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Analysis and Study of the Influence of the Proposed Mabiantian Reservoir on the Embankment of Dongfeng Forest Avenue

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Keywords: Embankment, Shear Test, Consolidation Test, Seepage Test, Effective Stress Principle, Stability Coefficient

Abstract: In order to study the influence of Mabiantian reservoir on the stability of Dongfenglin Avenue embankment slope after impaction, the physical and mechanical property parameters and hydraulic property parameters of embankment filler and subgrade were obtained by indoor shear test, consolidation test and permeability test, natural Angle of rerest test and permeability test on site. According to k. Terzaghi effective stress principle, the stability of slope after water storage is analyzed. The calculation shows that the slope stability coefficient of Dongfenglin Avenue embankment is basically less than 1.05 after impaction, indicating that local collapse and landslide may occur after impaction, which seriously threatens the safety of Dongfenglin Avenue and the impaction function of Mabentian Reservoir.

1. Preface

The rapid expansion of cities and the rapid economic development of the Yunnan-Guizhou Plateau lead to the increasing shortage of water resources [1], and the seriously uneven karst geological conditions and the time distribution of precipitation in the Yunnan-Guizhou Plateau are also the adverse factors of water shortage [2-3].Water resources development and utilization has increasingly become the main issue of urban construction and development, CHEN Junjie studied the water resources conditions in the future urban development of [4], JIA Wenji based on sponge city concept consider water resources utilization [5], ZHAO Pingting [6] and CHEN Zhaohui [7] study urban water resources from the aspects of water rights and water rights system development and utilization of Yilong new district Xingyi City Guizhou Province to promote the construction of industrial park and the development of agricultural irrigation, carried out the feasibility study of Mabiantian reservoir construction, evaluate the impact of the reservoir after Dongfenglin avenue embankment slope and subgrade stability.

2. Project Overview

2.1 Characteristics and Impacts of the Proposed Mabiantian Reservoir

2.1.1 Features of the Proposed Mabiantian Reservoir

Anlong County Mabiantian reservoir project is located in Dewo town, Xinqiao town, and Muzan town junction, Anlong county,Qianxinan Autonomous Prefecture ,the head waters are located in Luoshuidong ,which is the first class tributary Baishui river, Xijiang river basin,the Pearl river drainage area,the dam site above rainwater area 369.4km^2, the average flow of 7.47 m^3/s, is a natural lake forming into reservoir, it is the first level power reservoir of Baishui river, about 4.3km from Dewo town, 3.6km from Xinqiao town, there is the road to the dam area, the traffic is rather convenient.The main task of the project is to supply water and irrigation for the Xindelong Industrial Park, and take into account the comprehensive utilization of the construction of water ecological civilization.

2.1.2 Characteristics of Affected Structures of Proposed Mabiantian Reservoir

Due to the proposed construction of Mabiantian Reservoir project in Anlong County, according to Figure 1, the important influence structure is the Dongfenglin Avenue Dewo Section.The subgrade section of Dongfenglin avenue (mileage: K1 + 600~K3 + 840) is 60m in the excavated section and 80m in the filled section. The road is designed according to the urban trunk road standard, the load standard is urban class A, 8 two-way lanes, and the road section is double-width road type.After the completion of the road, the fast passage from Yilong pilot area to Anlong County will make the development of scenic spots along the road, make the New (bridge) De (wo) Long (guang) park more attractive and relieve the traffic congestion pressure of national Road 324 in the park.In short, the comprehensive completion of Dongfenglin Avenue is of great significance to accelerate the rapid development of Yilong pilot area.

3. Indoor Test and Field Test

Indoor test and field test are the basis and basis of demonstration, calculation, and analysis, and provide the parameter basis for calculation and analysis.Indoor test mainly includes geotechnical test and red clay seepage test, the field test mainly includes internal friction angle test, permeability test and permeability coefficient test of red clay formation under the road lying foundation.

3.1 Indoor Test

The purpose of indoor test is mainly to demonstrate the parameter basis of foundation stability and embankment slope stability, including geotechnical tests and seepage test.

