Experimental Study on Dynamic Properties of Loess in Xining Area under Cyclic Loading

Xiao Jin[1], Li Hui[1*], Zhang Shanjun[2], Jiang Ningshan[1], Ma Yanya[1]

[1]School of Civil Engineering, Qinghai University, Xining 810016, Qinghai;

[2]Faculty of Science, Kanagawa University, Kanagawa 3-27-1, Japan.

[*]Corresponding author: huili_cug@hotmail.com

Abstract: In order to study the dynamic characteristics of unsaturated loess in Xining area, this paper use GDS dynamic triaxial apparatus conduct the dynamic triaxial test indoor, the effects of different vibration times, water content and consolidation ratio on the hysteresis loop, dynamic elastic modulus and axial strain of unsaturated loess in Xining area were studied. The results show that: when the vibration times increase, the hysteresis loop from strain axis left moves to right and from sparse become tight; The higher moisture content and consolidation ratio, the hysteresis loop is nearer to large strain direction; With the increase of moisture content, the dynamic elastic modulus decreases of unsaturated loess, and the axial strain increases; With the increase of consolidation ratio, the dynamic elastic modulus and axial strain also increases. The dynamic elastic modulus and consolidation ratio have the same features of increase or decrease, axial strain, moisture content and consolidation ratio also have the same features of increase or decrease. The research results can provide reference for the study of dynamic characteristics and disaster prevention and mitigation of unsaturated loess under traffic load.

1. Introduction

The loess is a kind of yellow powdery soil with columnar joints formed in dry climatic conditions, it distribution area is quite extensive, mainly distributed in Qinghai, Gansu, Shanxi, Shanxi, Ningxia, etc. Among them, the distribution area of loess in Qinghai Province is 24,800 km^2[1]. With the implementation of China's western development strategy, the western economy has been promoted unprecedentedly. The construction of roads and railways has reached a new height, and the construction of roads and railways inevitably passes through the loess area. Therefore, people are also increasingly concerned about the research on the engineering properties of loess under the action of traffic loads, especially the study of its dynamic characteristics.

At present, Huang Bo, Ding Hao etc [2] studied the dynamic characteristics of soft soil by using half-sine wave simulated train load. Mu Kun and Guo Aiguo etc [3] studied the dynamic constitutive relation and the attenuation law of dynamic modulus of red clay in the original structure. However, most studies have been conducted on the dynamic characteristics of soft soil, clay and other saturated soils under the action of earthquakes, traffic and wave loads, and less research on the dynamic characteristics of unsaturated unsaturated loess [4-5]. The loess has a strong structure, and the change of external factors has a great influence on its strength and deformation, especially in the long-term cyclic load such as traffic loads, the damage will be more pronounced [6-8]. This article will use GDS dynamic triaxial apparatus to simulate the effect of long-term cyclic loading on the dynamic characteristics of unsaturated loess in Xining area, the change of the dynamic characteristics of

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unsaturated loess under different influence factors is discussed to make up the deficiency of this research. The study of the dynamic characteristics of unsaturated loess not only has a certain reference value for the correct analysis of its engineering nature, disaster prevention and mitigation, but also has a far-reaching impact on the improvement of people's living standards and rapid economic development in the western region [9].

2. Dynamic triaxial test

In this experiment, the British GDS dynamic triaxial test instrument is adopted, which consists of the following systems: the driving device, the pressure chamber cover and the balance hammer; confining pressure controller; anti-pressure controller; signal regulating device; high speed data acquisition and control card (HSDAC) or GDSDCS- light control system. GDS dynamic triaxial instrument built-in pressure sensor, no correction, high software integration, is a perfect combination of hardware and software, with more accurate stress, strain control mode and other advantages.

2.1 The test soil samples and preparation

The soil sample was taken from the vicinity of Haihu Road, Qinghai University, in Xining City, Qinghai Province. The soil depth was 4 m, artificial exploration wells were used to take soil. The soil samples taken out were wrapped in cling film, the joints were sealed with clear plastic, and then the soil samples were placed in a special soil sampling box and shipped back to the laboratory. The basic physical properties of the loess samples taken are shown in table 1.

Tab. 1 Basic physical indices of loess samples

Moisture content /%	Density/（$g\cdot cm^{-3}$）	Optimal moisture content /%	Maximum dry density /（$g\cdot cm^{-3}$）	Liquid limit /%	Plastic limit /%	Plasticity index
12.5~13.5	1.59	15.4	1.73	25.5	13.9	11.6

Place the recovered natural loess clods on the soil compactor and cut the specimens required for the test, observe the level and color of the soil samples during the cutting process, whether there are impurities, wormholes, whether the soil is even or whether there is cracks. Then use the water film transfer method to prepare the required moisture content according to the test requirements, after the fitting, it is kept in a sealed maintenance mold. And let it stand for at least 3 days. The purpose is to make the moisture as uniform as possible in the sample, the preparation of samples is shown in figure 1.

