INTRODUCTION

Along with the western development, the land shortage in western loess plateau is becoming more and more obvious, so the mountain is often excavated and ditch is often filled to create more land, which would cause many geotechnical engineering problems. Therefore, the domestic and foreign scholars have conducted a lot of researches [1-9]. In the subgrade embankment, the stability and deformation control of high embankment slope is one of the important factors related to the quality of construction, which deserves great attention. Due to the failure of the slope due to the self weight or other factors related to weight, the general model test can not truly reflect the actual stress and strain state of the slope. In addition, we cannot know the process of slope deformation only through field investigation and spot monitoring, but the geotechnical centrifuge model test can reproduce the self weight stress field with good similarity, which has been widely used in the slope engineering [10-13]. This paper constructs the model and does the centrifugal model tests with the change of water level, taking loess high embankment slope of a valley in Yan’an as an example, and the test results can provide reference for similar engineering design.

CENTRIFUGE MODEL TEST

2.1 Testing equipment

The test machine used is LXJ-4-450 for geotechnical centrifuge model developed by China Institute of Water Resources and Hydropower Research. The designed maximum acceleration is 300g, with 1500mm basket length and 1000mm width and height. The length of model box is 1350mm, width is 400mm and height 900mm. Data acquisition equipment includes 5 laser displacement sensors and the acquisition and camera system.

2.2 Similarity ratio

Centrifuge model tests reproduce the self weight stress field of the prototype. The model is not only geometrically similar to the prototype, but also the parameters, such as stress and strain of corresponding position, should be similar to ensure that the model can reflect the characteristics of the prototype.
prototype. The specific similarity ratio is shown in table 1.

<table>
<thead>
<tr>
<th>Physical quantity</th>
<th>Similarity ratio (prototype / model)</th>
<th>Physical quantity</th>
<th>Similarity ratio (prototype / model)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Displacement</td>
<td>n</td>
<td>Stress</td>
<td>1</td>
</tr>
<tr>
<td>Time</td>
<td>$n^2$</td>
<td>Strain</td>
<td>1</td>
</tr>
<tr>
<td>Area</td>
<td>$n^2$</td>
<td>Moisture content</td>
<td>1</td>
</tr>
<tr>
<td>Volume</td>
<td>$n^3$</td>
<td>Buckling safety factor</td>
<td>1</td>
</tr>
<tr>
<td>Volume weight</td>
<td>n</td>
<td>Void ratio</td>
<td>1</td>
</tr>
<tr>
<td>Length</td>
<td>n</td>
<td>Cohesion</td>
<td>1</td>
</tr>
<tr>
<td>Density</td>
<td>1</td>
<td>Internal friction angle</td>
<td>1</td>
</tr>
</tbody>
</table>

2.3 Model design

This experiment takes the loess high embankment slope of a valley in Yan'an as the prototype, and according to the size of model box, determines similarity ratio of the centrifugal test as $n=120$. The soil is mainly Ma Lan loess, appearing greyish yellow. The soil sample is mainly fine grained soil, being the powder soil, because the specific gravity of $G_s$ is 2.70-2.71, the liquid limit of $WL$ is 23.5%, the plastic limit of $WP$ is 15.5%, and the plastic index $Ip$ is 8. The average dry density of the prototype slope is 1.60g/cm³ with the average water content 11.73% and it is known from the table 1 that the soil properties of the model should also meet the standard.

The purpose of this study is to monitor stability and deformation of loess embankment slope when the water level is rising, and design 4 water levels, with elevations of 100mm, 180mm, 260mm and 330mm. The length of test model is 1250mm, width 400mm and height 500mm. On the top side is placed a handmade permeable plate of 100mm thickness, into which water service pipe can be inserted. The internal is to store water, and multiple weep holes are evenly distributed in one side of the panels. Except the top and the bottom, there are 2 platforms on the slope, with 3 sections whose slope ratio are respectively 1:1.7, 1:2.1 ratio and 1:3.7, so the synthetic ratio is 1:2.3. The laser displacement sensors are installed at each level of the platform and the corresponding position in the middle of the slope, and the vertical deformation of the corresponding position in the whole test process is tested. The model is shown in figure 1.

2.4 Modeling

Because the test $g$ value is high, it would produce a very high water pressure, so water proof is very important to ensure that all water pass through the soil. Therefore, the corners of the box are sealed by sealant before making the slope model, and air it for 2-3 days after each sealing. Then seal it again after it is completely dry. Thus, water proof is made two times in all.

