Study of Dynamic Characteristics of Subgrade Soil under High Frequency Dynamic Load

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Abstract. By exerting high frequency dynamic load on the subgrade soil, the dynamic elastic damping ratio was tested under different dry density, with comparing and analyzing the results of dynamic triaxial tests, it presented the influence of dynamic elastic modulus and damping ratio on the development of subgrade soil. The results showed that the dynamic elastic modulus of the different dry density subgrade soil under high frequency dynamic load, which decreases with the increase of dynamic strain, the smaller the dry density is, the faster the dynamic elastic modulus decays; the dynamic shear modulus law is consistent with the development trend of elastic modulus, it decreases with the increase of dynamic shear deformation, the larger the elastic modulus of soil is, the larger the dynamic shear modulus is; although the damping ratio is discrete, with the increase of the dynamic shear stress, the damping ratio as a whole tends to increase, the higher the dry density is, the slower the damping ratio increases.

1. Introduction
Dynamic elastic modulus, dynamic shear modulus and damping ratio of soil are very important parameters of soil dynamic characteristics, which directly affect soil layer response analysis and seismic safety evaluation of engineering site. On the study of soil dynamic properties, domestic and foreign scholars have carried out more extensive research, the dynamic modulus and damping ratio of sandy soil and cohesive soil were studied respectively by seed, Idris [1] and Hrdin, Black [2], the dynamic shear modulus and damping ratio of a large amount of rockfill materials were tested by Xianjing Kong et al. [3], Zhongyou Hu et al. [4] made experimental study on the variation characteristics of damping ratio of loess in different areas, Lin Ma et al. [5] have studied the dynamic characteristics of loess under different confining pressures, the dynamic deformation characteristics of Lanzhou loess under different frequencies have been studied by Qian Wang [6] et al. As far as the dynamic elastic modulus and damping ratio of loess are concerned, the scholars mainly studies the dynamic characteristics of undisturbed loess soil, but little research is done on the dynamic characteristics of subgrade soil under high frequency dynamic load.

Based on this, this paper used 20 KN microcomputer-controlled electro-hydraulic servo dynamic triaxial testing machine to test the dynamic elastic and damping ratio of the existing Foundation soil under high frequency dynamic load, it will give the influence of different dry density on the dynamic elastic modulus and damping ratio of dynamic compacted soil. The development of this study will be very important to the further study on the dynamic properties of subgrade soil under high frequency vibration, it can also provide reference for site seismic response analysis and calculation.
2. Test Soil Sample and Test Content

2.1. Test Soil Sample
The test soil samples were taken from the foundation soil under the city wall of Xi'an, Shanxi Province. The depth of soil taken from the top of the city wall was 23 m, and the soil was yellow Brown and uniform. The related physical properties are detailed in Table 1.

| Sample Number | Density (g/cm³) | Dry Density (g/cm³) | Moisture Content (%) |
|---------------|-----------------|---------------------|----------------------|
| 1             | 2.040           | 1.59                | 20.9                 |
| 2             | 2.038           | 1.69                | 20.6                 |
| 3             | 2.155           | 1.79                | 20.4                 |

2.2. Test Method
The test was carried out in accordance with the “Geotechnical Test Specification SL237-032-1999” [7]. All soil samples were prepared into 50 mm by 100 mm cylindrical. Before cyclic loading, the samples were consolidated under eccentric pressure, the lateral consolidation pressure \( \sigma_{rc} = K_0 \sigma_{vc} \), and the lateral pressure Coefficient \( k_0 \) were 0.69, the consolidation is not drainage during the test. Taking into account the urban traffic factors, the added dynamic load frequency of 3Hz sine wave. After consolidation and stabilization, dynamic stress is applied to the axial direction of the samples from small to large step, and the order of dynamic stress is 10 times, until the samples produces 1% deformation. In the process of dynamic stress, the time history curves of dynamic stress and dynamic strain were recorded simultaneously by the data acquisition instrument through the stress and strain sensors.

