Dynamic Performance of High Liquid Limit Clay under Vehicle Load

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Abstract. High liquid limit clay is widely distributed in China with its special properties. GDS dynamic triaxial test was carried out to investigate its dynamic response under vehicle load in the article. The response law of the accumulative strain and plastic modulus of the high liquid limit clay under different dynamic stress amplitude, cycle times, compaction, water content and confining pressure was attained. The research results have important reference value for the design of high liquid limit clay subgrade.

Keywords. High liquid limit clay, vehicle load, critical dynamic stress, accumulative strain.

1. Introduction
There are a large number of clays with high natural water content, high liquid level and high plasticity in the southwest China, such as Yunnan, Guangxi, Hunan, Shandong and Henan provinces and autonomous regions. The red clay is the most typical in Southwest China, and the alluvial and silting cohesive soil in the yellow River flood area is the main one in the eastern region. The high liquid level clay is widely distributed in Guangxi. High liquid level soil has higher silt and clay content, low strength and large deformation [1-2].Generally, subgrade soil is prone to subsidence and deformation under the action of traffic load, but the dynamic stability of subgrade soil is not fully considered in the design of highway subgrade. The bearing capacity and deformation of subgrade soil under traffic load is one of the key points of subgrade filling quality control. Scholars at home and abroad have carried out some research on this problem. Based on the dynamic shear strain parameters, Hu Yifeng [3] analyzed the long-term dynamic stability of Tertiary sedimentary clay in Nuremberg, Germany, and determined whether to replace the soil and the long-term dynamic stability index based on the determination of replacement depth by resonance column test. Okur D V [4] carried out a large number of dynamic triaxial tests and considered that the plastic index and confining pressure should be combined to determine the development of cumulative deformation. In order to analyze the influence of traffic load on the cumulative deformation of soil, Gibel [5] proposed an analysis method based on the correlation function of traffic load characteristics and soil strength characteristics. Based on Gibel's research, Abedelkrim [6] considered the effect of residual stress on cumulative deformation. Compared with ordinary cohesive soil, Guangxi high liquid limit clay is difficult to lose water, difficult to compact, and has low strength [7]. Under dynamic load, it shows different dynamic characteristics with ordinary clay.
In this paper, GDS dynamic triaxial test was adopted to simulate the variation law of high liquid limit clay subgrade performance with vehicle load (dynamic stress amplitude), cycle times, compaction degree, water content, confining pressure (subgrade buried depth) under vehicle load, which provides reliable reference for enriching dynamic parameter system of subgrade design of high liquid limit clay.

2. Test Sample and Experimental Plan

2.1. Soils Physical Properties

The soil samples were taken from Wuning County, Nanning, Guangxi province. According to the JTGE40 2007 [8], the basic physical properties of the soil measured are shown in table 1.

| Proportion Natural moisture content/% | Liquid limit/% | Plastic limit/% | Plasticity index | Optimal moisture content/% | Maximum dry density/g·cm⁻³ | Free expansion rate/% |
|-------------------------------------|---------------|----------------|------------------|--------------------------|--------------------------|---------------------|
| 2.56                                | 44.1          | 54.9           | 30.1             | 24.8                     | 24.6%                    | 1.60                | 32.6                |

2.2. Test Scheme

Using GDS dynamic triaxial test equipment, wet preparation and static pressure method are used to form remolded test samples. The influence of vehicle load (stress amplitude), confining pressure (subgrade buried depth), compactness, water content, cycle times and other conditions are mainly considered when applying load. The test conditions of design conditions are as follows: (1) the moisture content of subgrade construction is controlled as the optimal moisture content ± 2% in the code The test moisture content is 22.6%, 24.6% and 26.6%; (2) the compaction degree of roadbed is not less than 94% according to the specification, and 92%, 94% and 96% are taken into account of the variability of site construction; (3) considering the buried depth of subgrade within 10 m, the test design confining pressure is 50 kPa, 100 kPa and 150 kPa respectively; (4) considering the influence of different vehicle load on subgrade, the design is 10, 20, 30 and 40 kPa respectively Dynamic stress amplitude.

