they do not exist. On the contrary, they will still be shown the effects on soil behaviors.**
- **A simplified theory can not reflect those influences, which can cause a theory to has very large uncertainty.**

Example 1: Strength

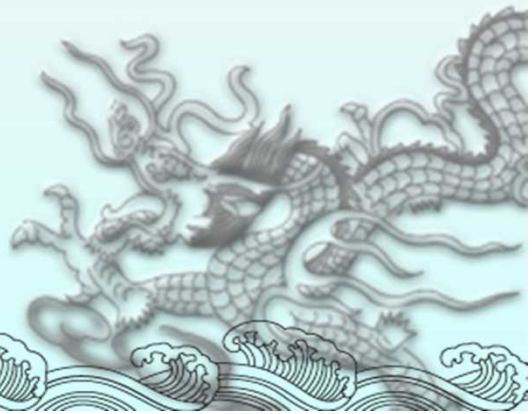
- **Mohr-Coulomb strength theory is widely adopted by engineers.**
- **In this theory, total stress or effective stress is the only variable to control soil strength.**
- **The influences of many other factors are ignored in the theory, which have been contained by the parameters c and φ. Therefore, the experimental results of c and φ have lost their physical meaning of cohesion and friction angle, respectively. These parameters actually include the effects of other factors, which leads to their discreteness.**

Example 2: Deformation

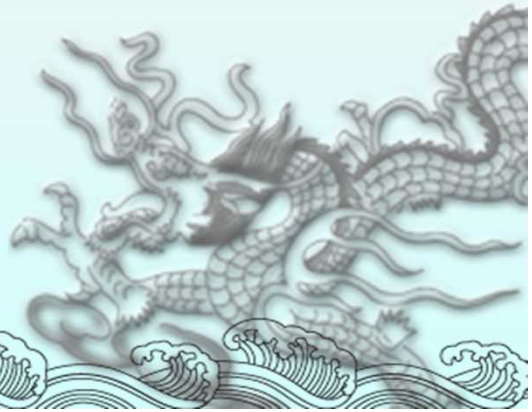
- **Triaxial shear instrument is considered to be an perfect geotechnical laboratory equipment. The effective stress in a soil sample usually can be accurate controlled in the triaxial test. However, the other influence factors, such as soil internal structure, physical-chemical effect of pore water, void ratio, etc., are difficult to control by triaxial shear instrument, which leads to errors and uncertainties.**
- **It is well known that for the same person, using the same triaxial instrument and method, applying the same effective stress and doing the same experiment. But the experimental results are different with some errors for different samples .**
- **In the past, those error have been attributed to the disturbance of soil samples. But in fact, there are some influential factors that are difficult to be controlled in the triaxial instrument, which cause errors.**

Conclusion

- **At present, the soil mechanics theory is overly simplified. It is difficult to reflect the impact of many important factors, which leads to the prediction result by soil mechanics to have very large uncertainty.**



2. Discussions on Effective Stress Principle



- **Soil mechanics is the study of soil deformation and strength in the framework of mechanics.**
- **As mentioned above, soil deformation and strength depend on many factors.**
- **Continuum mechanics mainly studies the relationship among stress , deformation and strength in single-phase materials.**
- **The soil is multiphase mixture, where the saturated soil is the simplest two phase mixture. The large error will produce if the total stress is adopted for saturated soil.**
- **Therefore, the influence of the liquid phase should be considered.**
- **An equivalent stress approach was adopted by Terzaghi to consider the effects of liquid phase.**

- **This method is a simplified approach, just as adopting the temperature stress to deal with the temperature problems.**
- **The two forms of effective stress were explored from two perspectives of strength and deformation by Skempton (1960).**

$$\sigma'_{ij} = \sigma_{ij} - ku_{\mathrm{w}}\delta_{ij}$$

- **An effective stress formula considered the physical-chemical action was given by Mitchell (1976).**

$$\sigma'_{ij} = \sigma_{ij} - u_{\mathrm{w}}\delta_{ij} + \left(A - R\right)\delta_{ij}$$

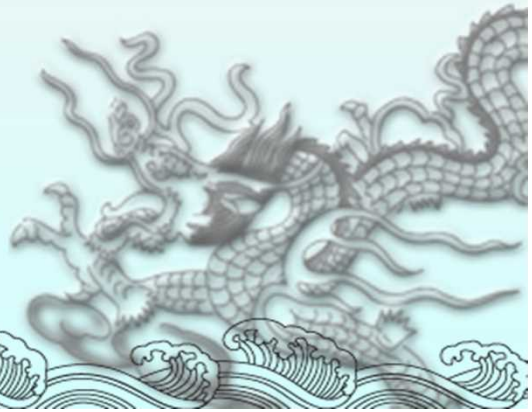
- **The effects of other factors are converted to the formulas of equivalent stress in these approach.**

- **The above approach is a simplified method, in which the stress in continuous medium mechanics is replaced by the effective stress. Then the models of deformation and strength for saturated soils can be established in the same way as that of single-phase continuous medium mechanics.**
- **Why the approach of effective stress is a simplified method?**
- **It is because that the multi-phase, multi-variable, complex multi-field problem is simplified as a single-phase mechanical problem by using the approach of effective stress . It should be noted that a multi-field problem is not a single phase mechanics problem.**