3.1.1 Geotechnical Test

This geotechnical test is mainly to test the physical and mechanical properties under the saturated state of red clay, providing a basis for the calculation and analysis of subgrade stability. Through field sampling, the test process and results are as follows Figures 1-5 and Tables 1-4:

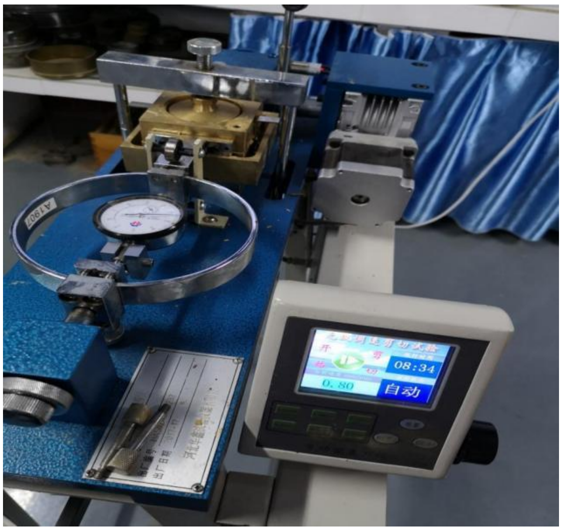

Figure 1: Direct Shear Test Diagram

Figure 2: Consolidation Test Diagram

Table 1: Direct Shear Test of Soil Samples with Red Clay

<table>
<tr><td>Trial basis</td><td colspan="2">JTG E40-2007</td><td colspan="2">Sample number</td><td colspan="3">Embankslope soil sample 1</td></tr>
<tr><td>Sample description</td><td colspan="2">No plant roots</td><td colspan="2">Sample name</td><td colspan="3">Adamic earth</td></tr>
<tr><td>condition of experiment</td><td colspan="2">temperature:20.0~22.0 ℃
relative humidity:61.0~62.0%</td><td colspan="2">Date of test</td><td colspan="3">20190504</td></tr>
<tr><td>Main instruments and equipment and serial number</td><td colspan="7">Strain-controlled straight shear instrument</td></tr>
<tr><td colspan="2">Pressure (kPa)</td><td colspan="2">100</td><td colspan="2">200</td><td>300</td><td>400</td></tr>
<tr><td colspan="2">Percent table reading when breaking(0.01mm)</td><td colspan="2">38.900</td><td colspan="2">51.9</td><td>62</td><td>89.000</td></tr>
<tr><td colspan="2">Shear stress(kPa)</td><td colspan="2">32.275</td><td colspan="2">43.06143</td><td>51.4414</td><td>73.843</td></tr>
<tr><td colspan="2">Cohesive strength(kPa)</td><td colspan="2">16.9</td><td colspan="2">angle of friction</td><td colspan="2">7.6</td></tr>
<tr><td colspan="2">Correlation r</td><td colspan="6">0.974</td></tr>
</table>

