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Undrained monotonic and dynamic triaxial properties of the aeolian sand

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Abstract. The aeolian sand from the Mu Us Sandy Land was tested by triaxial tests, and the shear strength and dynamic mechanical characteristics were explored. A novel way was used to prepare the sand specimens. The shear strengths were tested under isotropic consolidation pressure of 50 kPa, 100 kPa and 200 kPa, respectively; the dynamic mechanical characteristics were tested under initial effective confining pressures of 50 kPa, 100 kPa and 200 kPa, respectively, with a consolidation ratio of 1.5 or 1.0. A fully compressive sine wave was adopted in cyclic triaxial tests with an excitation frequency of 1Hz in cyclic triaxial tests in which eight progressive displacement amplitudes were adopted. The test result showed that the aeolian sand had an effective angle of 33.9°, and the relationship between the dynamic shear modulus and the dynamic axial strain could be expressed by Hardin-Drnevich equation in which the best fitted value for reference strain was also suggested.

1. Introduction

Mu Us Sandy Land also known as Maowusu Desert is in the southern part of China Ordos Desert, with an elevation of 1000 m to 1300 m. It is formed with a variety of sand types which are easily moved by the wind while the sand dunes are very common.

With the economic development of western China, there are urgent requirements to construct railways, highways or other infrastructures in these sandy lands. The coal transportation railway from the western Inner Mongolia to central China (abbreviated as Menghua Railway) is the longest coal transportation railway in China. It starts from Haolebaoji Station in Northern Inner Mongolia, passes through Inner Mongolia Autonomous Region, Shaanxi Province, Shanxi Province, Henan Province, Hubei Province and Hunan Province, and ends in Ji'an City, Jiangxi Province, with a total length of 2,050.953 kilometers. It is planned with a transportation capacity of 200 million tons every year with an estimated investment of 170 billion Yuan. It is another long channel for coal transportation in China after the Datong-to-Qinhuangdao Railway in Shanxi province.

The Menghua Railway is planned to come across Mu Us Sandy Land with more than 100 km, of which the mileage between DK32+000.00 and DK32+820.00 is most severely affected by the mobile sand hazards. In this area, the sand is moved by the wind with a maximum wind speed of 15 m/s. The



railway is under a high risk of covered by the mobile sand dunes. The damage degree of sandstorm to the railway is assessed to be serious. The sand is uniform in size with poor gradation, and most sand land is more than 10 m deep. However, there is an abundant rainfall with an annual rainfall of 364.70 mm which is favorable to the vegetation on the sand land. This area is featured with crescent-shaped mobile dune chains, with a small number of semi-fixed dunes, mainly covered with *Artemisia ordosicas*, *salix psammophilas* and other irrigation vegetation accompanied by a small amount of willow forest.

It is economic to use the sand resources as portion of construction materials for railway due to lack and transportation difficulty of construction materials in the sand land. In the design plan, the ground is designed to be compacted by heavily rolling and the lower subgrade is filled with the site sand. It is necessary to understand the mechanical performance of the sand.

2. Test preparation

2.1 Tested sand

The sand samples are taken from a construction site between DK32+000.00 to DK32+820.00 of Menghua Railway which is most severely affected by the sand hazards. The fine sand has a uniformity coefficient $C_u = 3.19$ and curvature coefficient $C_c = 0.69$ (Figure 1) with poor gradation. The specific gravity is 2.66, and the minimum and maximum void ratios are 0.503 and 0.786, respectively. The compaction curve (Figure 1) shows two maximum dry densities, one with a water content of 4.7%, corresponding to a dry density of about 1.725 g/cm^3 , and the other with a water content of 12%, corresponding to a dry density of 1.721 g/cm^3 . These compaction features mean the sand can obtain maxim densities through dry compaction or wet compaction. The lower subgrade is filled with moist sand and then vibrated by rolling and the ground below the subgrade is compacted by heavily rolling.