- **Unsaturated soil is a three-phase mixture. Adopting the effective stress of saturated soil to deal with the problem of complex unsaturated soil is incomplete and unsatisfied, and it can't be accepted by engineers, which exist large error.**
- **Similar to the case of saturated soil, the three-phase, multi-variable, complex three field problem is simplified as a single-phase mechanics problem by using the approach of effective stress , when the equivalent unsaturated soil effective stress is adopted.**
- **The corresponding deformation and strength models were established by using the effective stress for unsaturated soil. Owing to lack enough independent variable, the deformation model is still unsatisfied.**
- **The theory of unsaturated soil mechanics will be difficult to make substantial progress, if the effective stress principle is still hold.**

- **The effective stress principle tells us that the soil strength and deformation are determined by the effective stress.**
- **But the principle does not say that the soil strength and deformation are determined only by the effective stress , and it does not say that the effective stress is the only independent variable to determine the strength and deformation of soils.**

- **Therefore, for the strength and deformation of unsaturated soils, adopting two variables, e.g. net stress and suction, is superior to the use of a single effective stress for unsaturated soil .**

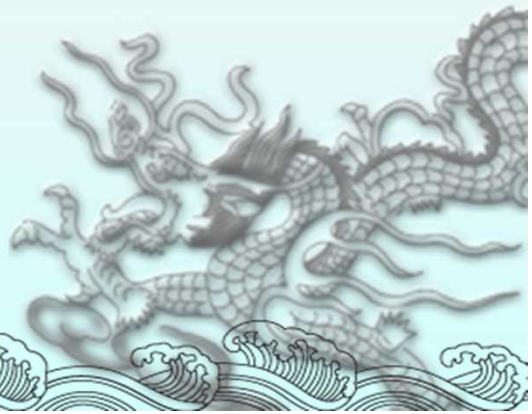


The limitations of effective stress

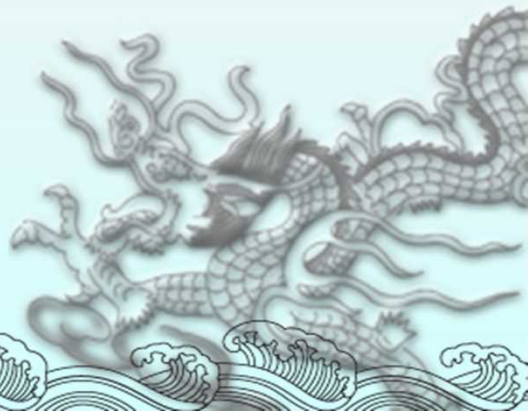
- **As discussed above, the soil is a kind of easy variable material. Therefore, there are many factors affected its strength and deformation.**
- **It is a simplified approach to consider the various influencing factors (e.g. pore water pressure, suction, degree of saturation, physico-chemical effect, etc.) into some forms of effective stress, i.e. reducing a multi-field complex problem into a single-phase mechanical problems by using the effective stress.**

- **Soil is a kind of friction material. Its deformation and strength depend mainly on the skeleton stress (effective compressive stress), friction coefficient and contact area among soil particles, connection strength.**
- **The connection strength among soil particles is determined by the soil internal structure and its variation, which may be related to changes in the external environment (e.g., temperature and humidity), but may not be directly related to the effects of external forces or stress.**
- **In other words, the soil deformation and strength are not only depend on the skeletal stress or effective stress.**
- **Other factors affected the connection strength of soil grain will also affect its deformation and strength, such as physico-chemical action, suction and degree of saturation.**

To suggest a study method from a multi-field perspective



- **Under the framework of classical theory, it is difficult to break through the shackles of the theory, and it is difficult to obtain a comprehensive and in-depth understanding of the shortcomings and limitations of classical theory.**
- **Only by jumping out of the framework of the classical theory, getting rid of its influences, and re-examining the classic theory with a broader perspective, we can comprehensively and deeply understand its shortcomings and limitations.**
- **This report is intended to rethink the effective stress principle from a broader perspective.**



- **Therefore the researchers should not only pay attention to the effect of effective stress (this is certainly correct), but also consider the effects of other factors to be as the independent state variables rather than to be some parameters or some conditions.**
- **Because the constitutive models of deformation and strength are change with these variables. For example, the deformation and strength formulas at low temperature or low degree of saturation conditions are different from that at high temperature or high degree of saturation.**
- **From the perspective of multi-field coupling to examine the classical soil mechanics problems, a lot of new problems and knowledge growth point will be produced, and the knowledge and understanding of the original problem will broaden and deepen.**

- **Therefore, the soil deformation and strength should be studied from the multi-field perspective.**
- **Others factors are treated as independent variables (or independent field variables), rather than are simplified as the effective stress.**
- **Besides, the coupling in multiple fields can be considered.**
- **It is clear that the study of soil deformation and strength from a multi-field perspective is a more complete and scientific approach.**

Thanks