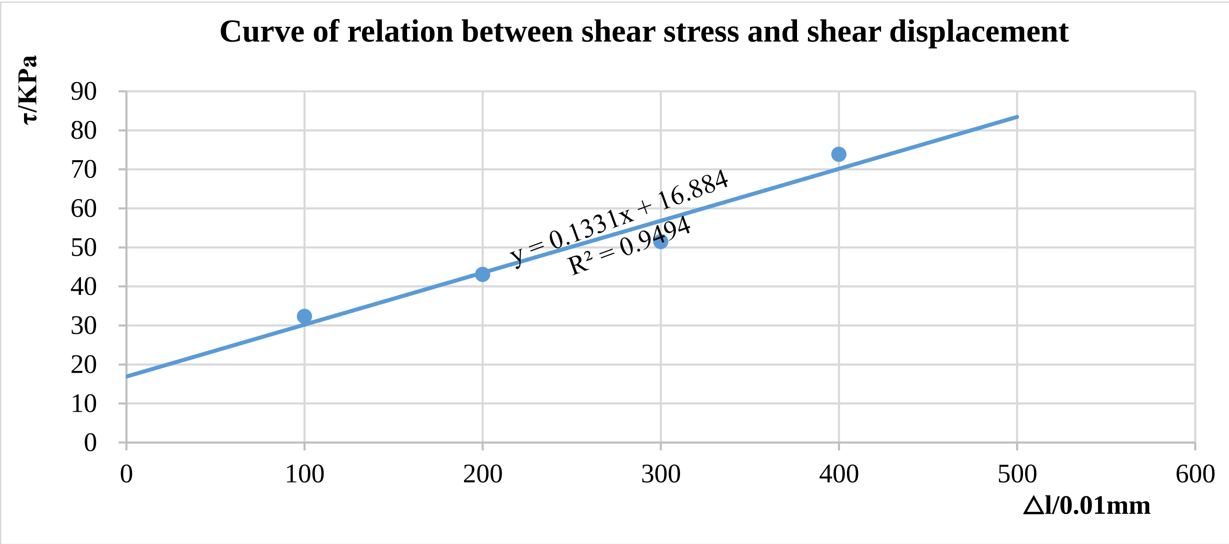

Figure 3: Curve of relation between shear stress and shear displacement

Table 2: Direct shear test table of saturated soaked remolded red clay

Trial basis	JTG E40-2007		Sample number	Bridge platform back fill soil 1
Sample description	No plant roots		Sample name	Adamic earth
condition of experiment	temperature:20.0~22.0 ℃ relative humidity:61.0~62.0%		Date of test	20190504
Main instruments and equipment and serial number	Strain-controlled straight shear instrument			
Pressure(kPa)	100	200	300	400
Percent table reading when breaking(0.01mm)	15.000	44.9	50.7	44.900
Shear stress(kPa)	12.446	37.254	42.06579	37.254
Cohesive strength(kPa)	11.2	angle of friction	4.5	
Correlation r	0.794			

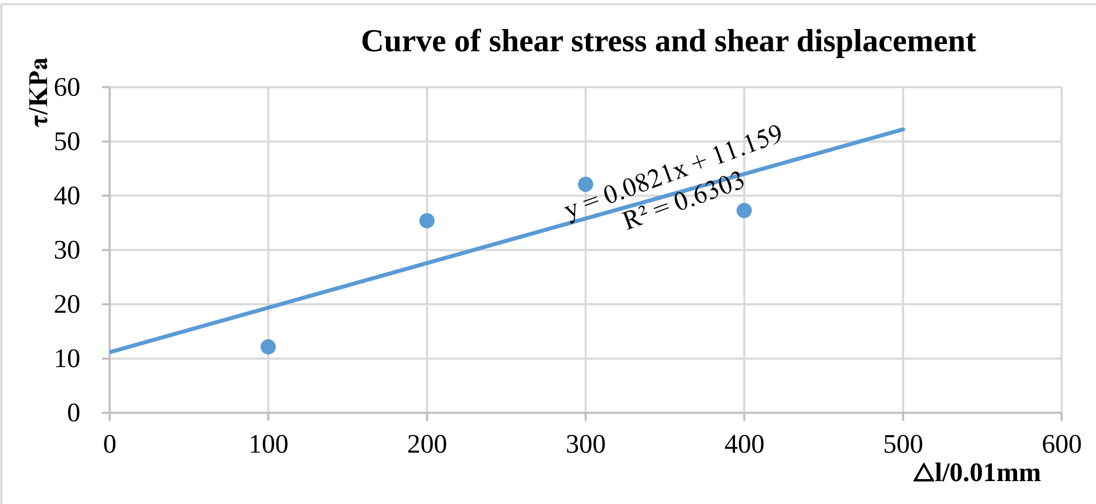

Figure 4: Curve of shear stress and shear displacement

Table 3: Consolidation test of remolded soil samples soaked in saturated red clay (sampled from embankment slope)

Test and record table of the compression coefficient, compression modulus, compression index, and consolidation coefficient of soil consolidation (uniaxial consolidation instrument method)										
Trial basis	JTG E40-2007					Sample number		Embankment slope soil samples 1		
Sample description	No plant roots					Sample name		Adamic earth		
condition of experiment	Temperature: 20.0~22.0 ℃ relative humidity: 61.0~62.0%					Date of test		20190504		
The original height of the sample h_0(mm)	20.01		Pretest porosity ratio e_0			0.64		C_V		e-p curve
Calwe time (h)	Pressure P_i (kPa)	Total deformation of sample (mm)	Compressed sample height (mm)	Unit settlement (mm/m)	void ratio	Average test height (mm)	Difference of unit settlement (mm/m)	modulus of compression (kPa)	coefficient of compressibility ($10^{-3}kPa^{-1}$)	
0	0	0	20.010	0	0.32	20.667	65.7	761.42	1.73	
24	50	1.314	21.324	65.7	0.23	21.630	30.6	1634.80	0.81	
24	100	1.926	21.936	96.3	0.19	22.304	36.8	2718.75	0.49	
24	200	2.662	22.672	133.0	0.14	22.959	28.7	3486.06	0.38	
24	300	3.236	23.246	161.7	0.11					

