Research on physical and mechanical properties of Xinjiang Daxigou loess

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Abstract. The technology and methods of construction of embankment dam are closely related with the dam soil. Therefore, physical and mechanical properties of soil material must be studied. In this paper, with the study of Xinjiang Daxigou dam soil, compaction characteristics, compression characteristics, strength properties and wetting deformation characteristics were analyzed. The results showed that compaction work has great impact on the dry density, but the extent must be noted when increasing compaction to improve the compaction degree. Soil compaction has great impact on the compression characteristics. Compression coefficient rapidly decreased as the pressure increases. Inflection point can be observed when the pressure reaches a certain level. Compression modulus increases with the increasing pressure and compaction degree. Water content and void ratio indicators have a certain function with strength index. Duncan - Chang model parameters present certain regularity as the change of moisture content and compaction, and the compaction degree has a great influence on parameters. Stress level has a significant influence on wetting deformation, which is closely related to the compaction degree.

1. Introduction

The material of embankment dam is earth-rock material in local, which is closely related to the technology and methods of construction of embankment dam and the dam soil. It is necessary to study the physical and mechanical properties of soil. The compaction characteristics, strength properties, wetting deformation characteristics and other physical and mechanical properties of the soil are important factors about the security and stability of embankment dam [1-3].

Because of the special geographical and climate environment, Xinjiang loess is different from other regions loess. Zhou Tingru [4] (1963) first studied the Xinjiang loess, he thought that the loess in Xinjiang is closely related to glaciers and local drought environment. After the 1980s, Wen Qizhong [5], Zhang hung [6], TengZhiHong [7] and other people studied the loess of northern Xinjiang. They thought that the formation of the loess of northern Xinjiang is similar to the Malan loess. Since the 1990s, many scholars performed the further work in Xinjiang loess [8-11]. They thought that most of the loess of northern Xinjiang is the product of the early dry cold climate environment. After 21st century, the research of Xinjiang loess was expanded to the whole Xinjiang region [12] [13], which involves micro-structure [14-16], paleomagnetic and ancient climate [17]. Even so, its research was started relatively later than that of the area in the middle areas of the Yellow River. The study of the physical and mechanical characteristics of loess in Xinjiang is quietly less.

In this paper, with the study of the reshaping of the different degrees of compaction loess, the compaction characteristics, compression characteristics, strength properties and wetting deformation characteristics of Xinjiang loess were analyzed.

2. The test soils and test methods

2.1 Test soils

In this paper, the test soil was taken from T2 soil yard in Daxigou dam, which was located in IV level terrace. The soil, between the non-dispersion soil and the dispersion soil, belong to the expansive clay of eolian loess. The basic physical properties are shown in table

2.2 Test methods

According to the maximum dry density of 0.88, 0.90, 0.92, 0.95 and 0.98 times, the dry density are 1.61g/cm^3, 1.65g/cm^3, 1.68g/cm^3, 1.74g/cm^3 and 1.79g/cm^3. Various physical and mechanical properties tests were performed in accordance with the "Standard of soil test method".

Table 1 The basic physical properties indexes of Daxigou loess

Percentage of Particle size（%）									Compaction25N（power is 592.2kJ/m^3）		
> 0.075mm	0.075 ~ 0.005mm	< 0.005mm	Non-uniform coefficient Cu	curvature coefficient Cc	D_{50}(mm)	Plastic limit ω_P(%)	Liquid limit ω_L(%)	Plastic index Ip	optimal water content (%)	Maximum dry density (g/cm^3)	Permeability coefficient (cm/s)
2.7	70.32	26.98	8.33	1.33	0.011	19.8	27.4	7.6	14.5	1.8	2.5×10^{-5}

(1)Preparation of soil

Preparation water content was 13.8％ (the optimal water content). Nature dry dehumidification and humidifying water transfer membrane methods were used to make saturated specimen.

(2) Compaction test

DJS—3 standard light portable compaction instrument was used. Seven kinds of design scheme were designed. The experimental scheme was shown in table 2.

Table 2 Compaction test program

Compaction times	5	10	15	20	25	35	45
Power of compaction (kJ/m^3)	118.4	236.9	355.3	473.8	592.2	829.1	1066.0

(3) Compression test

We controlled the optimal water content, namely, 13.8％, when preparing different compaction degree of the remolded sample. We tested the vertical pressure step by step, and respectively read peer pressure dial indicator reading.

(4) Triaxial test

We mainly carried out consolidation drained triaxial shear tests. The triaxial shear apparatus which was made by Nanjing electric power automation equipment factory. The shear ratio was 0.016 mm/min. The consolidation stress ratio Kc was 1.0. The consolidation confining pressure were 100, 200, 300, and 400kPa. The water contents were 9.2%, 13.8%(the optimal water content), 17.2%, and saturated water content respectively. The pressure chamber was circumscribed and the value shear was measured by dial gauge which was connected to the pressure chamber.

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3. The test results and analysis

3.1 Research of the soil compaction characteristics

The compaction curve of different compaction power is shown in Fig 1. The relation of the compaction times with the maximum dry density and optimum water content is shown in Fig 2.

