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Prediction-Forecast and Slip-Control for One Slope

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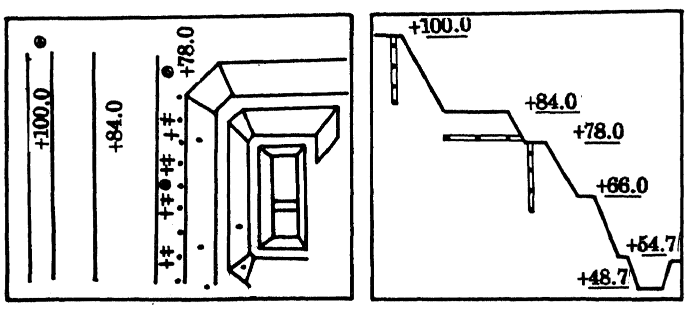
SYNOPSIS Firstly,combining the engineering geological conditions of the slope, this paper analyses the forms and main causes of the slope possible slip, and predicts the slope's stability in the different construction periods of the gully at the bottom of slope. In the basis of these, the work plan of quick cutting quick erecting for the gully is emphatically discussed. Then, the paper presents the slope monitoring method and monitoring results. At last, the paper re-analyses the site-monitoring data. The results of monitoring and re-andysis prove that work plan of quick cutting and quick erecting is correct and the poured concrete improves the state of the force on the slope and takes really effect on pressing the slope's bottom in time.

INTRODUCTION

The QingJiang hydroelectric station, in one tributary of the Changjiang River, with 12 million kilowattes installed capacity, has a man-made slope. The slope is designed about 50 meters high from the floor of the gully, +48.7m, to the terrene, +100.0m, with a shape like a convex ladder, and its average gradient is 48.5 degrees(Fig.1). The composition of the slope is



multi-points displacement gauge
rift meter   simply rift meter
• CLY displacement gauge
Fig.1. sketch map of slope's plan, section and instruments installed

soft and weak shale. There are many small faults and joints in the slope. In the constructing period of the slpoe upon the gully, several down falls happend to the slope, it made that almost none berms exsited under +78.0m. For this, the stability of the slope in the gully construction period is predicted. By the prediction, it is known that if normal construction speed were used in the gully construction, not only the construction difficulty should be great, but also large scope down falls and landslides should happen possibly. Therefore, it will be key that how to guarantee the construction safe, form the slope and erect the station's structures on schedule. This paper will emphatically introduce the successful experiments for sloving these problems.

GEOLOGICAL CONDITIONS OF THE SLOPE

The slope is made of Cambrian system shale and sandstone, with deep grey, grey-black and grey-green. The rock interlayer distanace is 15~25cm, middle thick. The strike of rock layer is N65° ~75° E and dip direction is 34 ° ~40° . The strike of rock masses intersects the slope's surface, it is advantageous to the slope's stability.

According to a lot of the results of test in laboratories and the site, we known that the shale is weak, breaking and joints and thin cracks development, and exists obviously the characteristic of multi-layer.The mechanics parameters of the shale are those as table 1.

Table 1. Machanics parameters of the shale

coagulability (MPa)	friction coefficient
0.07~0.13	0.54~0.73

The geological reconnaissance shows that the hydrogeological conditions of the slope district are simple. However, the gully is easy to be formed a sluice area and the slope becomes a converging water passageway since the gully is in the bottom of the slope. It will be disadvantageous to the stabillty of the slope with cracks.

PREDICTION-FORECAST OF SLOPE'S STABILITY AND CONSTRACTION MEASURES DECISION

The average gradient of the slope is 54.7° under +84.0m berm, with every berm slope grand 66° . The slope is a high-steep shale slope, moreover, there are many large joints or small faults in +78.0m berm along with the slope's strike. So,it is easy to happen tension correction collapse,fall or landslide along with the joints or faults when the gully is cut. Therefore,in order to draw up a reasonable work plan, the slope's stability in the different construction periods of the gully must be predicted.

1. The slope's stability prediction

In the basis of anaysing the engineering geological conditions, Janba method is used to calculate the stability coefficients of the slope when the gully is cut or erected to +60.0m, +54.7m, +51.0m and +48.7m level.