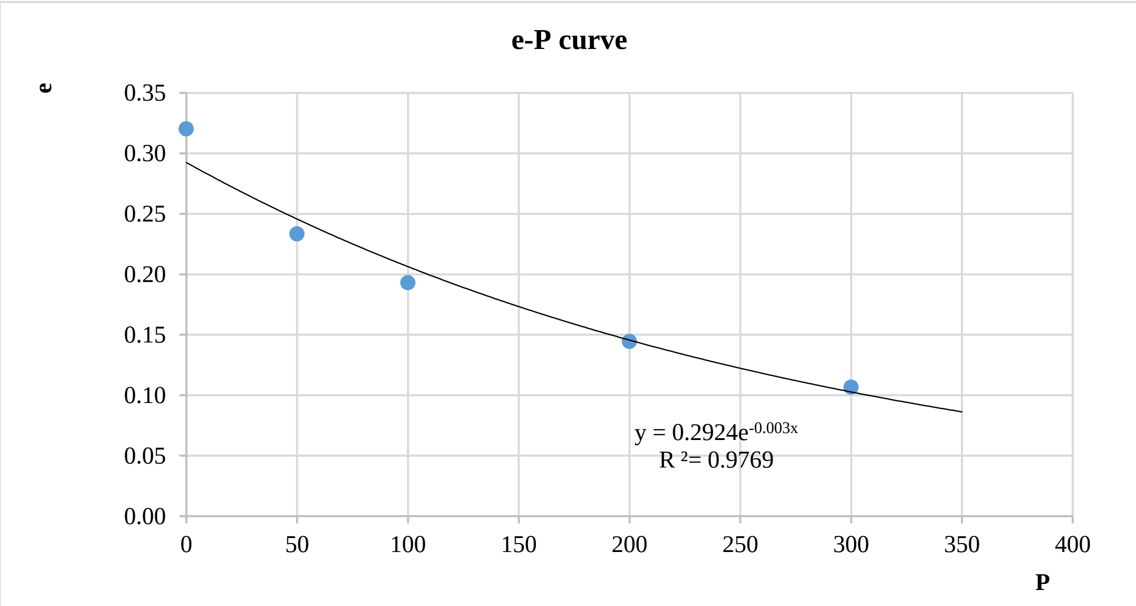

Figure 5: e-P curve drawing of the sampling point of embankment slope

Table 4: The consolidation test of soil samples (sampling point of abutment back)

<table>
<tr><td colspan="11">Test and record table of the compression coefficient, compression modulus, compression index, and consolidation coefficient of soil consolidation (uniaxial consolidation instrument method)</td></tr>
<tr><td colspan="2">Trial basis</td><td colspan="4">JTG E40-2007</td><td colspan="2">Sample number</td><td colspan="3">Bridge platform back fill soil 1</td></tr>
<tr><td colspan="2">Sample description</td><td colspan="4">No plant roots</td><td colspan="2">Sample name</td><td colspan="3">Adamic earth</td></tr>
<tr><td colspan="2">condition of experiment</td><td colspan="4">temperature:20.0~22.0 ℃ relative humidity:61.0~62.0%</td><td colspan="2">Date of test</td><td colspan="3">20190504</td></tr>
<tr><td colspan="2">The original height of the sample h_0 (mm)</td><td colspan="2">20.01</td><td colspan="2">Void ratio before test e_0</td><td colspan="2">0.64</td><td colspan="2">C_V</td><td rowspan="11">e-P curve</td></tr>
<tr><td>Calwe time (min)</td><td>Pressure P_i (kPa)</td><td>Total deformation of sample (mm)</td><td>Compressed sample height(mm)</td><td>Unit settlement (mm/m)</td><td>void ratio</td><td>Average test height (mm)</td><td>Difference of unit settlement (mm/m)</td><td>modulus of compression (kPa)</td><td>coefficient of compressibility ($10^{-3}kPa^{-1}$)</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>20.010</td><td>0</td><td>0.20</td><td rowspan="2">20.186</td><td rowspan="2">17.5</td><td rowspan="2">2850.43</td><td rowspan="2">0.42</td></tr>
<tr><td rowspan="2">7</td><td rowspan="2">50</td><td rowspan="2">0.351</td><td rowspan="2">20.361</td><td rowspan="2">17.5</td><td rowspan="2">0.18</td></tr>
<tr><td rowspan="2">20.531</td><td rowspan="2">17.0</td><td rowspan="2">2942.65</td><td rowspan="2">0.41</td></tr>
<tr><td rowspan="2">7</td><td rowspan="2">100</td><td rowspan="2">0.691</td><td rowspan="2">20.701</td><td rowspan="2">34.5</td><td rowspan="2">0.16</td></tr>
<tr><td rowspan="2">20.972</td><td rowspan="2">27.0</td><td rowspan="2">3698.71</td><td rowspan="2">0.32</td></tr>
<tr><td rowspan="2">8</td><td rowspan="2">200</td><td rowspan="2">1.232</td><td rowspan="2">21.242</td><td rowspan="2">61.6</td><td rowspan="2">0.13</td></tr>
<tr><td rowspan="2">21.454</td><td rowspan="2">21.2</td><td rowspan="2">4719.34</td><td rowspan="2">0.25</td></tr>
<tr><td rowspan="2">7</td><td rowspan="2">300</td><td rowspan="2">1.656</td><td rowspan="2">21.666</td><td rowspan="2">82.8</td><td rowspan="2">0.10</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
</table>

