Brief Introduction of Engineering Property for Coarse Grained Soil

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Abstract. Coarse grained soil has been widely used in engineering construction for their excellent physical and mechanical properties. This paper presents the influence factors of shear strength, static and dynamic deformation characteristic of coarse grained soil, and finds that the dynamic property of coarse grained soil under cyclic load would be an important research direction.

1. Introduction
Coarse grained soil is wide spreading and abundant reserves in nature. Since coarse grained soil has excellent engineering property like good compacting effect, high permeability, great packing density, high shear strength and small settlement deformation, it has been widely applied in engineering construction[1,2], such as earth-rock fill dam, railway embankment or soft foundation treatment. With the larger applied range of coarse grained soil, the engineering property of it also has been deep studied by many researchers. This paper mainly introduces the influence factors on shear strength, static and dynamic deformation characteristic of coarse grained soil.

2. Shear strength property
As a kind of granular mixtures, coarse grained soils are seldom subjected to tensile stress. The typical lose-stability type is that one part of particles slip over another part along the interface between them, viz. shear failure. Hence, the shear strength property has been usually studied in engineering. The factors influence the shear strength of coarse grained soils including coarse grains content, the strength of coarse particle, maximum particle size and confining pressure.

2.1. Coarse grains content
In engineering point of view, the separation particle size, which separates coarse particle and fine particle, is often equal to 5mm, and thus using a parameter $P_5$ to express the content of coarse particles. A large number of studies have shown that when $P_5$ is below 30%, the shear strength remains unchanged with increasing $P_5$. On the other hand, when $P_5$ changes from 30% to 70%, the shear strength would increase and reach the maximum value. Finally, when $P_5$ is beyond 70%, the shear strength would not increase and even slightly decrease$^{[1-3]}$. The reason for this is that coarse particles are suspend in the fine particles for $P_5<30\%$. This kind of soil structure is called "dense-suspended texture" that shear strength is controlled by the fines. With the increase of $P_5$, the coarse particles begin to contact with each other and shear strength is controlled both by coarse and fine particles. Especially, when $P_5$ reaches 70%, the coarse particles can exactly form skeleton in which the fines fill up the voids. In this situation, the soil
performs the optimal shear strength and this kind of soil structure is called "skeleton dense texture" which has the maximum density. Hereafter, the soil structure transforms into "skeletal void texture", for the fine particles cannot fill up the void among the coarse ones, and the shear strength would decrease with the increase of $P_5$.

Bagherzadeh-Khalilzahi\cite{4} found that the appearance of the maximum friction angle for coarse grained soil is not related to the particle graduation, but is dependent on the optimal content of $P_5$.

2.2. The strength of coarse particle

The mineral composition of coarse particles has a remarkable effect on the strength property of coarse grained soil. Refs [3] revealed that the high strength of coarse particle would make the friction angle increase about 2~4°. It is because that there are remarkable difference between hard rock particle and soft rock particle for the strength of particle edge which can form interlocking for improving the ability to resist shear.

2.3. Maximum particle size

If other factors are fixed, the larger maximum particle size, the greater value of internal friction angle (i.e. $\phi$). Based on the relationship between fractal dimension of shearing surface and maximum particle size and the relationship between fractal dimension of shearing surface and shear strength indexes\cite{5}, the shear strength indexes indeed increase with the increase of maximum particle size. But the effect of maximum particle size is limited for the content of coarse particles in soil. Thus, the prediction of shear strength through maximum particle size is inappropriate.

2.4. Confining pressure

Confining pressure is an important factor influences shear strength, mainly because its change reflects the effect of shear dilatation and grain breakage on shear strength. On low stress condition, the strength envelope line for coarse grained soil are usually expressed by Coulomb equation\cite{6}:

$$\tau = c + \sigma_n \tan \phi$$  \hspace{1cm} (1)

where $c$ is the cohesion coefficient of soil.

On high stress condition, the grain graduation and structure density of soil would change, for the grains breakage and realignment. After that, the form of strength envelope can change into curve and it can be expressed by Duncan equation\cite{7}:

$$\phi = \phi_0 + \Delta \phi \log\left(\frac{\sigma_3}{P_a}\right)$$  \hspace{1cm} (2)

where $\sigma_3$ is the confining pressure; $P_a$ is the technical atmosphere pressure; $\phi_0$ is friction angle under standard atmospheric pressure; $\Delta \phi$ is the decreasing value of friction angle after confining pressure increases 10 times.

3. Static deformation characteristic

In recent decades, with the development of testing technology, the deformation process from beginning to failure can be continuously measured, through the combined utilization of small-strain testing device and traditional deformation testing device in triaxial apparatus. Therefore, the static deformation characteristic of coarse grained soil has been gradually lucubrated.

On the condition of microstrain level, sand, gravel and soft rock have the linear elasticity property when the order of magnitudes of axial strain is below $10^{-5}$. In this situation, the static dynamic deformation parameter is the same as the dynamic one.

The stress-strain relationship of coarse grained soil can be divided into strain hardening type and strain softening type\cite{8}. Based on a large number of researches, Guo\cite{1} concluded that the characteristic of stress-strain for coarse grained soil is as follow:

(1) The initial segment of stress-strain curve for coarse grained soil is steeper than that of other soils, viz. the increase rate of stress is great.
(2) The stress-strain curve of coarse grained soil is usually strain softening type, which has typical peak strength, except for the high pressure condition.