To control the water level, obvious signs can be established in the corresponding position in the porous panel with some expandable polyethylene. And then a high-definition camera is installed in the previous plate, so the relative position of EPE and water level marks can be seen through the video, in order to control the water level. The test soil is made on site and filtrated through 2mm screen, and then the water content is allocated to 11.73%, sealing for 24h. When filling, the thickness of each layer should be controlled in 50mm, according to the prototype model. The measurement equipment and other auxiliary equipment are installed, and finally a test model forms, as shown in figure 2.
2.5 Testing process

The finished model is put in the centrifuge with the strict requirements, and the test begins. Centrifugal acceleration increases from 0g to 120g, maintaining 200s, and add water in the case of 120g acceleration. During the process of adding water, the water level should be observed through the video all the time, and adjust the water intake velocity of the water pipe to guarantee the stability of water level. Operate it 10min under each water level, and 25min under the most advanced level. The actual test procedure: add water to the first stage (100mm), and keep the water level under the 600s; add water to second water level (180mm), and keep 630s; add water to third water level (260mm), and keep 610s; add water to the fourth water level (330mm), and after keeping in the 1620s start to unload until the shutdown.

3 RESULT ANALYSIS

3.1 Analysis of slope deformation characteristics

Each position of the slope in the whole test process do not have a large lateral displacement changes without overall and local damage, and the slope flatness does not have greater change than before. Comparing with the lateral deformation, the vertical settlement displacement of the measured points varies greatly, and the relationship between the settlement deformation and the time and acceleration is shown in Figure 3.

![Figure 3](image1)

From the graph it can be seen that the initial centrifuge loading rate is increasing, and when it reaches 30g, it tends to be uniform. When the speed is 977s, the acceleration reaches 120g, and the g value remain the same; when 977s-1177s, there is no water in the water permeable board; when 1177s-1777s, the water level remains 100mm; when 1777s-2407s, water level remains 180mm; when 2407s-3017s, water level remains 260mm; when 3017s-4637s, water level remains 330mm. Then, stop the test. According to the similarity ratio of the centrifuge model test, when the acceleration increases to 120g, the corresponding prototype slope has been constructed. Deformation during the loading of 0-120g is called deformation in the construction period; when reaching and maintaining 120g, the deformation occurring at this time is called the deformation after work. “-” indicate the deformation of the downward development, showing as the settlement deformation. On the other hand, it shows as heaving deformation. Figure 3 shows that with the increase of the water level, the settlement and deformation of point 1 and point 2 is gradually increasing, while the deformations in point 3, point 4 and point 5 do not change significantly. The deformation in the construction period is larger in the total deformation, which indicates that the good construction quality and the long construction time can help to avoid large settlement after construction.

With the increase of centrifugal acceleration, the settlement of point 1 to 4 is also increasing. The greater the filling thickness, the greater the settlement deformation, only with minor deformation in point 5. When the acceleration reaches 120g and the g value is kept constant, the settlements of the point 2, point 3 and point 4 are gradually stabilized. And the settlement of point 1 is still developing, but the deformation rate is decreasing. After the current condition maintains at 200s, inject water, to make with water levels at 100mm, 180mm, 260mm and 330mm. And at the acceleration 120g each water level does not change, and observe the deformation of each point, shown in Table 2 and figure 4.

![Figure 4](image2)

From the figure 4, it can be seen that there are significant settlements in measuring point 1 and point 2, there are only small deformation in measurement point 3, point 4 and point 5.
Compared with deformation of each stage in each measurement point, it is not difficult to find that, except the thickness of the filling, the change of groundwater level is also an important factor affecting the deformation. The measuring point 1 corresponds to the top with the maximum filling thickness, and the thickness of prototype reaches 60m. And the location is also affected by the change of water level first, and with the increase of the water level, the deformation gradually increases with the maximum deformation after construction. Measuring point 2 is located in the first stage with filling thickness 42.8m. Due to the limited test time, the water penetration does not completely pass here, and the increasing amount of deformation after construction is less than 1. Comparing with the deformation of slope top and first level platform, the deformation in the middle slope, second level platform and toe (3 points, 4 points and 5 points) is very small. On the one hand, it is because the filling thickness is relatively small. On the other hand, due to the limited test time, each part is not affected by the rising water level, and the slope deformation is stable quickly without large deformation.

The following conclusions and suggestions are obtained by analyzing the characteristics of slope deformation: for filling engineering in gully area, underground drainage measures are the top priority. If the underground drainage measures are not smooth, it would result in water level rising. Not only the settlement deformation greatly increases, but also stabilized time of embankment consolidation is prolonged, which is not conducive to land use after construction. Construction quality plays an important role in the embankment, so to extend the construction time as far as possible can reduce the settlement after construction. Although the slope is gentle, the single slope height should not be too high. Therefore, level platform should set to reduce shearing stress in slope toe.

3.2 Slope stability analysis

For the calculation of slope safety factor of the centrifuge test model, Xu Guangming [14] proposed that it can be determined by the critical acceleration and the design acceleration of the model. But there is no overall or partial destruction of the slope in this experiment. Therefore, combining with the existing experimental results, this paper uses the finite element software to analyze the stability of the slope.

In the experiment, there is no complete seepage process, but according to the above analysis, when the water level is stable in 330mm, there will be 4 kinds of different flow patterns. In addition, to reflect the impact of water level changes on the slope stability, water level rises 84mm or 42mm, equivalent to water level of prototype increasing by 5m or 10m. Because the displacement is one of the key problems of high fill engineering and the high embankment forms high stress, the limit equilibrium method based on finite element stress is used to evaluate the slope stability, seen in table 3.