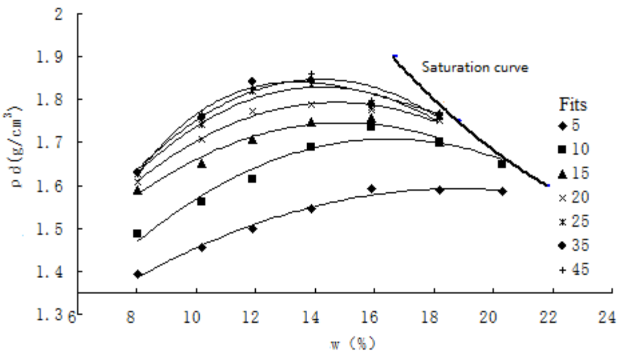
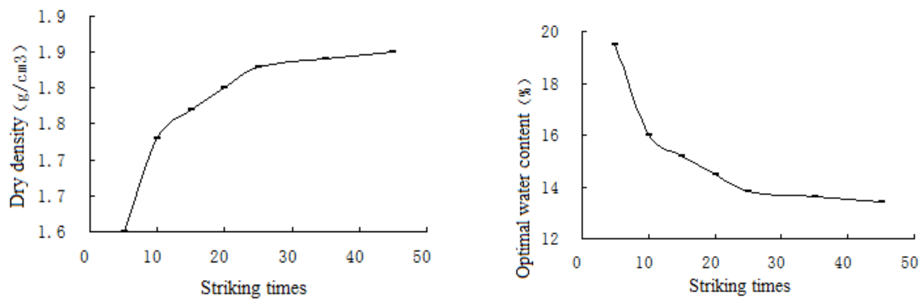


Fig. 1 Compaction curves under different compaction times



(a) (b)

Fig. 2 Curves of compaction times between maximum dry density and optimum moisture content

The Fig.1 and Fig. 2 show that compaction power has a great influence on dry density. The maximum dry density increases with increasing of compaction power, but the optimum water content reduces gradually. The increment of maximum dry density reduces gradually with increasing of compaction power. The maximum dry density does not unlimited increase with the increasing of compaction work after the compaction power reaching a certain value. From the safe and economic consideration, the most reasonable compaction times is 25 times. This is consistent to the fitted relationship of the compaction function and maximum dry density by Blotz with the method of least squares. Through increasing the compaction, the increasing of compaction power will lead to reduce of optimum water content. The optimal water content is 14.5% when each layer has 20 hits, the optimal water content is 13.8%. When each layer has 25 hits and the hit times increases to 45 times, the optimal water content reduces to 13.4%. Therefore, the attention should be paid to control water content in practical engineering.

3.2 Research on the soil compression characteristics

The parameters of Duncan-chang E-μ model was solved, and the various rulers of parameters with the changes of the compaction degree and water content were analyzed.

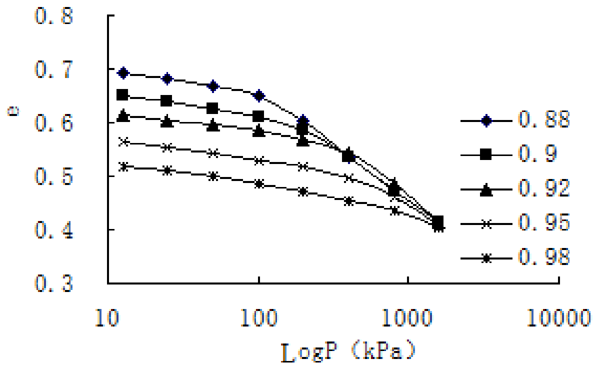
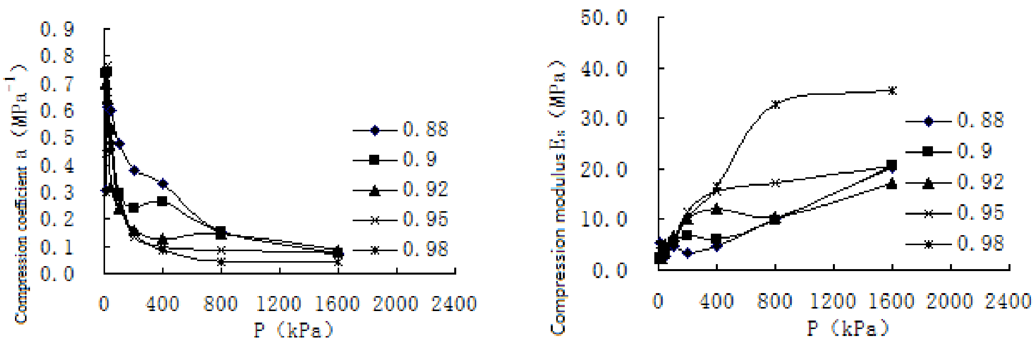


Fig. 3 e-lgP curves of different compaction degree

The Fig. 3 shows that the pore ratio decreases rapidly with the confining pressure increasing at the lower pressure. The smaller of the compaction degree, the faster of the increasing speed of the pore ration. This is because the soil is more likely to be compaction at the lower compaction degree. The compression curve fell more and more slowly with pressure increasing. Every pore ratio is close to the same value at any compaction degree. This is because the minimum pore of the same ratio is a constant value. The soil particles were difficultly increasing to compact with the increasing of the pressure, and pore ratio is more and more close to the minimum.