3.1.2 Indoor Infiltration Test

Because road embankment fillings belong to gravel soil according to soil quality, their permeability is larger, the constant head test method can be used to measure the permeability of fillings.

The principle of constant head test method is to keep the head constant during the whole test process, so the head difference is also constant as shown in Table 6.

During the test, fill the saturated sample with section A and length L. Open the water valve and make the water flow from the top and down through the sample and be discharged from the outlet.After the head difference of △h and the seepage flow Q is stabilized, measure the amount of water V flowing through the sample after a certain time t, then

$$V = Q \times t = v \times A \times t$$

According to Darcy's law, $v = k \times i$,then $V = k(\Delta h / L) \times A \times t$

Thus, it is concluded that $k = \frac{QL}{A\Delta h}$

Table 5: Statistical table of constant head test

specific gravity of soil partical	2.7			Sample height (cm)	30		Spacing of side pressure holes (cm)	10		Broken area of sample (cm^2)	78.5	Average permeability coefficient	0.2420
void ratio				Test dry mass (g)	4500		Soil sample description	Gravel earth					
trial number	process time (S)	piezometric level(cm)			Water level difference (cm)			hydraulic slope	Infiltration of waterQ (cm^3)	permeability coefficient KT (cm/s)	average water temperature T (℃)	correction Ht/η2	Permeability coefficient at 20℃ water temperature
		1 tube	2 tube	3 tube	H1	H2	average H						(cm/s)
1	15.69	269	264	262	5	2	3.5	0.35	100	0.2320	13.5	1.176	0.2728
2	28.73	269	264	262	5	2	3.5	0.35	150	0.1900	13.5	1.176	0.2235
3	41.71	269	264	262	5	2	3.5	0.35	200	0.1745	13.5	1.176	0.2052
4	9.69	269	263	260	6	3	4.5	0.45	120	0.3506	13.5	1.176	0.4123
5	20.93	269	263	260	6	3	4.5	0.45	150	0.2029	13.5	1.176	0.2386
6	30.35	269	263	260	6	3	4.5	0.45	170	0.1586	13.5	1.176	0.1865
7	42.86	269	263	260	6	3	4.5	0.45	200	0.1321	13.5	1.176	0.1553

According to the test statistics and calculation, the average permeability coefficient of embankment filler is 0.2420 cm/s.

3.2 Field Test

3.2.1 Determination of Internal Friction Angle of Embankment Filler

The Angle of repose and the angle of internal friction reflect the internal friction characteristics of granular materials, because the natural angle of repose is the appearance of internal friction characteristics, for the lack of cohesion of granular materials such as sand, the angle of repose is equal to the angle of internal friction. Using the geological compass, the parameters of natural angle of rerest of embankment filler after many tests are listed as follows Table 6:

Table 6: Field test statistics of natural angle of repose

Thickness of filler aggregate	Natural Angle of repose(°)	average value(°)
thick	42	42
thick	44	
thick	40	
thin	48	46.3
thin	45	
thin	46	

Therefore, it can be equivalent to say that the internal friction angle of the fine aggregate of the subgrade filler is 46.3°, and that of coarse aggregate is 42°. According to the most unfavorable factors, the minimum value is taken, and the internal friction angle of the subgrade filler is 42°. Since the filler is mainly gravel, gravel, and breccia with a small amount of clay, the cohesion can be set as 0.