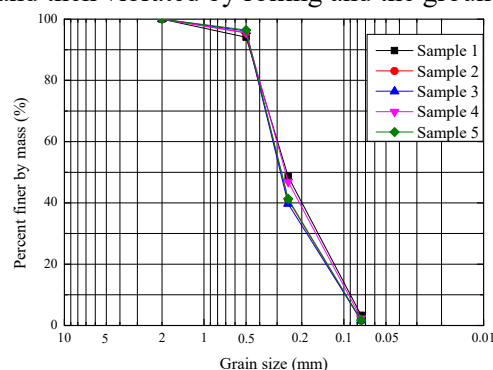


Figure 1. The grain size distribution of the aeolian sand.

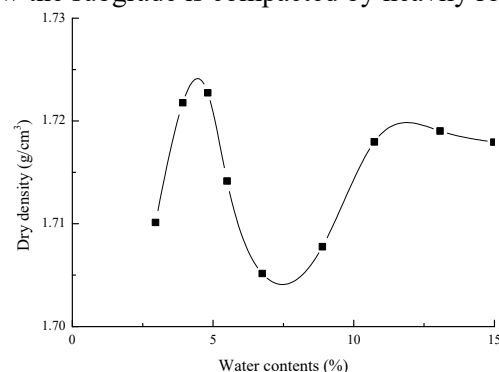


Figure 2. The compaction curve of the aeolian sand.

2.2 Specimen preparation

The sand is required to be prepared to a relative density of 0.7. Initially we prepared the sand specimens by moist tamping method in which the sand is prepared with about 5% water content and then compacted by several layers. This method however, is recognized to have a structure different from the natural structure of aeolian sand. Since the lower pedestal of triaxial instrument cannot be taken off, the compaction preparation shall be conducted on the seat, which may cause a possible damage to the triaxial instrument.

The dry pluviation is another method common used in laboratory. It has been conducted by keeping the funnel at a fixed height above the base of the 76 mm to 100 mm long split mould. Raghunandan *et al.* compared several sand specimen preparation methods and suggested that the void ratio was influenced more by the mass-flow and less by the distance through which the sand particles fall during dry pluviation^[1]. When saturated, the specimen will be vacuumed first and then the pores be filled with de-aired water from the bottom. It was a so long time usually continuing several hours.

There are also other methods such as water pluviation method^[2-4] which may be simple to prepare a saturated specimen without further saturation procedures. Kuerbis and Vaid introduced a sand specimen preparation method—the slurry deposition method may be more complex and difficulty to move the specimen to the triaxial pedestal^[5]. In this paper the method proposed by Bishop was used with a small modification^[6], which was deemed as an effective way to resemble the structures of the aeolian sand. We had a transparent plastic plug with a hole to keep the funnel steadily (Figure 3). The plastic plug may be a little larger than split mould in the outer diameter while center hole has an inclination. The funnel lower outlet is encased a rubber pipe. Stretch the rubber membrane outside the top open of the split mould. After installation of the split mould, just press the plastic plug over the top open of the split mould, and use a section of membrane to seal the gap between the plug and mould, and then insert the funnel into the plug hole. The gap between the funnel outlet and the plug hole will be sealed with the rubber pipe. Then let the sand flows steadily and fairly rapidly into the split mould. A tamper rod may be used to obtain a designed density by tamping.



Figure 3. The plastic plug over the split mould.

2.3 Test method

In order to obtain the mechanical characteristics of the aeolian sand, triaxial compression tests and cyclic tests were carried out on the aeolian sand. According to the design drawings, the sand are compacted to relative density of not less than 0.7 as group C fills for the subgrade. Therefore, all the specimens were prepared to a relative density of 0.7, $e_0=0.644$ with a diameter of 39.1 mm and a height of 79 mm to 80 mm according to specifications in *Code for Soil Test of Railway Engineering*(TB10102-2010, J1135-2010), and the dry mass is 160.8 g. The specimens were first loaded to 20 kPa of confining pressure to check the B value which should be controlled to be 0.98 or more. The back pressure saturation is adopted. The isotropic consolidation stresses for strength test were 50 kPa, 100 kPa and 200 kPa, respectively. The undrained shear tests were carried out after isotropic consolidation ($K_c=1.0$). The shear rate was calculated to reach 15% in within 2 hours, and the failure was determined by an obvious peak or the axial strain of 15%.