3. Dynamic Characteristics of Subgrade Soil under High Frequency Dynamic Loading

3.1. Effect of Different Dry Density of Soil on Elastic Modulus
According to the dynamic triaxial test results, they can give the relationship between the reciprocal of the dynamic elastic modulus \( (1/E_d) \) and the dynamic strain \( \varepsilon_d \). There is a good linear correlation between \( 1/E_d \) and \( \varepsilon_d \) of subgrade soil under different dry density dynamic load, such as equation (1), where \( a \) and \( b \) are model parameters.

\[
\frac{1}{E} = a + b\varepsilon_d \tag{1}
\]

From the relationship between the reciprocal of the dynamic modulus \( (1/E_d) \) and the dynamic strain \( \varepsilon_d \) in figure 1, it is found that the dynamic modulus decreases with the increase of the dynamic strain at different dry densities under the same dynamic strain, the greater the dry density is, the greater the dynamic elastic modulus is. The reason is that the higher the dry density is, the denser the soil is, and the stronger its ability to resist shear deformation is. With the continuous deformation of the soil sample, the more loose the soil sample, the weaker the connection force between the soil particles is the faster the dynamic elastic modulus decays.

3.2. Effect of Different Dry Density of Soil on Shear Modulus Ratio
The dynamic elastic modulus and dynamic strain measured by dynamic triaxial test are converted into dynamic shear modulus \( G_d \) and dynamic shear strain \( \gamma_d \) by using the following equation (2) and equation (3):
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gure 1. $1/E_d \sim \varepsilon_d$ relation curves of loess under the different dry density.

$$G = \frac{E_d}{2(1+\mu)}$$ \hspace{1cm} (2)

$$\gamma_d = \varepsilon_d (1 + \mu)$$ \hspace{1cm} (3)

$\mu$ is Denis Poisson of the loess in the Formula. The non-linear curve fitting of the experimental results is given in figure 2, it is the relation curve of $G_d/G_{d_{\text{max}}} \sim \gamma_d$ under the different dry density.

Figure 2. $G_d/G_{d_{\text{max}}} \sim \gamma_d$ relation curves of loess under the different dry density.

The normalized curves of $G_d/G_{d_{\text{max}}} \sim \gamma_d$ under the different dry densities show that the dynamic shear modulus decreases with the increase of dynamic shear strain, and the dry density has a significant effect on the development of dynamic shear modulus, the larger the dry density is, the slower the decrease of the dynamic shear modulus is, and the larger the dynamic shear modulus is. The dynamic shear modulus law is consistent with the development of elastic modulus with the increase of dynamic shear deformation. The larger the elastic modulus, the larger the dynamic shear modulus.
3.3. Influence of Different Dry Density of Soil on Damping Ratio

The dynamic stress dynamic strain hysteretic curve under different dry density is drawn according to the dynamic triaxial test, the relation curve of damping ratio (D) and dynamic shear strain (γd) under different dry density is obtained after normalization, which is shown in figure 3.

![Graph](image)

Figure 3. D ~ γd relation curves of loess under the different dry density.

From the curve of figure 3, it can be found that the damping ratio is discrete, but with the increase of dynamic shear stress, the damping ratio on the whole tends to increase; the effect of dry density on the damping ratio is weak at the initial stage of dynamic shear strain, in the later period, the higher the dry density is, the slower the damping ratio is. The main reasons are as follows: the higher the dry density is, the greater the energy consumed for resisting shear deformation is, and the lower the damping ratio is.

4. Conclusion

The main conclusions drawn from the study are as follows:

(1) Under the high frequency dynamic load, the dynamic elastic modulus and dynamic strain of subgrade soil still have a good hyperbolic relationship. Under the different dry density, the dynamic elastic modulus of soil decreases with the increase of dynamic strain, the smaller the dry density is, the faster the dynamic elastic modulus decays.

(2) Under the different dry densities, the dynamic shear modulus is consistent with the development trend of elastic modulus, with the increase of dynamic shear deformation, the dynamic shear modulus increases with the increase of elastic modulus.

(3) At the different dry densities, the damping is more discrete than at first, with the increase of dynamic shear stress, the damping ratio increases as a whole, and the damping ratio increases gradually with the increase of dry density.

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