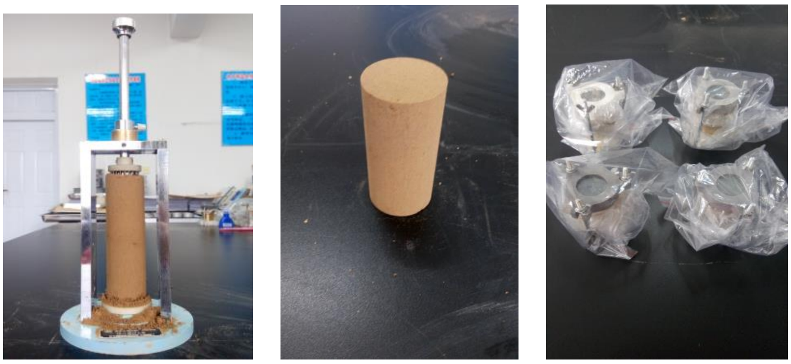


Fig. 1 The preparation process of sample

2.2 Test plan and steps

Usually, the traffic load can be simulated sine wave, half sine wave or triangle wave, irregular wave, undrained test is mostly simulated by sine wave, and the drainage test is generally simulated by half sine wave. In this test, a consolidated undrained test method was used, a sine wave was used to simulate the traffic load, and a dynamic triaxial cyclic test loading method was used for load control. The loading frequency is 3 Hz, the vibration amplitude is 20 kPa, and the number of vibrations is 5

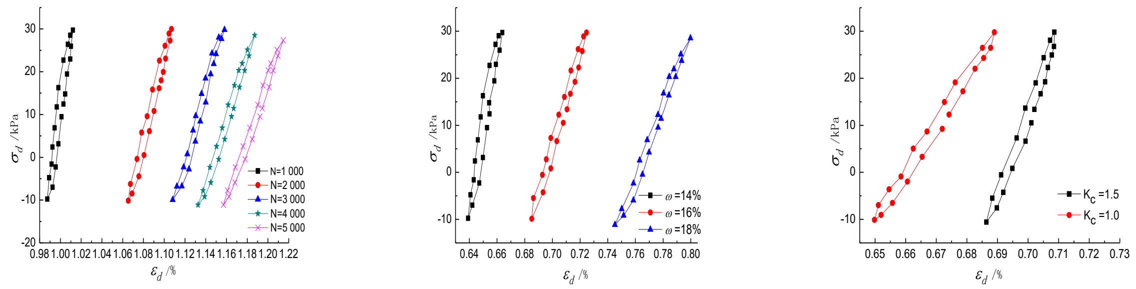
000. The test confining pressure is 100 kPa. The two consolidation methods are equal pressure and bias. The consolidation ratio is 1.0 and 1.5, and the moisture content is 14%, 16%, and 18%.

First, the sample was installed, then 100 kPa confining pressure was applied to the pressure consolidation, according to the consolidation and stability criteria in the geotechnical test regulations (SL237-1999) [10]. when the change of consolidation and drainage within 1 h is less than or equal to 0.1 cm^3 consolidation is completed. The pressure consolidation is before bias consolidation, after the isostatic consolidation is applied, the axial pressure is applied at a predetermined axial strain rate, when the axial pressure is 150 kPa, the bias consolidation is completed. During the consolidation process, the drainage valve is always open. After the consolidation is completed, the dynamic load is applied to start the vibration, the test terminated when the number of vibrations reaches 5,000, and the drain valve is closed during vibration.

3 Test results and analysis

3.1 Hysteresis loop analysis

The soil is a non-ideal elastomer and its dynamic stress (σ_d) waveform is not synchronized with the dynamic strain (ε_d) waveform, the dynamic strain waveform lags behind the dynamic stress waveform in time. The corresponding dynamic stress and the dynamic strain value at the same moment in each period are the hysteresis curve [11]. The curves of σ_d-ε_d under different vibration frequency (N), different moisture content (ω), and different consolidation ratio (K_c) are shown in Fig.2.