For the dynamic response of aeolian sand under railway loads, the cyclic tests were conducted to explore the damping ratio and dynamic shear modulus. Because the dynamic properties of sand are little affected by frequency^[7], the excitation frequency is 1Hz in our tests. A fully compressive sine wave was superposed on the specimen after consolidation, which was different from general triaxial test research for earthquake. The specimens were tested under different displacement amplitudes of 0.01 mm, 0.02 mm, 0.04 mm, 0.08 mm, 0.16 mm, 0.32 mm, 0.64 mm and 1.28 mm, respectively. The initial effective confining pressures were 50 kPa, 100 kPa and 200 kPa, respectively, with a consolidation ratio of 1.5, and consolidation ratios of 1.0 and 1.5 for an effective confining pressure of 100 kPa.

3. Test results

For the triaxial shear tests, the corresponding the effective stress paths are shown in Figure 4, indicating the applied shear stress, first increases and then drops rapidly to a constant, steady state or residual strength value. The porewater pressure however, increases and then drops rapidly until tended to a steady value (Figure 5), which is different from Mohamad^[8]. The degree of effective frictional angle is 33.9°.

For the cyclic triaxial tests, Figure 6 and Figure 7 show the normalized shear modulus and the damping ratio with different consolidation ratios at an initial effective confining pressure of 100kPa. It can be seen that the normalized shear modulus drops rapidly with the increase of dynamic strain, while the damping ratio increases. They all tend to attain a steady value after the dynamic axial strain reaches 1%.

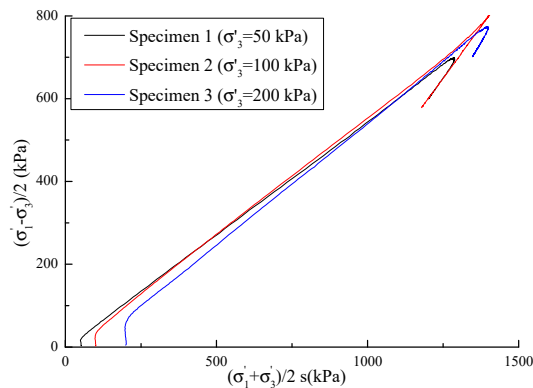


Figure 4. Effective stress paths in shear triaxial tests.

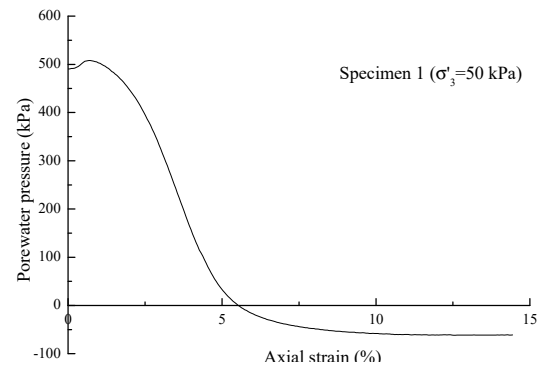


Figure 5. Variation of pore water pressure in shear triaxial test.

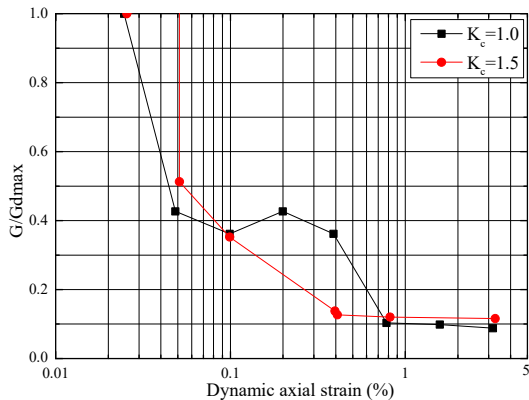


Figure 6. Curve of relationship between Normalized dynamic shear modulus vs. dynamic axial strain for $K_c=1.0$ and 1.5.

