Numerical Analysis on the Sandy Slope Reinforced with Sand Bags

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Abstract—In recent decades, many expressways and railways have been construction in Western China. One of important projects is Menghua Railway as a major energy transportation line. Since most of its Contract I routine is located in Maowusu Desert, it seems the first choice is to utilize the sandy soil to construct the railway subgrade. The sand bag structure is explored as a reinforcement method for as railway sandy subgrade by numerical analysis. The Flac3D is selected as the calculation tool with its GeogridSEL structural element used to simulate the function of geotextile bag. It is assumed the geotextiles remain elastic in the calculation, and the failure occurs at the interface between geotextiles and surrounding soil. The results show that when bagged sand is used, the internal friction angle of sandy soil can be appropriately reduced, or a steeper slope can be used, but the friction angle between bagged sand and geotextile is required to be larger. At the same time, if the internal friction angle of sand is small, in order to obtain a smaller slope, geotextile is required to be subjected to a larger tensile stress.

1. INTRODUCTION
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. 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.
In this desert land, the sandy soil 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.

Contract I of Menghua Railway is located in the hinterland of Mu Us Desert with a large amount of aeolian sand resources. The railway subgrade is made of local materials, and the ground beneath the subgrade is filled with aeolian sand. The subgrade slope is linear with a slope ratio of 1:1.75. If the slope is reinforced with sand bags, i.e. bagged sand, it is possible to reduce the slope ratio and save the construction cost.

Large-scale sand filling bag technology refers to sewing woven cloth into a mold bag with a certain size and special shape by machine or manually with a purpose of containing sand soil. It has been widely applied in flood control, road construction, embedment and hydraulic engineering [1-3]. Important construction methods and experiences had been gained [4,5]. These applications have invoked the researches on the stability and water flow characteristics various methods including model test and in-situ case studies [4-11]. Centrifuge test is introduced as an alternative for the widely used pressure filtration and falling head tests to evaluate retained sediments properties [6]. Large-scale performance tests were performed type of fabric and to quantify the number of flocculants necessary to promote flow through the tube [7]. The influence of the filling material in woven bags, source frequency, and number of exciters on vibration reduction was investigated [10]. Most of these researches emphasized the influence of retained sediment properties in a moisture condition on the stability or soil erosion. For geotextile bags contained dry material such as dry sandy soil from desert, little research has been conducted, the interaction mechanism between sandy soil and the geotextile bag.

2. PROPERTIES OF SANDY SOIL
Several sandy soil samples were taken on a construction site between DK32+000.00 to DK32+820.00 of Menghua Railway. These can be classified to fine sand. It has a uniformity coefficient \( C_u = 3.19 \) and curvature coefficient \( C_c = 0.69 \) (Fig.1) with a poor gradation. The specific gravity is 2.66; the minimum and maximum void ratios are 0.503 and 0.786, respectively. The compaction curve (Fig.2) shows two peaks of 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 soil can obtain maximum densities through dry compaction or wet compaction.

Triaxial tests were also conducted and found the sandy soil has an internal friction angle is 34\°.

![Figure 1. THE GRAIN SIZE DISTRIBUTION OF THE AEOLIAN SAND](image-url)
3. METHOD

For a purpose of time-consuming to explore the mechanism of subgrade slope constructed with sand bags, on-site model large model test is desired but the model test requires a large hydraulic filling machinery fill the sandy soil into bags. Since it is difficult to obtain in desert region, the model test can not be carried out. Therefore, we try to to investigate the effect of bagged sand on the stability of engineering slope by numerical analysis method.

First of all, we set up a subgrade slope with sand as the filling material. Under natural conditions, its angle of repose should be equal to the angle of internal friction. Assuming a slope ratio of 1:1.5, the corresponding angle of repose is 33.69°. If the internal friction angle of sand is 34°, the calculated slope is stable. If we reduce the internal friction angle of sand to be a smaller one, such as 30°. Then the slope will inevitably be unstable. In this case, the slope reinforcement effect of bagged sand can be evaluated.

The Flac3D is selected as the calculation tool with its GeogridSEL structural element used to simulate the function of geotextile bag. It is assumed the geotextiles remain elastic in the calculation, and the failure occurs at the interface between geotextiles and surrounding soil, i.e. a frictional slipping. There are four performance indexes for the calculated structural unit: stiffness K per unit area of the geotextile, cohesion, friction angle, and effective normal stress. The effective normal force is the pressure exerted by the soil on the GeogridSEL unit. The relationship between tensile stress and tensile displacement will be obtained if the geotextile is tensioned. Because it belongs to friction phenomenon, it also has corresponding peak tensile stress, slope of tensile stress and displacement curve, friction angle and cohesion. The slope of the tensile stress and displacement curve is the stiffness K, while the friction angle and cohesion are the slope and intercept of the maximum normal stress and maximum tension curve.