<table>
<thead>
<tr>
<th>Number of measuring points</th>
<th>Filling thickness</th>
<th>Stage 1 (120g Without water)</th>
<th>Stage 2 (120g Water level 100mm)</th>
<th>Stage 3 (120g Water level 180mm)</th>
<th>Stage 4 (120g Water level 260mm)</th>
<th>Stage 5 (120g Water level 330mm)</th>
<th>Total Deformation after construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Point 1</td>
<td>Model /mm</td>
<td>500</td>
<td>-0.659</td>
<td>-0.704</td>
<td>-0.879</td>
<td>-0.915</td>
<td>-3.365</td>
</tr>
<tr>
<td></td>
<td>Prototype /cm</td>
<td>60</td>
<td>-7.905</td>
<td>-8.447</td>
<td>-10.547</td>
<td>-10.978</td>
<td>-40.380</td>
</tr>
<tr>
<td>Point 2</td>
<td>Mode /mm</td>
<td>357</td>
<td>-0.076</td>
<td>-0.126</td>
<td>-0.131</td>
<td>-0.201</td>
<td>-1.715</td>
</tr>
<tr>
<td></td>
<td>Prototype /cm</td>
<td>42.8</td>
<td>-0.908</td>
<td>-1.510</td>
<td>-1.573</td>
<td>-2.413</td>
<td>-20.579</td>
</tr>
<tr>
<td>Point 3</td>
<td>Mode /mm</td>
<td>254</td>
<td>-0.040</td>
<td>-0.011</td>
<td>-0.005</td>
<td>-0.021</td>
<td>-0.025</td>
</tr>
<tr>
<td></td>
<td>Prototype /cm</td>
<td>30.5</td>
<td>-0.482</td>
<td>-0.130</td>
<td>-0.057</td>
<td>-0.254</td>
<td>-0.305</td>
</tr>
<tr>
<td>Point 4</td>
<td>Mode /mm</td>
<td>154</td>
<td>0.043</td>
<td>0.026</td>
<td>0.025</td>
<td>0.021</td>
<td>0.049</td>
</tr>
<tr>
<td></td>
<td>Prototype /cm</td>
<td>18.5</td>
<td>0.518</td>
<td>0.311</td>
<td>0.300</td>
<td>0.251</td>
<td>0.587</td>
</tr>
<tr>
<td>Point 5</td>
<td>Mode /mm</td>
<td>110</td>
<td>-0.008</td>
<td>-0.001</td>
<td>-0.001</td>
<td>-0.001</td>
<td>-0.002</td>
</tr>
<tr>
<td></td>
<td>Prototype /cm</td>
<td>13.2</td>
<td>-0.092</td>
<td>-0.008</td>
<td>-0.011</td>
<td>-0.008</td>
<td>-0.026</td>
</tr>
</tbody>
</table>

The parameters used in the calculation are mean values sampled in the field after the test. It can be seen from the results that compared to the prototype
slope, when the upstream water level is 39.6m, 44.6m and 49.6m and a complete flow forms under each water level, the overall and local slope is still stable. However, with the increase of the water level, the safety factor of the slope has a significant decrease. Thus, the construction of underground drainage measures can prevent underground water level rising, which can not only reduce the embankment deformation effectively, but also improve the stability of the slope. Consider a percolation model, the slopes of $\{1,2\}$, $\{2,3\}$ and $\{1,4\}$ gradually are gradually gentle, and when slope heights gradually increase, the safety factors are reduced gradually, which shows that the slope safety factor is greatly influenced by the slope height, and the weight of the slope is an important factor to affect the stability of the slope. In addition, from the view of optimized design, the overall slope is gentle, easy to lead to ponding in the slope, so the slope drainage measures must be done in order to reduce the impact of surface water infiltration on the slope. The gentler the slope is, the more land it covers, making low land utilization rate. Thus, reinforced soil or retaining structures can be used to design more reasonable slope. On the one hand, it can meet the requirements of slope deformation and stability, and on the other hand, it can improve the utilization of land.

4 CONCLUSION

This paper reaches the following conclusion after studying loess high embankment slope of a valley in Yan’an with centrifugal model test and analyzing deformation characteristics and stability of slope with finite element method.

(1). The consolidation deformation during construction occupies a larger proportion in deformation of loess high embankment slope. Therefore, to ensure the construction quality, to appropriately extend the construction time in the allowable range is conducive to the large settlement after the construction.

(2). The overall slope rate of the model is 1:2.3 with gentle degree 23.5°. By centrifuge model test and finite element analysis, it can be known that with the increase of the slope underground water level, the whole and part of the slope is still in stable condition. However, the rising ground water level not only greatly increases the deformation of slope surface subsidence, but also significantly reduces the safety factor of the slope. Thus, for the embankment in the gully area, underground drainage is the top priority, and the underground drainage measures has important significance.

(3). In the high embankment slope design, reinforced soil and retaining structures can be used with a reasonable ratio, to achieve the goal of optimal design.

REFERENCES