The mechanics model of Janba method is as Fig.2. The calculation formula of the slope's

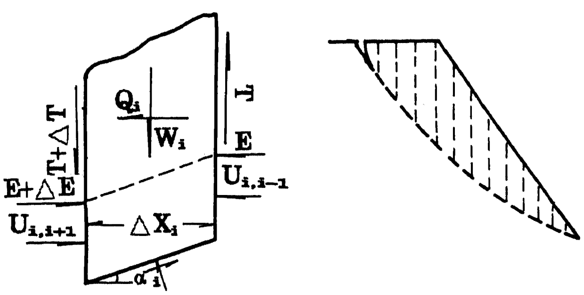


Fig.2. Mechanics model of Janba method

stability coefficient is

$$F_s = \frac{\sum \left[C_i \triangle X_i + (W_i + \triangle T_i - U_i) f_i \right] \dfrac{\sec^2 \alpha_i}{1 + \dfrac{f_i}{F_s} tg\,\alpha_i}}{\sum Q_i - \sum (W_i + \triangle T_i) tg\,\alpha_i} \qquad (1)$$

where Fs is the stability coefficient of the slope; W_i is the weight of No. i strip rock block; U_i represents the pore water presure; T_i is the vertical shearing force between No. i and No. i+1 strip blocks; Q_i is the horizontal loads of No.i block; f_i and C_i represent separately the friction coeffictent and coagulability of No. i block on slip surface.

The mechanics parameter Values in calculation are $C=1.98\times10^5$Pa , f=0.3 and $\gamma=2.62\times10^4 N/m^3$. The calculaltion results are as table 2.

Table 2. Prediction results of the slope's stability

height of working face	H(m)	+60.0	+54.7	+51.0	+48.7
stability coefficient	Fs	1.56	1.27	1.10	0.93

* H is the height of working face , cutting from up to down or erecting from down to up.

By regression analysis of the table 2, the relations between H and Fs are known (table 3).

Table 3 Relations between H and Fs

Fs	0.90	1.00	1.05	1.10	1.15	1.20
H(m)	+47.51	+49.64	+50.66	+51.65	+52.62	+53.55

We know that the stability coefficients of a slope have relations with the deformation development stages of the slope. Refering to the reference [1] , We can believe that the slope is in partial deformation stage when the gully is cut to + 54. 7m and in ultimate equilibrium state and into acceleration deformation stage when cut to +51.0m. When the gully is cut to +48.7m level, the slope will slip. If the gully can be poured concrete to +54.7m (Fs=1.27) in time, the slope's slip can be contraled mainly. If the gully is poured concrete to about +60.0m, the slip-contral of the slope can be ensured.

2. Considing for constraction decision

By foregoing paragraphs analysis, it is known that the slope is in dangerous period when the gully is cut under +51.0m level. Obviously, for safe construction, the slope is in mainly stable state must be ensured when the gully is cut to +48.7m. For this, water removing, resisting sliding reinforcing and supporting of the slope surface as well as cutting upon slope for reducing load etc. may be used. However, it is obvious that these methods not only have large amount of work,not worthwhile in economy, but also require long construction time. Therefore, these methods are very disadvantageous to the gully's construction which is required to pour concrete to established height before high-water season.

In view of the geological conditions of the slope and the predicting results, we consider using quick construction plan, namely to shorten the construction time and try to finish the construction task before the slip of the slope. If the quick construction plan can be successfully carried out, not only a lot of manpower and material resources are used sparingly, but also a large amount of time is saved. Using quick construction plan, there are advantageous conditions as follows.

1) The destailuizing of a slope is a course from gradual change to sudden change, and the course time depends on Fs and the characteristic of the slope's rock masses etc.. By the predicting results and the similar examples, it is known that the slope only may be in slow slip stage when the gully is cut to +48.7m. So, the time of the slope destabilizing, comparatively speaking, is longer.

2) Fs=0.93, after the cutting of the slope is finished. Therefore, the stability state of the

ılope in cutting course can be improved by ıupport measures like guniting or grouting and ·ockbolts etc..

ı)By table 3, we know that the deformation of :he slope is in acceleration stage when the ılope is cut to about +51.0m, but the surplus :utting height is 2.3 meters and the cutting ›arth and rock is only about 600 cubic meters :ight now. Therefore, concentrating the :onstruction power, under construction guide of :he site monitoring,inside 10~15 days,finishing :he 600 cubic meters cutting and reecting the ıydroelectric structures to +54.7m level, 'S=1.27, are completely possible. So, the ›lan of quick cutting and quick erecting is 'inished possibly.

ı) We know that room overlooking the slope is small through Fig.1. So, although the pusher Landslide happens to the slope, it is not Large zone.

5) The whole construction course is done under the site monitoring guide and konwing the slope's deformation stage. Therefore, the construction safety can be ensured.