3. Test Results and Analysis

3.1. Critical Dynamic Stress

It can be seen from figure 1 that the variation curve of cumulative strain with different dynamic stress amplitude (10 kPa, 20 kPa, 30 kPa and 40 kPa) with cycle times under 50 kPa confining pressure and 1 Hz vibration frequency. when the dynamic stress amplitude is small (10 kPa), the cumulative of plastic strain of the sample increases linearly with the cycle number, but the increase is slow, which indicates that the sample is in the process of gradual compaction when the stress amplitude is low. After loading to a certain number of cycles, it can be considered that the specimen has reached the state of strain stability, which is called "stable type" curve.

As the stress amplitude increases (30 kPa, 40 kPa), The strain of the sample also increases obviously with the increase of the cycle number at the beginning of vibration, and the greater the stress amplitude is, the faster the strain growth rate is. When the cyclic vibration reaches 200 times), the slope of the curve increases sharply, which indicates that the internal deformation of the sample changes rapidly from initial compaction to plastic damage until the specimen is destroyed Lines are called "failure" curves. When the dynamic stress amplitude is between 10 kPa and 30 kPa, the variation law of strain versus cycle curve is between the above two cases, which indicates that there is a critical stress amplitude when the specimen changes from strain stability to plastic failure. It is preliminarily known that the value is in the range of 10 kPa-30 kPa, which is called "transitional" curve.
Figure 1. Strain versus cycle curves.

It can be seen from the analysis of the dynamic elastic modulus data of the high liquid limit clay samples under different dynamic stress amplitudes in Figure 2, when the stress amplitude is constant, the dynamic elastic modulus gradually decreases to a certain stable value. When the stress amplitude is 10 kPa and 20 kPa, the dynamic elastic modulus of the sample is between 80 MPa and 90 MPa, which is much larger than the stable value (50 MPa-60 MPa) corresponding to the dynamic stress amplitude of 30 and 40 kPa. The dynamic elastic modulus is the comprehensive reflection of the soil resistance to deformation under cyclic load. It can be further determined that the critical dynamic stress amplitude is between 20 kPa and 30 kPa. In addition, the vibration cycles required for the dynamic elastic modulus to reach the stable value have little relationship with the change of stress amplitude, which tends to be stable when N=500, and the subgrade soil can keep dynamic stability within the dynamic stress amplitude of each test. In addition, the larger the dynamic elastic modulus is, the smaller the dynamic elastic modulus of high liquid limit clay is. The dynamic stress amplitude increases from 10 kPa to 40 kPa, and the stable value of dynamic elastic modulus decreases from 90 MPa to 50 MPa, with a decrease of more than 45%.

Figure 2. Relationship between dynamic elastic modulus and cycle times under different dynamic stress amplitudes.

3.2. Influence of Compaction Degree

It can be seen from the analysis of the cumulative strain curve with the number of cycles under different compaction degrees shown in Figure 3. When the compaction degree is less than 96%, the strain development curve can be divided into two stages: strain surge and strain stability. When the compactness is equal to 96%, the strain increases linearly as the number of cycles increases, and the cumulative strain is only 45% of the cumulative strain with 90% compaction degree when the vibration number N=3000. Figure 4 shows the curve of cumulative strain changing with compaction degree under different vibration times. Figure 4 also shows that when the compactness is 90%, the cumulative plastic strain is affected by both vibration cycles and compactness. When the compactness
increases to 96%, the amplitude of cumulative strain under different vibration times is low and the change is small, which is mainly controlled by compaction degree. The curve of dynamic elastic modulus with cycle times under different compactness is shown in figure 5. Under the same test dynamic stress time condition, the dynamic elastic modulus of the test sample increases with the increase of the degree of compaction, the degree of compaction increases from 90% to 96%, and the stable value of the dynamic elastic modulus of the sample increases by about 40%.