The e-lgP curve can be divided into three phases obviously. Firstly, the internal structure of soil has not been damaged obviously, and the compression curves keep a steady state. Secondly, the internal structure of soil is damaged and secondary structure gradually formed. The compression curve shows a nonlinear relationship obviously. Thirdly, the internal structure of soil is completely damaged, the adjustment of internal structure of soil is mainly secondary structure formation. The compression curve shows linear change. At the beginning of the compression deformation, deformation of soil is mainly elastic deformation. The soil particles begin to slip with the increasing of pressure, and the deformation mainly shows plastic deformation. The inflection point of the e-lgP curve is the yield point, corresponding to yield pressure. The yield stress increases gradually with the increase of degree of compaction. For example, when the compaction degree is 0.88, the yield pressure is about 100 kpa. When the compaction degree is 0.98, the yield pressure is about 800 kpa. We can obtain the compression coefficient and compression modulus Es and draw the relationship curve with the overlying pressure. As shown in Fig. 4.



(a) (b)

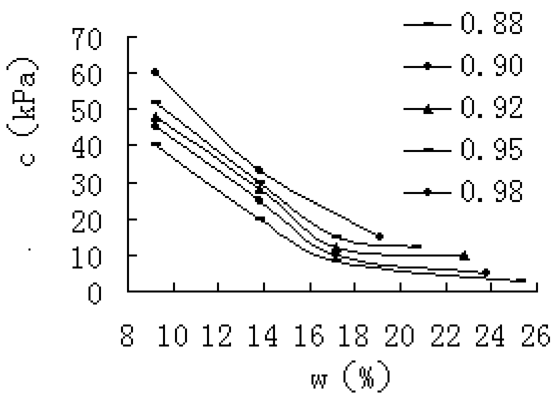
Fig. 4 A-P and Es-P curves of different compaction degree

The Fig.4 (a) shows that the compression coefficient reduces rapidly with the increasing of pressure at the same compaction degree. When the pressure reaches a certain degree the turning points appeared, then the compression coefficient reduces slowly with the increasing of pressure. The coefficient reduces with the increasing of compaction degree at the same pressure, which shows that the higher compaction degree and the more difficult to compact.

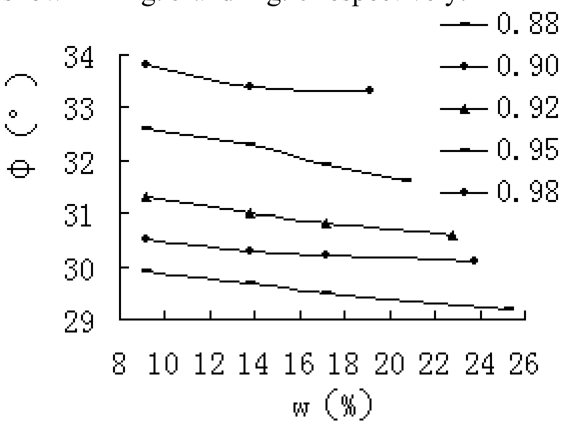
The Fig. 4 (b) shows that the compression modulus Es increases with the increasing of pressure, and linear increases with the compaction degree at the small compaction degree. The increase speed decreases graduay when the compaction degree increase to a certain value, and the inflation point appears. The compression modulus increases with the increasing of compaction degree at the same pressure, the compression modulus increases rapidly at the high compaction degree, which shows compaction degree has a great influence on the compression modulus.

3.3 Research on the soil static strength characteristics

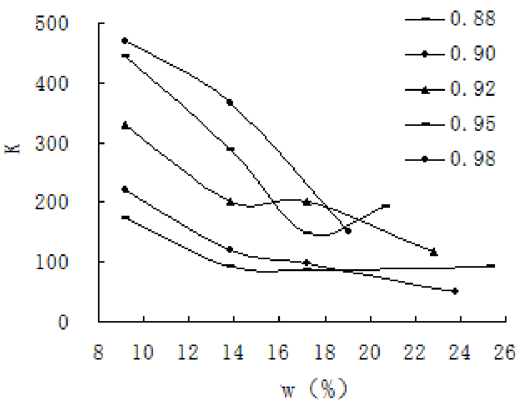
The parameters of Duncan-chang E-μ model was solved, and the various rulers of parameters with the changes of the compaction degree and water content was analyzed. The curves of parameters with the changes of compaction degree and water content are shown in Fig. 5 and Fig. 6 respectively.