3 Construction decision

In the basis of aforementioned analysis, by conscientious discussion, we think the quick construction plan is practicable and decide to use it.

MONITORING SYSTEM AND MONITORING RESULTS OF THE SLOPE

1. Monitoring system

According to the engineering geological conditions and the results of stability prediction of the slope, for timely and accurate catching the deformation of the slope in the construction course of quick cutting and quick erecting, and ensuring the construction safety, in the monitoring design, not only remote survey in dangous time is considered, but also the accuracy and reliability of the monitoring are thinked. So, the monitoring plan, mechanical and electric instruments verify one another, microcosmic and macroscopic investigations combine each other and the earth surface and underground monitoring at the same time, is used. The instruments will be installed additionally with the deformation and cracks development of the solpe. Finally, the installation of instruments is that as Fig.1.

2. Monitoring results

The reasonable construction plan that obtains by scientific prediction and combining the site monitoring is a decisive factor for the successful coonstruction of the slope. The gully, at the bottom of the slope, was smoothly erected to +54.7m level on schedule, on 16th January, 1990, and it made the slope stabilize. The typical displacement curve of the slpoe by monitoring with the gully's construction is as Fig.3 and the creak developments on the grade surface by naked eye observation are as Fig.4. Table 4 shows the deformation features of the slope.

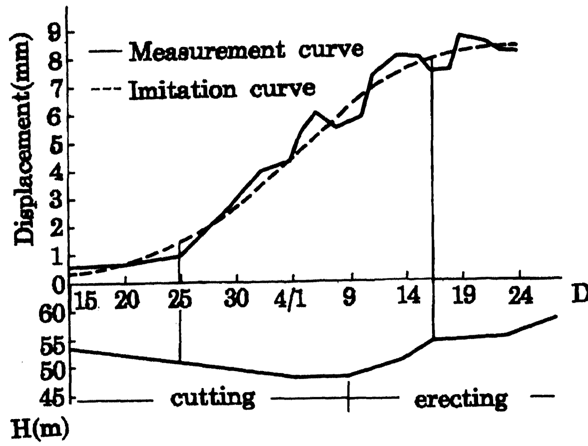
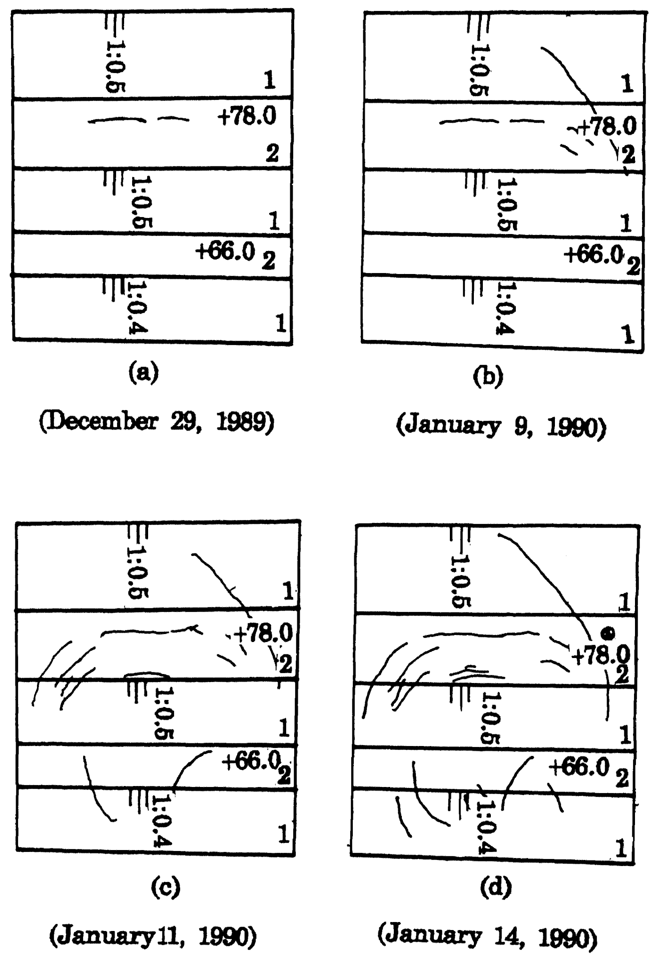