4. CALCULATION

4.1. Calculation parameter and boundary condition

Consider the subgrade configure as shown in Fig.1: the width of shoulder is 6 m, and the slope height is 6 m with a slope ratio of 1:1.5. If the slope is in a state of just attaining stability, the internal friction angle is 34° through stability assessment. If the internal friction angle of sand is reduced, GeogridSEL can be added as a function of bagged sand to ensure slope stability. The problem is simplified to plane strain type. In Flac3D, the model is built according to a 3-dimensional model with one-unit thickness of 1 m as shown in Fig.3.

Sand soil is considered as an ideal Mohr-Coulomb material with a bulk modulus of 5×108 Pa and a shear modulus of 1×108 Pa. The geotextile has a thickness of 5 mm with a stiffness per unit area of
2.3×10^6 N/m^3. At a given the slope, there are four factors that affect the performance of geotextiles. For simplicity, only the friction angle of geotextiles is considered here to assess the slope stability by varying the internal frictional angle between bagged sand and sandy soil. These parameters of sandy soil and geotextile are listed in Tables I and II.

![Figure 3. GEOMETRY CONFIGURE OF NUMERICAL MODEL](image)

| TABLE 1. NUMERICAL PARAMETERS OF SANDY SOIL |
|--------------------------------------------|
| Density (kg/m³)   | Bulk modulus (kPa) | Shear modulus (Pa) | Cohesion (Pa) | Angle of internal friction (°) |
|------------------|---------------------|--------------------|---------------|-------------------------------|
| 2000             | 5.0E8               | 1.0E8              | 0             | 20 to 32                      |

| TABLE 2. NUMERICAL PARAMETERS OF GEOTEXTILE |
|---------------------------------------------|
| Elastic modulus (Pa) | Poisson’s ratio | Area stiffness (N/m³) | Cohesion (Pa) | Angle of internal friction (°) |
|---------------------|----------------|-----------------------|---------------|-------------------------------|
| 2.6E9               | 0.33           | 2.3E6                 | 0             | 2 to 57                       |

In the calculation, for a purpose of calculation stability, horizontal displacement is constrained on the left slope boundary, and the vertical and horizontal displacement are constrained on the bottom boundary while the displacement is constrained normal to the calculated section plane of the whole model.

Fig.4 shows the geotextile reinforcement in the sandy soil slope. Totally there ten layers of geotextile and one connection geotextile laid on the slope. It is assumed that the thickness of bagged sand is 600 mm after it is filled with sand, and a total of 10 layers are piled up to 6 m high to form a sandy slope.

![Figure 4. CURVE OF INTERNAL FRICTION ANGLE OF SAND VERSUS FRICTION ANGLE OF GEOTEXTILE](image)

4.2. Numerical result

Fig.5 the change curve of internal friction angle of geotextile structural unit with a decrease of internal friction angle of sand, which shows a non-linear relationship. When the sand friction angle changes...
from the initial angle of repose to 28°, the GeoSEL friction angle changes greatly. When the internal friction angle of sand is lower than 28°, SEL friction angle and internal friction angle of sand are basically linear.

![Figure 5. CURVE OF INTERNAL FRICTION ANGLE OF SAND VERSUS FRICTION ANGLE OF GEOTEXTILE](image)

Fig. 6 shows the tensile stress distribution of geotextiles when the internal friction angle of sand is 30° and the friction angle of GeogridSEL structural unit is 22° (referred to as the first case); Fig. 7 shows the case when the internal friction angle of sandy soil is 20° and the friction angle of GeogridSEL structural unit is 57° (referred to as the second case). It can be seen from these two figures that the maximum tensile stress of geotextile in the first case is obviously smaller than that in the second case; the former is about 1/7 of the latter. It is reasonable to understand that the smaller the internal friction angle of sand, the worse the stability of slope, which requires the geotextile to bear more tension. Therefore, the sand filling-bag with sufficient tensile strength should be selected according to the reinforced slope and the mechanical properties of the filling sand. If the strength of the filling bag is too low and it is broken, the slope may become unstable.

The above calculation explores the relationship between internal friction angle of sand, slope ratio of slope and friction angle between filling bag and sand. Tensile strength of filling bag is also an important factor affecting slope stability. Sufficient tensile strength should be considered in selection of geotextile filling bag.

![Figure 6. GEOTEXTILE TENSILE STRESS AT AN INTERNAL FRICTIONAL ANGLE OF 30° FOR SANDY SOIL AND A FRICTIONAL ANGLE OF 22° FOR GEOGRIDSEL UNIT](image)
5. CONCLUSION
This paper discusses the feasibility of using bagged sand to reinforce sand slope with a slope of 1:1.5 through numerical analysis. The results show that when bagged sand is used, the internal friction angle of sand can be appropriately reduced, or a steeper slope can be used, but the friction angle between bagged sand and geotextile is required to be larger. Otherwise the slope is not easy to achieve stability. At the same time, if the internal friction angle of sand is small, in order to obtain a smaller slope, geotextile is required to be subjected to a larger tensile stress. When the tensile strength of the material is exceeded, the geotextile is prone to tensile failure, leading to slope instability.

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