(3) In the process of shear failure, the value of strain corresponding to the peak stress for coarse grained soil mainly focuses on 2%~8% and is not more than 15%, which is lower than other soils. Thus, the standard of shearing strength with uniform strain is not suitable for coarse grained soil.

(4) With respect to volumetric strain, the deformation of coarse grained soil caused by shear dilatancy performs larger and earlier. Especially, on the condition of great density and small lateral stress, it appears at the beginning.

4. Dynamic deformation characteristic

There are three typical deformation behaviors in dynamic stress-strain relationship for soil under cycle load, viz. nonlinearity, hysteresis and strain accumulated. They are influenced by some factors such as vibration times, stress state, particle characteristic and drainage condition. In order to study the dynamic deformation characteristic of coarse grained soil, the dynamical modulus, damping and residual deformation are used for describing it.

4.1. Dynamical modulus and damping

It is the dynamical $G_{ep}$ and damping ratio $\lambda$ that are used for reflecting the nonlinearity and hysteresis of dynamic stress-strain relationship of soil and they are expressed as the function of dynamic strain amplitude $\varepsilon_d$. On the condition of small strain, $G_{ep}$ depends on vertical effective consolidation stress and is not relevant to horizontal consolidation stress. But $G_{ep}$ would seems to be controlled by horizontal stress or average effective stress when strain becomes large\[8\].

Hardin provided an empirical formula for estimating the $G_{ep}$ of sand through laboratory test:

$$G_{ep} = G_{in} \cdot P_a \cdot F(e) \cdot \left(\frac{P_e}{P_a}\right)^n$$  

\[3\]

where $\sigma_0$ is the mean effective stress; $G_{in}$ is the coefficient of modulus; $e$ is the void ratio; $F(e)$ is the function of void ratio, for round particles or sand $F(e) = (2.17-e)^2/(1+e)$, for angular particles $F(e) = (2.97-e)^2/(1+e)$; $n$ is the index of modulus, which is between 0.4 and 0.6.

In order to depict the variation of modulus with the increase of dynamic strain amplitude, normalization processing is applied to $G_{ep}$, which is corresponding to a certain strain amplitude, through initial modulus ($G_{ep})_{max}$ under small strain:

$$\delta = \frac{G_{ep}}{(G_{ep})_{max}}$$  

\[4\]

Some researchers found that confining pressure, compaction degree and particle graduation are the most important factors that have the effect on dynamical shear modulus. With the increase of confining pressure, the normalized curve of modulus gradually shifts upward. Also, the greater content of coarse particles, the larger value of shear modulus, but the normalized curve is still unchanged.

The damping represents the ratio of lost energy to maximum elastic energy in a cycle time. There are usually two empirical relationship for expressing the dynamical damping characteristic of coarse grained soil: the one is establishing the relationship expression between dynamical modulus and damping ratio directly, such as equation (5) proposed by Hardin\[9\]; the other one is establishing the empirical relationship from various influencing factors\[10\].

$$\lambda = \lambda_{max} (1-\delta)$$  

\[5\]

where $\lambda_{max}$ is the damping ratio corresponding to dynamical modulus closed to 0.

4.2. Dynamical residual deformation

The influence factors on dynamical residual deformation of coarse grained soil are mainly the cyclic load, load times, initial stress condition, drainage condition, saturability and density degree of soil. Shen\[11\] carried out large-scale triaxial tests and proposed the relationship between residual strain and load times
where $\varepsilon_{vr}$ is the residual volumetric strain; $\gamma_{d}$ is the residual shear strain; $c_{vr}$ and $c_{dr}$ is the slope of trial curve on semilog coordinate, which has the follow empirical formula:

$$\varepsilon_{vr} = c_{vr} \log(1 + N)$$

$$\gamma_{d} = c_{dr} \log(1 + N)$$

where $S_i$ is the strain level; $\gamma_{d}$ is the amplitude of dynamical shearing strain; $c_1, c_3, c_4$ are the experimental parameters.

Jia\cite{12} carried out some residual deformation tests for sand gravel by GDS dynamic triaxial equipment, and analyzed the effect of particle graduation and initial stress state on residual deformation based on the equations proposed by Shen\cite{11}. The test results revealed that the ability of soil for resisting dynamical load increase with the increase of the content of coarse particles, if the initial state are the same.

Yang\cite{13} carried out a series of dynamic triaxial tests for coarse grained soil in different stress conditions. He found that the axial strain and volumetric strain can be divided into residual strain and reciprocating strain, the former performs monotonically increase and the later fluctuates irregularly. Additionally, he discussed the influence of vibration times, confining pressure, consolidation ratio and radial synchronous vibration on deformation characteristic of coarse grained soil.

Wang\cite{14} revealed that the formation method of soil specimen has an effect on the dynamical residual deformation, on the basis of the large-scale triaxial tests for graded crushed stone. As compared to tamping, the vibration for making soil specimen would make the residual deformation fall almost twice as far. The residual deformation of skeleton dense texture is three times less than that of dense-suspended texture or skeletal void texture.

5. Conclusion

With the development of engineering construction, coarse grained soil is widely used for its excellent engineering property. But because of the lack of test condition and equipment, the researcher for coarse grained soil is still deficiency. Therefore, it needs intensive study, especially for the dynamical characteristic under cyclic load.

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