3.2.2 Determination of Permeability Coefficient of Embankment Foundation-Red Clay Stratum

To test the permeability of red clay stratum in Dongfenglin Avenue, subgrade the pit test method is adopted.

Pit test method is to dig a certain depth (30-50 cm) in the surface dry soil square or round pit test, pit bottom 3-5 meters from the diving level, pit bottom spread 2 to 3 cm thick filter coarse sand, to test the pit water, must make the test pit water level is always about 10 cm higher than the bottom of the pit. To facilitate the observation of the water level in the pit, a ruler is placed at the bottom of the pit.

At the beginning of the test, the flow was controlled continuously and uniformly, and the water layer thickness (z) in the pit was kept as a constant value (e.g., 10cm). When the amount of water injected stabilizes and lasts for 2 to 4 hours, the test is over. When the test rock layer is coarse sand, gravel, or pebble layer, the thickness of the water layer in the pit z can be controlled to be 2 ~ 5cm.In the seepage test, the hydraulic gradient of seepage is:

$$\frac{H_k + z + L}{L} \approx 1$$

Then the infiltration coefficient is:

$$k = \frac{Q}{F} = V$$

In the formula: Q—— stable infiltration flow, cm3/min; F is the seepage area of the test pit, cm^2;

Hk —— capillary pressure head, cm, whose value can be determined by referring to Table 1;

L ——the water penetration depth, cm, at the end of the test, which can be determined by using a twist drill (or other drilling tool) after the test;

K ——Infiltration coefficient, cm/min.

The test record table is arranged as follows Tables 7-11:

Table 7: Field test equipment and parameters of pit test method

Test equipment	specifications	quantity
Timer stopwatch		1
Measuring cylinder	500ml	2
jig		1
Vernier caliper		1
ruler	30cm	1

Table 8: Test pit method - No. 1 test pit statistical table

Pit No.	Water injection(ml)	time(s)	The permeability coefficient(cm3/min)
	2400	796	
1	4800	559	
shape	3052	491	1.32*10-4
	2400	450	Infiltration depth
circular	100	1328	
size	10	3985	
	10	4040	
37.75cm	10	4050	42cm

Table 9: Test pit method - No. 2 test pit statistical table

Pit No.	Water injection(ml)	time(s)	The permeability coefficient(cm3/min)
2	480	458	6.37*10-5
	480	459	
shape	480	514	
circular	480	568	Infiltration depth
	480	1859	33cm
size	1	834	
37.75cm	1	840	
	1	846	

Note: To prevent leakage from affecting the measurement of permeability coefficient, smooth the side wall with mud surface

Table 10: Test pit method - No. 3 test pit statistical table

Pit No.	Water injection(ml)	time(s)	The permeability coefficient(cm^3/min)
3	480	158	1.18*10-4
	480	274	
shape	480	391	
circular	480	840	Infiltration depth
	480	1692	24cm
size	10	2859	
37.75cm	10	2962	
	10	2961	

Table 11: Test pit method - No. 4 test pit statistical table

Pit No.	Water injection(ml)	time(s)	The permeability coefficient(cm^3/min)
4	480	184	3.75*10-5
	480	629	
shape	480	797	
circular	480	1248	Infiltration depth
	480	1242	13cm
size	2	2855	
37.75cm	2	2852	
	2	2848	

According to Tables 8-11, the average permeability coefficient of foundation red clay stratum is $8.78*10^{-4}cm^3$/min. The test results show that the test results are reasonable. However, it is found that the different state and humidity of soil have great influence on the test results, and the lateral wall permeability of the test pit also has an obvious influence on the test results.

4. Stability analysis of embankment slope and subgrade under reservoir water storage condition

4.1 Current state of embankment slope of Dongfenglin Avenue

In Dongfenglin Avenue, Yilong New District, Xingyi City (distance: K1+600 ~ K3+840), the filling slope adopts the form of 1:1.5 two-stage to four-stage slope release (slope release Angle: about 33.7°) + dry stone slope protection (as shown in Figure 6). At present, all other works are completed except pavement. Through field survey and measurement, the measured slope Angle of K1+600 ~ K2+840 section is 38°, and that of K2+400 ~ K3+980 section is 40°~ 42°. According to the results of multiple field survey, both are in a stable state.