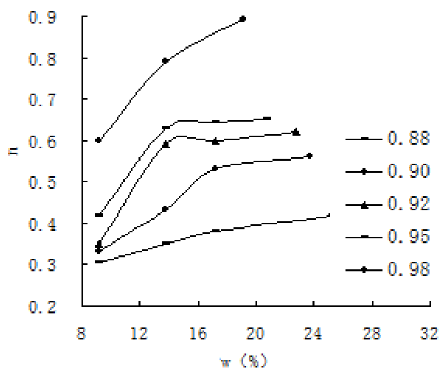
(a)



(b)



(c)



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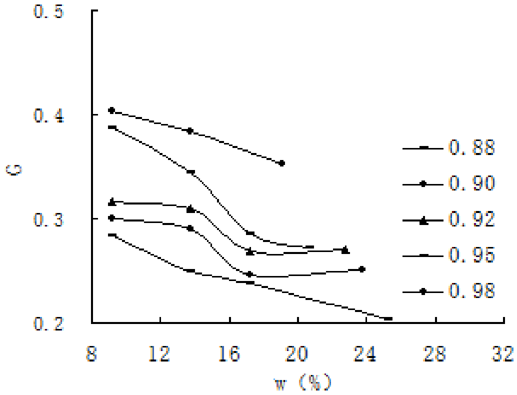
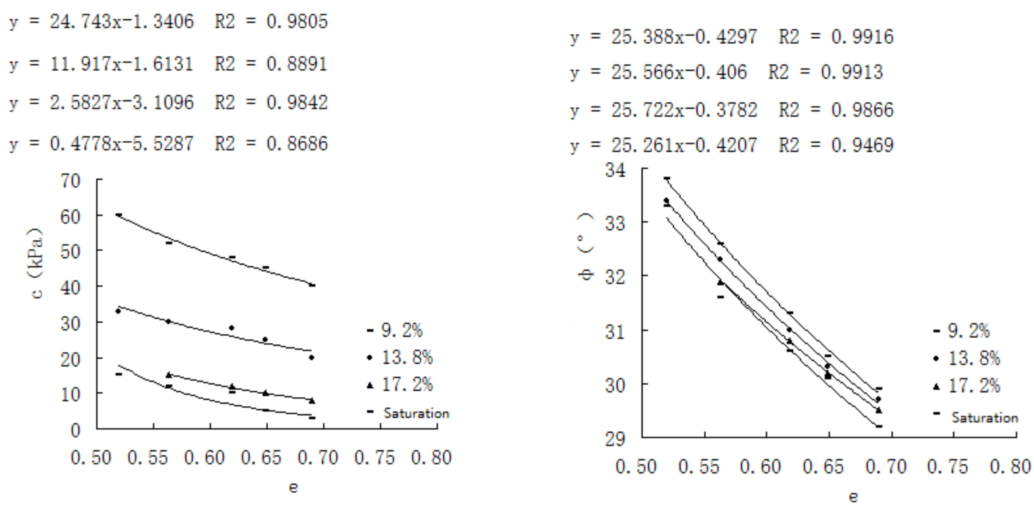
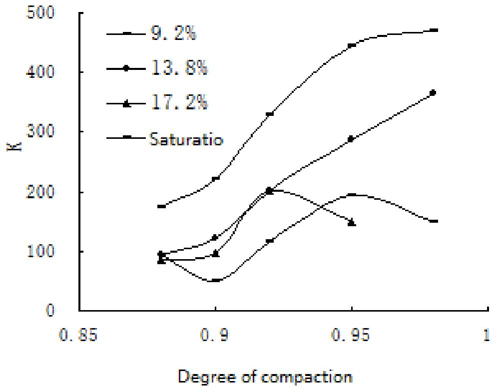


(e)
Fig. 5 Duncan - Chang E-μ model parameters with the water content



(a) (b)



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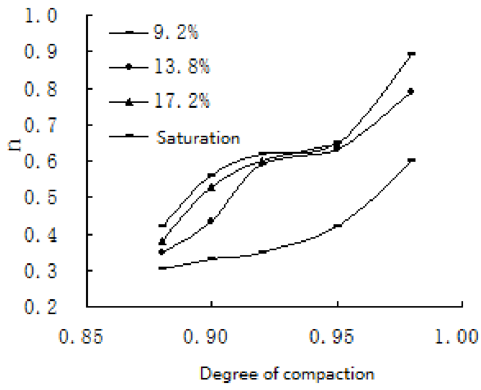

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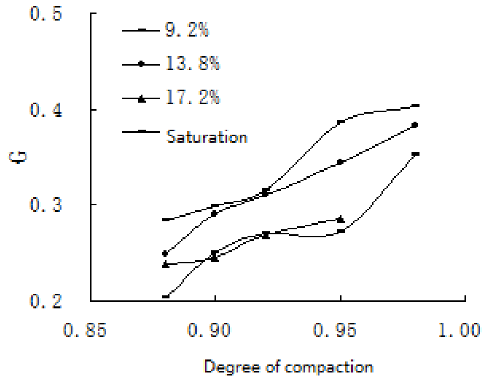


(e)

Fig. 6 Duncan-Chang E-μ model parameters with the compaction degree

The Fig. 5 (a) and (b) show that the soil shear strength has an obvious correlation with the water content. The shear strength is smaller with the higher water content. This is because that the increase of water content will cause decrease of the matrix suction in soil, which is characterized by the negative pore water pressure generally. The increase of water content will make Daxigou loess wetting and the strength of the soil reduce.