(a) Different vibration times (b) Different moisture content (c) Different consolidation ratio

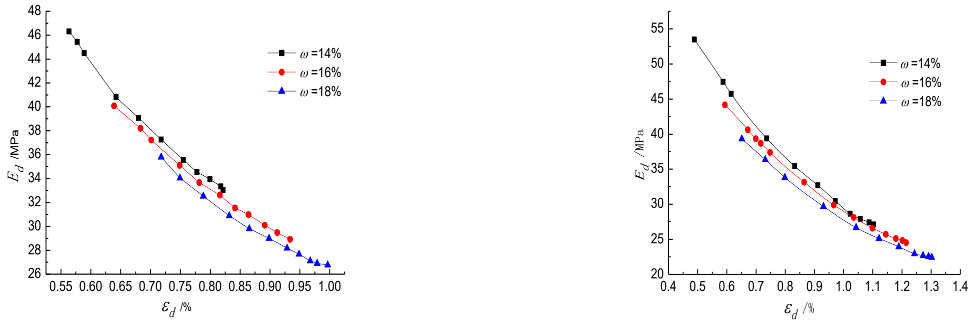
Fig. 2 The curves of σ_d-ε_d under different test conditions

It can be seen from fig. 2 that, under different conditions, the σ_d-ε_d is different, in the increasing process of N from 1, 000 to 5, 000 times, the hysteresis loop is closely spaced, and every 1,000 intervals between the two hysteresis loops are also shrinking. This is because ε_d increases rapidly when the vibration is just started, and the rate of ε_d increases gradually as N increases. When the water content and the consolidation ratio increase, the hysteresis loop moves from the left side of the strain axis to the right side, The higher the water content and the consolidation ratio, the closer the hysteresis loop is to the place where the strain is large (that is the right side of the strain axis). Because when the moisture content and the consolidation ratio increase, the σ_d is constant but the ε_d is increasing. Because the unsaturated loess in this area belongs to silty clay, its complex viscoelastic plasticity leads to the σ_d-ε_d curve is not completely closed [12].

3.2 Dynamic elastic modulus analysis

The dynamic elastic modulus (E_d) is equal to the ratio of σ_d and ε_d when the soil is in the elastic deformation stage, that is, the slope of σ_d-ε_d curve. Fig. 3 and fig. 4 are the curves of E_d - ε_d under different test conditions.

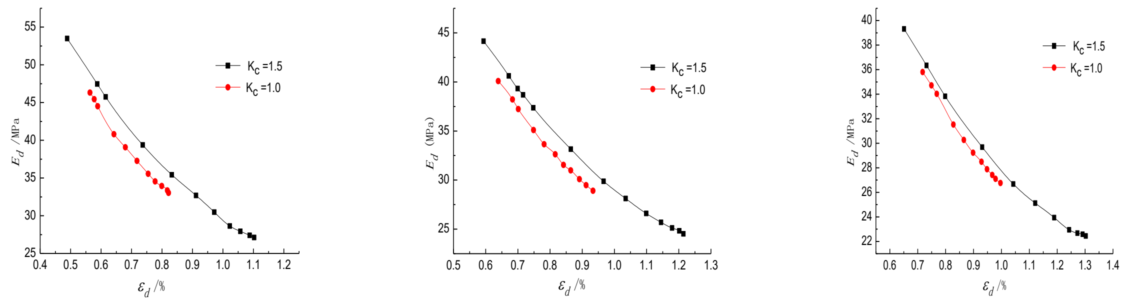
Fig. 3 shows that, when the moisture content is constant, the E_d of unsaturated natural loess has significant strain softening characteristics. E_d decreases nonlinearly as ε_d increases, and E_d decreases faster when ε_d is smaller; E_d decreases as ε_d continues to increase. When the consolidation ratio is constant, the same ε_d is generated, E_d decreases as the moisture content increases. The reason for this phenomenon is that when the moisture content continuously increases, the dynamic strength of the unsaturated natural loess decreases, and its structure also becomes more easily destroyed. Therefore, if we do not change σ_d, the moisture content is higher, the ε_d will be larger, and the E_d will be smaller.



(a) K_c =1.0 (b) K_c =1.5

Fig. 3 The curves of E_d -ε_d under different moisture content

Figure 4 shows that when the consolidation ratio is constant, the E_d nonlinearity decreases as ε_d increases, and as ε_d increases continue, the decreasing trend of E_d slows down. When the moisture content is constant, the same ε_d is generated, E_d increases as the consolidation ratio increases, and E_d increases and decreases with the consolidation ratio. The reason for this phenomenon is that the greater the consolidation ratio, the denser the soil is squeezed, and the larger σ_d is needed to produce the same ε_d, therefore, σ_d increases when ε_d is constant, which leads to an increase E_d.