**Figure 3.** Cumulative plastic deformation changes of soil samples with different compaction degree.

**Figure 4.** The curve of cumulative strain changing with compaction degree under different vibration times.

**Figure 5.** Variation of dynamic elastic modulus with compaction degree of soil sample.

From the above data analysis, it can be seen that the deformation characteristics and dynamic elastic modulus of the roadbed are very sensitive to changes in the degree of compaction. Therefore, in the process of subgrade filling, in order to reduce the adverse impact of accumulated plastic
deformation under traffic load on the subgrade, the subgrade compactness should be strictly controlled (the compactness should not be less than 96%).

### 3.3. Influence of Water Content

Water content is an important factor that affects the dynamic characteristics of high liquid limit clay roadbeds. It can be seen from the figures 6-8 that under 50 kPa confining pressure, 30 kPa dynamic stress amplitude and 1 Hz vibration frequency, the samples with moisture content of 22.6%, 24.6% and 26.6%, respectively, change with the cumulative plastic deformation of the vibration cycle. Figure 6 also shows that when the water content is 22.6% (2% lower than the optimal moisture content), the stable value of cumulative strain is only 26.6% (higher than the optimal moisture content of 2%) When the water content is low, the change range of cumulative strain with vibration number is small, and the amplitude of strain variation is small, which indicates that the stability of the sample under cyclic loading is higher when the water content is low. As the water content increases, the cumulative strain is controlled by vibration times and water content.

![Figure 6. Variation of cumulative plastic strain with cycle times.](image1)

![Figure 7. The change of dynamic elastic modulus with different water content](image2)
In the actual subgrade filling process, the moisture content has a great impact on the compaction quality. The current standard generally requires that the filling moisture content should be controlled within the range of 2% of the optimal moisture content. According to the experimental research results of this article, the dynamic elastic modulus and cumulative strain of the sample are sensitive to the change of moisture content, and the subgrade filling effect is the best when the moisture content is 22.6%. Therefore, it is recommended that the water content of the high liquid limit clay roadbed filler is two percentage points lower than the optimal water content.

3.4. Influence of Confining Pressure
In practical engineering, the confining pressure of soil varies with the depth of the stratum. Therefore, it is particularly important to consider the influence of confining pressure on soil dynamic characteristics in practical applications, especially for high-filled roadbeds [9-10]. Cyclic load tests were performed on soil samples under 3000 vibrations and different confining pressure conditions. The experimental results are shown in figure 9, and the development law of cumulative plastic strain of high-liquid limit clay samples under confining pressure is obtained. The experimental results show that as the confining pressure increases, the double-amplitude strain and cumulative plastic strain decrease significantly, and the attenuation amplitude is very small at a confining pressure of 100 kPa. Moreover, under the condition of confining pressure of 150 kPa, the double amplitude strain and cumulative plastic strain of different vibration times tend to be stable gradually. The confining pressure of 100 kPa is approximately equivalent to the stress state of the subgrade soil with buried depth of 4-5 m. Therefore, in the actual design and application construction process, the impact of dynamic load on subgrade soil with a buried depth of more than 4m cannot be considered.
4. Conclusion
(1) The test results and data analysis show that the critical dynamic stress of high liquid limit clay is 20-30 KPa. When the amplitude of the cyclic dynamic stress is less than the critical dynamic stress, the deformation of the sample tends to be stable as the number of cycles increases. When the cyclic dynamic stress is greater than the critical dynamic stress, as the number of cycles increases, the sample finally reaches a failure state. The dynamic elastic modulus of high liquid limit clay decreases with the increase of the dynamic stress amplitude, and decreases with the increase of the number of cycles, and tends to be stable when the number of cycles is 500.

(2) Water content has the greatest impact on the dynamic stability of high liquid limit clays, followed by compaction degree. When filling high liquid limit clay subgrade, the moisture content should be controlled within 2% below the optimal moisture content, and the compaction degree should not be less than 96%.

(3) Under the same dynamic stress amplitude, the greater the consolidation confining pressure, the smaller the cumulative plastic strain of high liquid limit clay. After the confining pressure increases from 50 kPa to 100 KPA, the cumulative plastic strain of the sample has attenuated to a very small value. It can be seen that the influence of dynamic load can be ignored when the subgrade depth exceeds 4 m.

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