The influence of water content on the cohesive force is more obvious than the internal friction angle. For example, as compaction degree is 0.88, the water content increased from 9.2% to 13.8%, the cohesive force rapidly reduced from 40kPa to 20kPa. However, internal friction Angle relegated from 29.9° to 29.7°. The reduction is small. This is similar to the mechanical properties of other region loess. It has a very high water absorption when the loess is in the condition of low water content. Loess having a very high water absorbing water in low moisture content state can lead to that soil particles softens and cohesion become smaller. While water absorption leads to inter-particles water film thicker and increase the distance between the particles, the internal friction angle becomes small.

We can find that the relationship of water content and the cohesive force approximate a quadratic function, and the internal friction angle approximate a linear relationship. Considering the mutual influence of both water content and degree of compaction, the effective stress strength index formula of Daxigou loess is deduced.

$C = a\omega^2 + b\omega + ce^n + f(e,\omega) + d$

$\phi = a'\omega + b'e^n + f'(e,\omega) + c'$

In the formula，e、ω——pore ratio、water content；

a、b、c、n——the test constant related to the C ；

a'、b'、c'——the test constant related to the φ.

The Duncan-Chang model shows some regularity of the changes of water content and compaction degree. k decreases with the increasing of water content under the same compaction degree, increases with the increasing of water content. F and D with the changes of water content are not obvious.

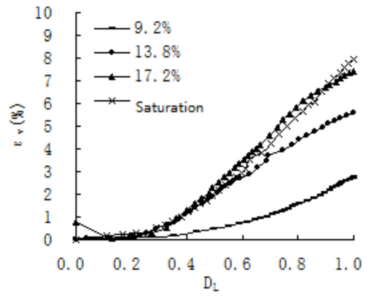
K、n、R_f、C、ϕ、G all increase with increasing of compaction degree under the same water content. The changes of F and D with compaction degree are not obvious. This means that the tangent modulus of elasticity Et and volume deformation modulus Bt increase quickly with the increasing of dry density. So we must strictly control the related indexes, such as compaction degree in engineering construction.

3.4 The influence of stress level on wetting deformation

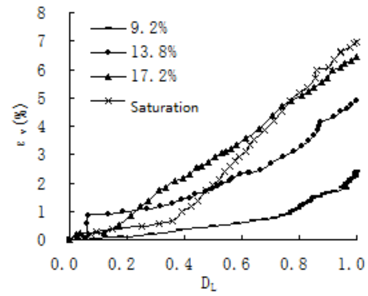
The soil forms wetting deformation because of the change of stress and strength after soaking. There are many influence factors of wetting deformation. In this paper, the influence of stress level on wetting deformation of Daxigou loess was analyzed based on the theory of double line method using conventional triaxial test.

3.4.1 The relation of Stress level and Volume strain

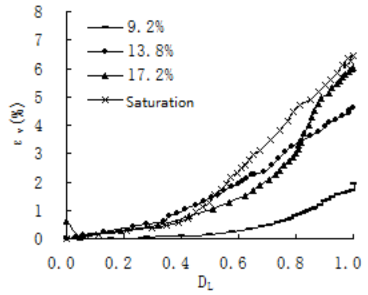
We can regard the gap of primary stress with 15% axial strain as $(\sigma_1 - \sigma_3)_f$, when the stress-strain curve is the hardening type curve. We can regard the max of $\sigma_1 - \sigma_3$ as $(\sigma_1 - \sigma_3)_f$, when the stress-strain curve is the softening type curve. We can obtain any primary stress gap corresponding to the stress level $D_L = (\sigma_1 - \sigma_3)/(\sigma_1 - \sigma_3)_f$.