Fig.3. Typical curve of slope's displacement



1-grade surface 2-berm ∫-crack
Fig.4. Sketch map of slope's crack development

Table 4. The deformation features of the slope

time	cutting or other influence factor	displacement speed (mm/day) Vmax	$\bar{V}$	producing and development of cracks on grade surface	measures
November ~25th December, 1989	cut to +51.0m	0.30	0.10	----	decide the quick cutting and quick erecting construction plan
25th~31th December, 1989	remove soil-stone, small snow from 25th to 27th	1.05	0.65	produce a crack(Fig.4a) on +78.0 berm	----
1th~4th January, 1990	cutting	0.23	0.13	the crack is developing slowly	----
5th~8th January, 1990	remove soil-stone	1.15	0.38	find new cracks on guniting surface on 6th	gunite lining on 5th,install 12 contingents of slit guages on 8th
9th~12th January, 1990	remove soil-stone	0.78	0.47	①produce associated cracks (Fig.4b) ②the width of main crack in +78.0m berm is about 1.0cm and the crack has malposition ③produce three associated cracks and the main crack has developed to the edge of the slope(Fig.4c) on 11th	erect No.1 layer concrete, high 2.6m,and install 2 contingents of slit guages on 9th
14th January, 1990	middle rain on the night of 13th, remove soil-stone in boundary and corner,handle shortfall cutting	----	0.30	①produce partial spalling of the guniting layer on the grade surface from +66.0m to +78.0m ②the cracks on the grade surface have cut through one anther (Fig.4d)	start pouring No. 2 layer concrete,high 3.4m,at 15:00 of 14th
16th~17th January, 1990	----	-----	0.08	①the slope become stable on 17th ②when the gully is erected to +60.0m,the main crack shows partial closure	erect to +54.7m on the afternoon of 16th

By the deformation laws of the slope in Fig.3, Fig.4 and talbe 4, it is not difficult to find that the prediction-forecast of the slope's stability before the construction is accurate, the quick construction plan is correct and quick erecting the hydroelectric structures achieve the goal of preventing slip in time.

RE-ANAYSIS OF THE MONITORING DATA

By aforementioned analysis, it is known that the implement of the quick construction plan depends on the time of the slope from acceleration deformation stage to slip. Through the prediction and the monitiring results, we know that the slope has gone into acceleration deformation stage when the slope is cut to +50.7m level. New, supposing the hydroelectric structures have not be erected in time after the slope gets into acceleration deformetion stage, what moment landslide will happen to the slope. By the analysis of the monitoring curve of the slope, GM(1,1)-Verhust integrated grey system model is used to forecast the moment of which landslide happen.

The white differential equation of GM(1,1) model is

$$\frac{du^{(1)}(t)}{dt}+au^{(1)}(t)=b \qquad (2)$$

that of Verhust model is

$$\frac{dp^{(1)}(t)}{dt}=ap^{(1)}(t)-b\ (p^{(1)}(t)) \qquad (3)$$

where a and b are the parameters to be determined, $u^{(1)}(t)$ is the monitoring data series after through average optimum, smoothed average and one-order accumulated, $p^{(1)}(t)$ is the one-order accumulated displacement speed series obtained by GM(1,1) model.

The landslide moment can be sloved by the equation(3). The soution is

$$t = \frac{1}{a} \ln \frac{a - bp^{(0)}(1)}{bp^{(0)}(1)} + t_0 \qquad (4)$$

where t is the time order that the slope starts to slip; t_0 is the first time order and $p^{(0)}(1)$ is the first displacement speed of the slope that is used to calculate.

We input the data of the acceleration deformation stage in Fig.3, operate GRFC.FOR program, the calculation program of grey forecast model, and gain the slip starting moment to be 12:39 of 17th. January, 1990. So there is one day difference between the starting moment of slip and pactal stable, 16th January, 1990, namely to stablize the slope ahead of slip. Thus it can be seen that construction plan of quick cutting and quick erectingg is a decisive factor for the suceessful cutting of the gully and above mention technical line and method are effective.

CONCLUSIONS

The successful stability prediction- forecast and smooth construction of the slope, it shows,

1) In the slope, under safety factor is less than or equal to 1.0,it is successful to predict the slope's stability before the slope is formed, to install the monitoring instruments and utilize the feedback techinque of the monitoring information to guide the site construction, as well as finally form the design slope.

2) Using the time of the slope from its creep deformation stage to slip to erect quickly the concrete structures at the slope's bottom and use it to resist the slope deformation is successful.

3)Above successful experiments show that using above mention method and technology to cut some slpoes with which safety factor is less than or equal to 1 is fully possible.

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