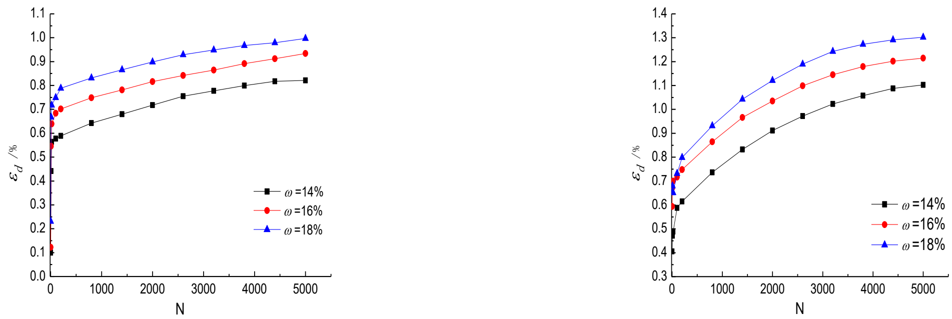


(a) ω=14% (b) ω=16% (c) ω=18%

Fig. 4 The curves of E_d -ε_d under different consolidation ratio

3.3 The curves of ε_d -N analysis

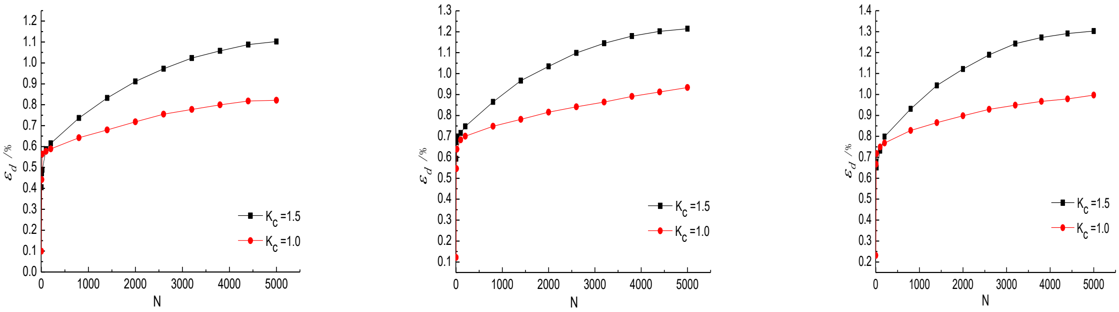
Fig. 5 and fig. 6 are the curves of the axial strain ε_d and the number of vibrations N under different test conditions From fig. 5, it is known that at the same moisture content, ε_d increases as N increases, and ε_d increases rapidly in the initial period of vibration, and it basically rises linearly, as N increases, the rate of increase of ε_d slows down and eventually becomes stable. This is in line with the actual situation. the road embankment sinks faster at the beginning of the journey, and then the rate of sinking slows down, eventually, it basically stabilizes and no longer sinks. When the consolidation ratio is constant, in the same situation as N, with the increase in the moisture content, the ε_d increases. This is because the moisture content increases, the strength of the soil decreases, and if σ_d is the same, a larger ε_d will be generated. From a general point of view, the biased consolidation is significantly faster than the increase in the isobaric consolidation ε_d at each moisture content.



(a) K_c =1.0 (b) K_c =1.5

Fig. 5 The curves of ε_d -N under different moisture content

As shown in fig. 8, the same consolidation ratio increases ε_d with N, and N has a turning point, the ε_d rises in a straight line between the initial vibration and the turning point. the increase is very fast. After the turning point, the rate of increase of ε_d is getting slower as N continues to increase, finally, it basically stabilizes. When the moisture content is constant, the ε_d increases with the increase of the consolidation ratio when N is constant, and the rate of biased consolidation is much faster than that of isobaric consolidation. Because when the other conditions are not constant, if the consolidation ratio is larger than the large soil samples will be compacted, the initial axial vibration stress will be large, and the resulting ε_d will increase accordingly, this causes a significant increase in ε_d in the following vibrations



(a) ω=14% (b) ω=16% (c) ω=18%

Fig. 6 The curves of ε_d-N under different consolidation ratio

4. Discussion and conclusion

Liu Xiaohong, Yang Guolin etc [13] studied the dynamic constitutive relation and dynamic modulus attenuation model of red clay under cyclic loading, but did not deal with the dynamic properties of unsaturated loess. Different types of soil structure and properties are different, and the experimental results will make a great difference. This paper studies the influence of different experimental conditions on the dynamic characteristics of unsaturated natural loess under traffic loads. The results show that the relationship between dynamic stress and dynamic strain of unsaturated natural loess is nonlinear; The dynamic elastic modulus decreases nonlinearly with the increase of the dynamic strain, and has a significant strain softening characteristic; The dynamic strain increases nonlinearly with the vibration. The accuracy of the GDS dynamic triaxial apparatus is very high. Using it for testing, the recorded data is more accurate and the results obtained are closer to the actual situation, it can greatly improve the accuracy of engineering design, thus saving engineering cost. The dynamic characteristics of unsaturated loess under the traffic load are very complicated and affected by many factors. Only a few factors have been studied in this paper, the dynamic characteristics of multi-factor coupling need to be further explored.

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