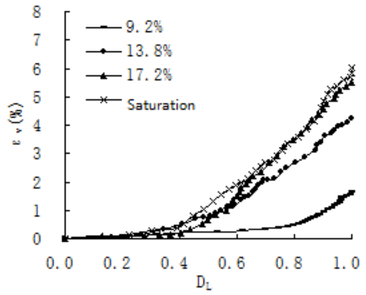
(a) Compaction degree 0.88



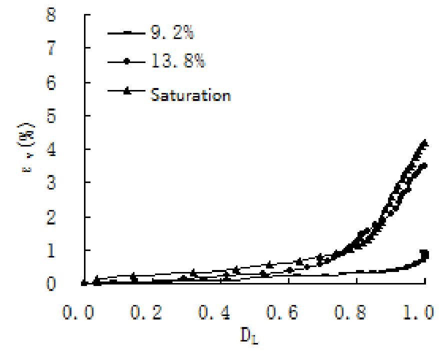
(b) Compaction degree 0.90



(c)Compaction degree 0.92



(d) Compaction degree 0.95



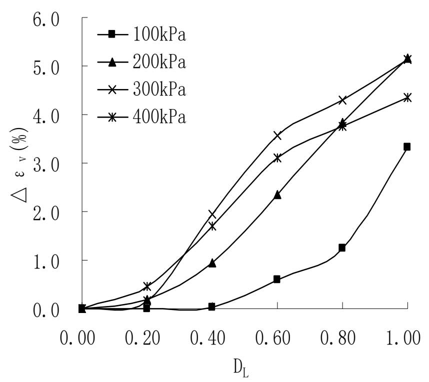
(e) Compaction degree 0.98

Fig. 7 Stress levels - body strain curves of 200kPa confining pressure

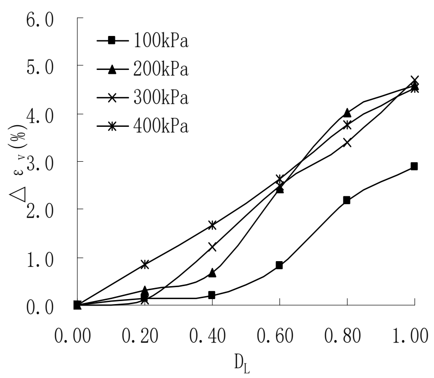
According to the stress levels -volume strain curves of different degree of compaction with confining pressure 200kPa (Fig.9), we can get the following conclusions.

(1) The volume strain increased with the increasing of stress level. When the stress level is lower, the volume strain increases slowly. When the stress level increases to a certain value, with the increasing of stress level, the speed of shear strain increases faster, and an inflection point appears. With the increasing of the confining pressure, the inflection point turns left and the critical stress level decreases under the same initial water content.

(2) The volume strain increases with the increasing of the initial water content under the same confining pressure and the same stress level. The influence of initial water for volume shear is more apparently when the water content is small at the lower confining pressure, but the curve is almost unanimous when the water content is close to the saturated water content.



(a) Compaction degree 0.88



(b) Compaction degree 0.90

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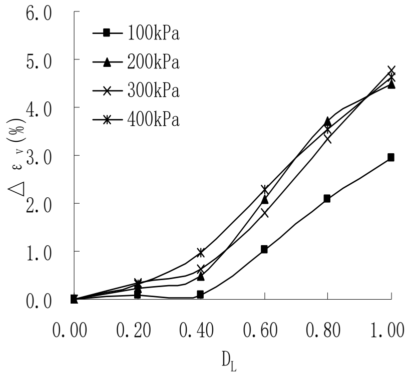
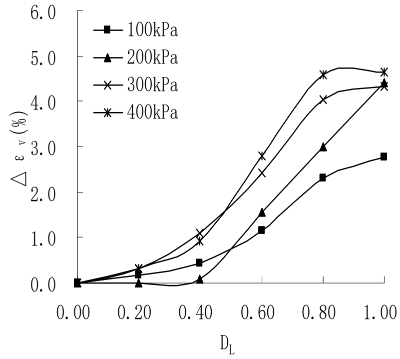
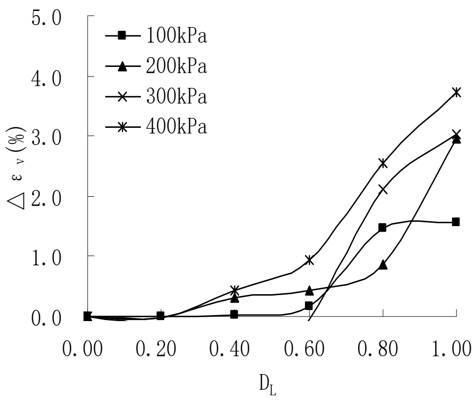


(c) Compaction degree 0.92



(d) Compaction degree 0.95

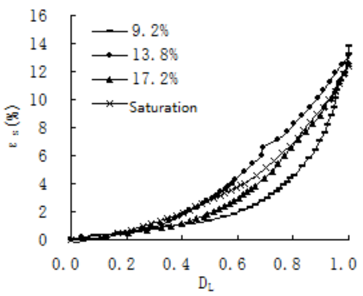


(e) Compaction degree 0.98

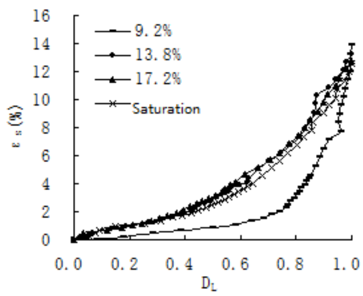
Fig. 8 D_L - $\Delta\varepsilon_v$ curves of different compaction degree

Fig. 8 shows that, under the same compaction degree, $\Delta\varepsilon_v$ increases with the increasing of stress level. Under the lower stress level, $\Delta\varepsilon_v$ increases more slowly. After the stress level increases to a certain value, $\Delta\varepsilon_v$ increases rapidly and the inflection point appears. All of the inflection point is close under different compaction degree, about D_L =0.6. The volume strain $\Delta\varepsilon_v$ has an increased trend with the increasing of confining pressure.

