Study on mechanical properties of the gravelly soils with consolidated-undrained conditions

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Abstract: A standard stress path triaxial test system (STDTTS) was applied to study the mechanical properties of gravelly soil at initial relative densities of 0.13, 0.51, 0.67 and 0.81 under confining pressures of 50, 100, 200 and 400 KPa, respectively. The results in the consolidated undrained tests show that all stress-strain curves behalf strain softening. With an increase of confining pressures, the pore pressure increases gradually and is almost irrelevant to initial relative density. With the increase of initial relative density, the peak strength of tested samples shows an up trend, and its strength conforms to the Mohr-Coulomb strength criterion.

1. Introduce

The mechanical properties of geotechnical materials are affected by confining pressures, initial relative density, stress path and other factors. Based on the results from triaxial tests, Lu et al. [1] found that particle breakage for sands occurs under high confining pressures and the specimen changes from dilatancy softening to shear hardening from low confining pressure to high confining pressure. Controlling the water content of sandy soil, Zhang et al. [2] pointed out that the stress-strain curves showed strain softening characteristics at low water contents and strain hardening characteristics at high water contents. Han J [3] studied the stress-strain curves and volume-change curves of sands adopting three stress paths. It is found that the peak stress of sands changed from large to small and the dilatancy varied from strong to weak under CTC, TC and RTC paths. Fan et al. [4] made an experimental study on the mechanical properties of sandy soil. It is found that the initial relative compactness is an important factor affecting the radial deformation and initial elastic modulus of sandy soil. Cai et al. [5] pointed out that the initial relative compactness had a significant effect on the dilatancy and effective mean normal stress of sand. Chen et al. [6] investigated the change of initial tangent modulus with initial relative densities. According to the strength envelope of sand under different initial relative densities and confining pressures, XU et al. [7] discovered that the shear strength of sand increased with a increase of initial relative density. Zhu et al. [8] researched the effect of initial relative compactness on the mechanical properties of saturated sandy soil through static triaxial tests. The brittleness of soil increases, failure strain decreases and the strength rises in varying degrees, with increasing initial relative compactness.

In this paper, unconsolidated and undrained triaxial tests were carried out, with the initial relative densities of 0.13, 0.51, 0.67 and 0.81 and confining pressures controlled at 50KPa, 100KPa, 200KPa and 400KPa, respectively, to study the mechanical properties of sands, including stress-strain
behaviors, pore pressure characteristics and strength characteristics.

2. Test description
Sandy soil is adopted in tests. The particle gradation curve is shown in Fig. 1. The test instrument is the Standard Stress Path Triaxial Test System (STDTTS) manufactured as shown in Fig. 2. The instrument consists of three axial pressure chambers, including air pressure control chamber, back pressure controller, axial pressure controller and sensor. Soil samples are prepared by layered compaction according to the Standard of Geotechnical Test Methods. The diameter and height of the samples are 50mm and 100mm respectively. The samples are saturated by the water head saturation method and the back pressure saturation method successively, and the saturation is completed when the pore pressure coefficient B value reached 0.95. The samples are consolidated after saturation, and the consolidation pressures are set as 50KPa, 100KPa, 200KPa and 400KPa, respectively. After consolidation, the samples are loaded by conventional triaxial stress path under the condition of no drainage with drain valve closed. With a loading rate of 0.01mm per minute, the tests are terminated when the axial strain reaches 15%.

Fig. 1 The grain gradation curve of the test gravelly soil

Fig. 2 Standard stress path triaxial apparatus
3. Stress-strain characteristics
The deviated stress-axial strain curves of gravel-bearing sand are shown in Fig. 3, with different initial relative compactness of 0.13, 0.51, 0.67 and 0.81 at confining pressures of 50KPa, 100KPa, 200KPa and 400KPa, respectively. According to figure 3, all samples show strain softening. The deviation stress increases with the increase of the axial strain on small strain condition. When the axial strain reaches about 2%, the stress reaches the peak stress. Over the peak stress, the samples enter the plastic flow state and the stress-strain curves show strain softening.

4. Pore pressure characteristics
The relation curves between pore pressure and axial strain of saturated sand are shown in Fig. 4. From Fig. 4, the void water pressure gradually increases and eventually tends to be stable with the increase of axial strain. Under the condition of coaxial strain, the void water pressure increases with the confining pressure. The variation of pore pressure with axial strain can be expressed by the following equation.

\[ u = \frac{\varepsilon_1}{(f + g\varepsilon_1)} \]  

(1)

Where f and g are test parameters, which are related to confining pressure and relative compactness.
5. Strength characteristics

From Fig. 5, the curves of the peak strength varying with initial relative density and confining pressure are displayed. It can be seen that the strength envelope of the gravel sand is approximately linear and the peak strength increases with the increase of the initial relative compactness and confining pressure. The strength characteristics can be described by the Mohr Coulomb strength criterion whose expression is as follows:

\[ \tau = c + \sigma \tan \varphi \]  

(2)

Fig. 5 Relation between \( \sigma_3 \) and peak strength under different initial relative density
6. Conclusion
(1) The stress-strain curves of gravel sands are all strain-softening, and the degree of softening decreases with the increase of initial relative compactness.
(2) The pore water pressure gradually increases with the axial strain in the form of a hyperbola. The peak pore pressure is little affected by the initial relative compactness under the same confining pressure and increases with the increase of confining pressure under the same initial relative compactness.
(3) The strength envelope of the gravel sand is linear, whose strength increases with the increase of the initial relative density.

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References
[1] Lu, Y., Zhou, G.Q., Gu, H.d., Experimental study of strength and deformation characteristics of sand under different pressures[J]. Chinese Journal of Rock Mechanics and Engineering, 2016, 35(11): 2369-2376.
[2] Zhang, D., Water content and modulus relationship of a compacted unsaturated soil[J]. Journal of Southeast University (English Edition), 2012, 28(2): 209-214.
[3] Han, J., Influence of sampling method and stress path on the shear behavior of saturated medium density fine sand[D]. Dalian: Dalian University of Technology, 2016.
[4] Fan, Z.Q., Experimental study on deformation characteristics of sand[D]. Dalian: Dalian University of Technology, 2009.
[5] Cai, Z.Y., Li, X.S., Deformation characteristics and critical state of sand[J]. Chinese Journal of Geotechnical Engineering, 2004.
[6] Chen, C., Influence of relative density on initial tangential modulus of gravelly sand[J]. Journal of Shenyang University of Technology, 2016, 38(5): 579-583.
[7] Xu, R.Q., Wang, X.C., Zhu, J.F., et al. Experiment of initial relative density effects on sand strength[J]. Journal of jiangsu university (Natural Science Edition), 2012, 33(03): 345-349.
[8] Zhu, J.G., Shi, J.w., Luo, X.h., et al. Experimental study on stress-strain-strength behavior of sand with different densities[J]. Chinese Journal of Geotechnical Engineering, 2016, 38(02): 336-341.