Figure 6: Photo of embankment slope of Linfeng Avenue, Yilong New District

4.2 Calculation of Embankment Stability Under Reservoir Storage Conditions

The embankment slope of Linfeng Avenue in Yilong New District, Xingyi City, was soaked for a long time during the water storage process of the proposed Mabiantian reservoir project in Anlong County, and the water level of the reservoir caused the embankment slope to flow upward, resulting in the reduction of the shear strength of the rock and soil mass of the slope, which seriously threatened the stability of the slope. Especially when the reservoir is in normal use, the water level in the reservoir area changes periodically because of the seasonal wet season and dry season. The rising process of water level causes upward seepage, and the falling process causes downward seepage, which seriously affects the stability of embankment slope and road safety.

Due to the impaction of Mabiantian reservoir, the groundwater formed stable seepage in Linfeng Avenue, embankment, and roadbed. In the stable seepage period, a stable seepage flow network is formed in the dam body.

4.2.1 Theory of computational analysis

The effective stress method is used to calculate the stability of the embankment slope during the stable seepage period.

(1) Calculation method of safety factor in stable seepage period

The effective stress method is used to analyze the stability of the embankment slope during the steady seepage period.

The effective stress method is based on the effective stress principle proposed by K. Terzaghi (1923) that the deformation and strength of soil in soil are closely related to the effective stress σ' in soil:

$$\sigma = \sigma' + \mu \quad (1)$$

to calculate and analyze the slope stability.

In the formula, σ is the total normal stress in the plane, kPa; σ' is the effective normal stress in the plane, kPa; μ is the pore water pressure, kPa.

According to formula (3-1), the effective stress method adopts the formula to calculate the pore water pressure u:

$$\mu = \mu_0 - \gamma_W Z \tag{2}$$

$$\mu_0 = \gamma \bullet hB \tag{3}$$

In the formula:

γ_W —— Water density(kN/m^3);

Z —— The distance of the water level outside the dam slope above the midpoint of the bottom surface of the strip(m);

u —— Pore pressure acting on the bottom surface of soil strip(kPa);

u_0 —— Pore pressure during construction(kPa);

B —— Pore pressure coefficient, user interaction;

γ —— The average bulk density of soil above a certain point(kN/m^3);

h —— Height of fill above a certain point(m).

The calculation formula of pore water pressure u is as follows:

$$\mu = \mu_i - \gamma_W Z \tag{4}$$

In the formula:

u —— Pore pressure acting on the bottom surface of soil strip(kPa);

u_i —— Pore pressure during steady seepage(kPa);

γ_W —— Water density(kN/m^3);

Z —— The distance of the water level outside the dam slope above the midpoint of the bottom surface of the strip(m).

(2) Calculation results of safety factor in stable seepage period

Through the rock and soil calculation software, according to the relevant physical and mechanical property parameters and road design and construction drawings, the stability of the calculation analysis is referred to the appendix (embankment slope stability calculation book), and the calculation results are shown in Table 12.

Table 12: Calculation results of embankment slope stability under water storage conditions in the reservoir area

Calculate the profile mileage number	Check flood level Fs	Designed flood level Fs	Stable water level Fs	Note
K1+600~K1+640	1.102	1.179	1.273	Safety factor & gt; 1.20 is the stable state; 1.20 & gt; safety factor & gt; 1.00 is under stable state; The safety factor & lt; 1.00 is the unstable state;
K1+660~K1+700	0.769	0.978	1.014	
K1+720~K1+740	0.848	0.887	0.929	
K1+760~K1+800	0.804	0.852	0.913	
K1+800~K1+820	0.762	0.815	0.877	
K1+820~K1+840	0.803	0.852	0.891	
K1+840~K1+880	0.792	0.844	0.898	
K1+880~K1+920	0.859	0.927	0.972	
K3+300~K1+340	0.884	0.936	0.996	
K3+740~K3+840	0.935	0.979	1.023	

Note: (1) Judging the stability according to ——GB50286-2013 embankment engineering design code;

Calculated according to the checked flood level of 1158.42m, the designed flood level of 1155.49m, and the stable water level of 1152m.

5. Conclusions

Through field test, indoor test, and theoretical calculation analysis, it is shown that the storage of Mabtian Reservoir has a great impact on the embankment section of Dongfeng Forest and threatens its operation safety.

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