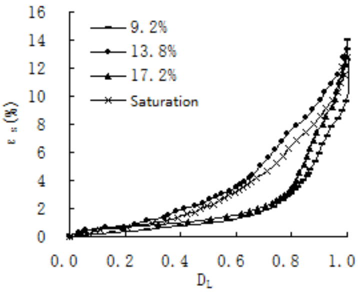
3.4.2 The relation of Stress level and Shear strain



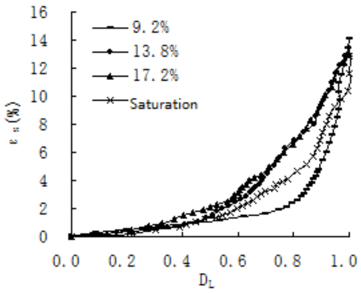
(a) Compaction degree 0.88



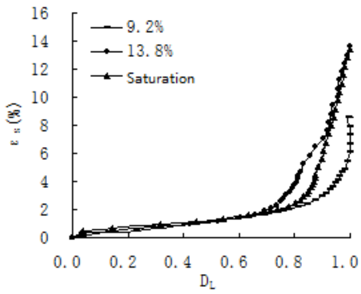
(b) Compaction degree 0.90



(c) Compaction degree 0.92



(d) Compaction degree 0.95



(e) Compaction degree0.98

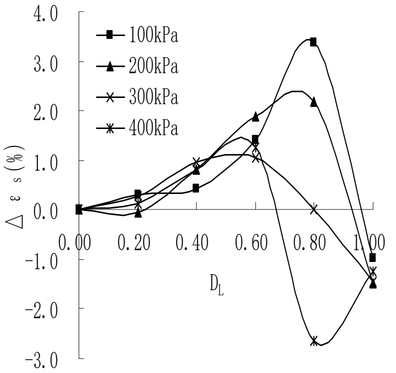
Fig. 9 Stress level - shear strain curves of 200kPa Confining pressure

According to the stress levels - shear strain curve of different degree of compaction with confining pressure 200kPa (Fig.9), we can get the following conclusions.

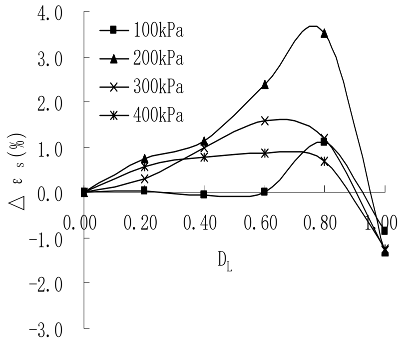
（1）The shear strain increased with the increasing of stress level. When the stress level is lower, the shear strain increases slowly. When the stress level increases to a certain value, with the increasing of stress level, the speed of shear strain increases faster, so there is a transition region. With the increasing of confining pressure, the transition region turns left and the critical stress level decreases until it is not obvious at the same initial water content.

（2）The shear strain increases with the increasing of the initial water content under the same confining pressure the same stress level. The influence of initial water for volume shear is more apparently when the water content is small at the lower confining pressure, but the curves are almost coincided when the water content is close to the saturated water content. The curves show more uniform with the change of water content at a high confining pressure.

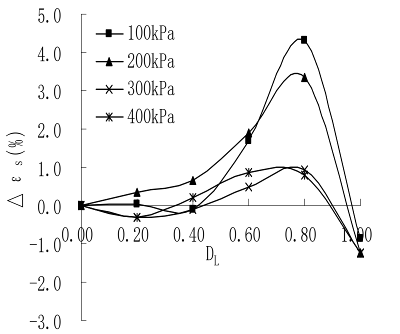
（3）The shear strain has a normalized tendency with the increasing of stress level under the same confining pressure and different initial water content. When the stress level reaches to 1, the gap of the shear strain under different initial water content is smaller.



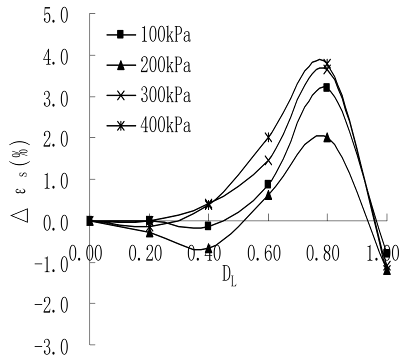
(a)Compaction degree0.88



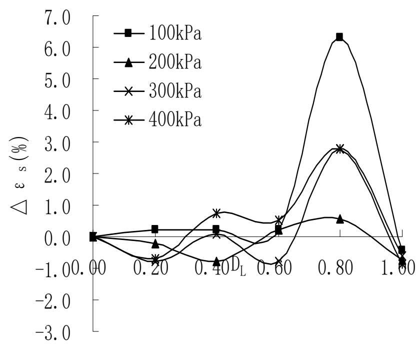
(b)Compaction degree0.90



(c) Compaction degree0.92



(d) Compaction degree0.95



(e) Compaction degree0.98

Fig. 10 D_L - $\Delta\varepsilon_s$ curves of different compaction degree

Fig.10 shows that $\Delta\varepsilon_s$ has an increasing trend with the increasing of confining pressure under the same degree of compaction. Under the same water content, the greater the degree of compaction, the greater the $\Delta\varepsilon_s$. When the stress level is low, $\Delta\varepsilon_s$ increases more slowly. when the degree of compaction is large, $\Delta\varepsilon_s$ shows ups and downs, fluctuating around 0. After the stress level arrived at a certain level, $\Delta\varepsilon_s$ increases rapidly. When DL=0.8, $\Delta\varepsilon_s$ is maximum. When DL>0.8, $\Delta\varepsilon_s$ reduces quickly to negative side.