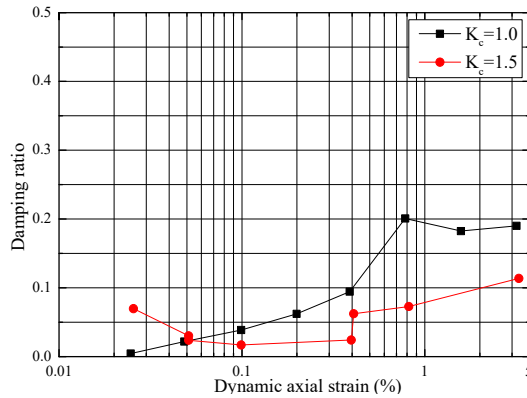


Figure 7. Curve of relationship between damping ratio and dynamic axial strain for $K_c=1.0$ and 1.5.

Figure 8 and Figure 9 show the normalized shear modulus and the damping ratio in tests with a consolidation ratio of 1.5. It can be seen that development of both the normalized shear modulus and the damping ratio are similar to that in Figure 6 and Figure 7. The dynamic shear modulus under different confining pressures can be expressed by the Hardin-Drnevich equation^[9]:

$$\frac{G_d}{G_{dmax}} = \frac{1}{1 + \frac{\gamma}{\gamma_r}} \quad (1)$$

where G_d is the dynamic shear modulus, G_{dmax} is the maximum one, γ is the dynamic axial strain and γ_r is the reference strain. Take $\gamma_r = 0.25\%$ to get a better fitting result as shown in Figure 8.

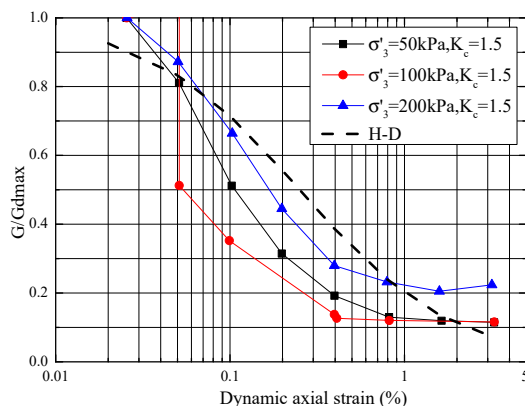


Figure 8. Curve of relationship between Normalized dynamic shear modulus vs. dynamic axial strain for $K_c=1.5$.

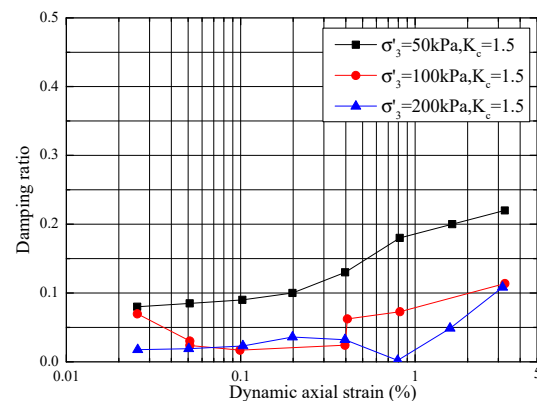


Figure 9. Curve of relationship between damping ratio and dynamic axial strain for $K_c=1.5$.

4. Conclusions

The aeolian sand from the Mu Us Sandy Land was tested by triaxial tests, and the dynamic mechanical characteristics were obtained. A novel way was used to prepare the sand specimens, and a fully compressive sine wave was adopted in cyclic triaxial tests. The test result showed that the aeolian sand had an effective angle of 33.9° , and the relationship between the dynamic shear modulus and the dynamic axial strain could be expressed by Hardin-Drnevich equation. The best fitted value for reference strain was also suggested.

Acknowledgments

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