4. Conclusions

In this paper, the compaction characteristics, compression characteristics, strength properties and wetting deformation characteristics of loess in Xinjiang Daxigou dam were analyzed. It provides reservoir parameters for the construction of Daxigou and a parameter model for the local similar engineering construction. At last, we get the following conclusions.

（1）The compaction work has a great influence on the dry density. 25 times is the most reasonable compaction times considering the safe and economic consideration. The increasing of compaction function will lead to the optimal water content decreases, so more attention must be paid to control water content in practical engineering.

（2）The soil compaction degree has a great influence on compression. Firstly, the compression coefficient reduces rapidly with the increasing of pressure. When the pressure reaches a certain degree, the turning points appears. Compression modulus Es increases with the increasing of pressure and degree of compaction.

（3）The relationship of water content and the cohesive force approximate a quadratic function, while the internal friction angle approximate linear relationship. Considering the mutual influence of both water content and degree of compaction, the effective stress strength index formula of Daxigou loess were deduced.

（4）The parameters of Duncan-chang mode shows some regularity with the change of water content and degree of compaction. The degree of compaction has a great influence on the parameters of Duncan-chang mode, so we must strictly control the related indexes such as compaction degree in engineering construction.

（5）The stress level has a significant effect on wetting deformation, and the influence degree is closely related to the degree of compaction.

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References

[1] Wang XG, Xing YC, Zhao JM. Geotechnical engineering problems associated with construction of water resource projects in western China [J]. Chinese Journal of Geotechnical Engineering, 2007, 29(8): 1129–1134. (in Chinese)
[2] NAKATA Y, HYODO M, HYDE A F L. Microscopic particle crushing of sand subjected to high pressure one-dimensional compression [J]. Soils and Foundations, 2001, 41(1): 69–82.
[3] NAKATA Y, KATO Y, HYODO M. One-dimensional compression behavior of uniformly graded sand related to single particle crushing strength[J]. Soils and Foundations, 2001, 41(2): 39–51.
[4] Liu DS. The loess and dry environment[M].Hefei: Anhui science and technology press, 2009.03.
[5] Zhou TR. Quaternary continental sedimentary main types of Xinjiang and its relationship with landform climate development[J].ACTAGeographica Sinica.1963,29(2),109-129.
[6] Su H,Wen QZ. The quaternary sedimentary geochemical characteristics in northern Xinjiang[J].Geochimica,1991,(1),56-63.
[7] Zhang HY,Wen HZ. New findings in the study of loess in Xinjiang [J]. The geological knowledge,1985(8),19-20
[8] Teng ZH. Some of the characteristics of loess and its forming conditions in Xinjiang preliminary understanding[J].Journal of northwest university (natural science edition),1986,16(1),69-76.
[9] Gao CH, Liu JQ. The research of Urumqi river basin loess[J]. Quaternary Sciences.1990,(3)，251-260.

[10] Zhao XY, Maimai TY, Liu JQ, Luo J. Since middle of late pleistocene kerry river basin in the loess sedimentary characteristics and environment evolution[J].Arid Land Geography.1993,18(1).
[11] Zhao XY. Kerry ya river mineral assemblage characteristics of loess and environmental significance[J]. Arid Land Geography.1997,20(3).
[12] Yu SH,Wen QZ. The geochemical features of rare earth elements in xinjiang region on the loess[J]. Arid Land Geography.1994,17(2),75-82.
[13] Fang XM, Shi ZT,Yang SL,Li JJ,Jiang PG. Tianshan loess and GuErBanTongGuTe desert development and drying of northern xinjiang[J].Science bulletin. 2002,47(7),540-545.
[14] Shi ZT, Dong M, Fang XM. The characteristics of later pleistocene loess-paleosol magnetic susceptibility in Yili Bason[J]. Journal of Lanzhou University(Natural Sciences).2007,43(2),7-10.
[15] Ye W, Jin HL. Depositional features and material sources of loess in Yili region,Xinjiang[J]. Arid Land Geography.1998,21(4),1-8.
[16] Ye W. Study on Magnetic Susceptibility of Loess and Paleosol Sequences in Westerly Region of Xinjiang[J]. Journal of desert research.2001,21(4),514-520.380-386.
[17] Ye W, Sang CQ, Zhao XY. Spatial-Temporal Distribution of Loess and Source of Dust in Xinjiang [J]. Journal of desert research.2003,23(5),514-520.