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Research On Slope Stability Analysis Method Based On Limit State Design Method Of Partial Coefficient

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Abstract. The arch dam design specification (SL282-2003) provides an allowable safety factor of 3.5 in abutment stability analysis, whether at the same safety level with value of 3.0 specified for gravity dams. The approach of ‘Ratio of Safety Margin’ can compare the safety factor with reliability index. The researches confirm that allowable reliability index of 4.45 and the allowable safety factor of 3.5 at the same level of risk control.

1. Introduction

The sliding stability of arch dam abutment is always very important during the design stage. The “design code for concrete arch dam (SL 282—2003)[1]” rules I grade arch dam under basic load combination, the safety factor of the abutment stability F_a=3.5, but the safety factor of gravity dam foundation sliding stability F_a=3.0, it can be understood that abutment force is more huge; even the abutment stability is not only related to the abutment stability of arch dam, but also affects the overall of the arch dam. Therefore, relative to the gravity dam, larger safety factor is necessary for the abutment stability. The “design code for concrete arch dam (DL/T5346-2006) [2]" rules the abutment stability design method is limited state design method of partial factor, and the original "F_a=3.5" is forbidding to use.

In the analysis of sliding stability of dam, this new method uses γ_0、ψ、γ_d、γ_{m1f}、γ_{m1c} 5 new parameters to calculate the safety factor, which compare with allowable safety factor of grade I buildings under normal operation conditions. The designing of arch dam is a traditional fields, the original requirements F_a=3.5 is accumulated in the long-term practice, to be replaced by a new method in the partial factor approach, standardized preparers and users should accept the rationality of the new safety standards and parameters, another issue is new standards of the safety factor in the specification whether at the same level of risking control.

In this paper, the author in the field of limit state design method of partial factor dam has done some exploratory research [3], [4]. In order to assess rationality of partial factor under a particular target condition, research team proposes an analysis approach called ratio safety margin, the conclusions show recommended values of partial factor c and f were basically reasonable, the safety factor of traditional method Fa=3.0 and the reliability index βa=4.2 at the same level of risk control, this paper intends to carry out the reliability index and partial factor standard of abutment slides stability.

For the sliding stability of the abutments, which reliability index of structure is allowable? The "hydraulic structural design standard (GB5019994)" rules allowable reliability index 4.2 under dam Grade Ⅰ and damage type II. The calibration of partial factor of gravity dam stability analysis is established on this basis [3-4]. However, the safety factor is improved from 3 to 3.5; the abutment stability reliability index should also be improved from 4.2 to a corresponding value. The value is obviously a very difficult problem, but also a fundamental problem must be solved, this paper makes a discussion.

2. Review stability deterministic model and reliability analysis of the basic theory

Sliding stability analysis of abutment is established in the potential unstable rock blocks based on the static equilibrium conditions. Londe (1993) proposed analysis model after the analysis of Marr Pa Jose case was shown in Figure 1 [5]. As can be seen from the chart, the arch thrust and potentially unstable wedge cross ridge are roughly parallel to the river direction. The wedge to slid must also along the arch dam (position of arch thrust) vertical plane form a split, a vertical surface which is an important condition, in the geological body has developed a set to approximately perpendicular to the arch thrust steep fracture surface. The abutment stability analysis model of Londe recommends have been incorporated into "the arch dam safety assessment guidelines of American energy" which was used to analysis slope wedge stability check [6-7].

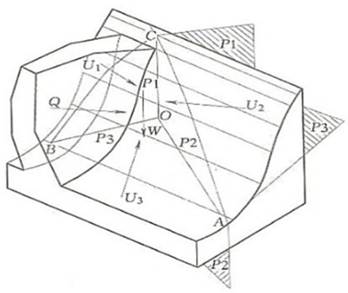

Fig. 1 Londe (1993) note analysis model proposed abutment unstable wedge

OABC rock wedges, P1, P2, P3 discontinuity, as in rock U1, U2, U3 as the water pressure, W weight, Q is the thrust of arch.The wedge stability safety factor formulation of the traditional model as follows:

$$F = \frac{\sum S}{\sum T} = \frac{\sum (Nf_1 + c_1 A)}{\sum T} \quad (1)$$

F is the safety factor of sliding stability; $\sum S$ is sliding force of wedge body, including cohesion and friction; $\sum T$ is thrust wedge ; N is a vertical sliding surface; and the normal force;$f_l$and $c_l$respectively on the sliding surface coefficient of friction and cohesion.

To calculate reliability index of the abutment sliding stability, need linear transformation of the safety factor expression [6-7], and after the conversion expression is as follows:

A_1, A_r respectively for about surface area; c_1, c_r and f_l, f_r are Cohesion and friction coefficient of the left and right sliding surface; in n_l and n_r two surface; j as a unit vector two smooth cross ridge, θ is an included angle of two surface is wedge weight; W the external load, and on the two surface of the pore water pressure force size, w is the unit force vector. Equation (2) shown that the safety factor of stability can be expressed as a linear function which is made of the shear strength parameters of slip surface. Take arch dam for example to illustrate the computational process of sliding stability safety factor of deterministic model.

$$\begin{cases} F = Ac_l + Bc_r + C\tan\phi_l + D\tan\phi_r \\ A = \dfrac{A_l}{a_w W} \\ B = \dfrac{A_r}{a_w W} \\ C = -\dfrac{(\boldsymbol{w}\cdot\boldsymbol{n}_l - \boldsymbol{w}\cdot\boldsymbol{n}_r\cos\theta)W\operatorname{cosec}^2\theta}{a_w W} \\ D = -\dfrac{(\boldsymbol{w}\cdot\boldsymbol{n}_r - \boldsymbol{w}\cdot\boldsymbol{n}_l\cos\theta)W\operatorname{cosec}^2\theta}{a_w W} \\ a_w = \boldsymbol{w}\cdot\boldsymbol{j} \end{cases} \tag{2}$$

3. The ratio of safety margin

The author's research team proposes a new criterion called the ratio of safety margin (RSM) which is used in the areas of traditional deterministic model of factor safety, reliability and limit states analyses. An equation for calculating RSM based on the reliability index is formulated.

RSM in terms of the traditional deterministic model of factor safety;

$$\eta_F = \frac{F}{F_a} \tag{3}$$

F is the calculated values of traditional deterministic model of factor safety; F_a is the respective allowable values in the specification.

RSM in terms of the limit states design model of partial factor of factor safety;

$$\eta_p = \frac{F_p}{F_{pa}} \tag{4}$$

F_p is the calculated values of limit states design model of partial factor of factor safety; F_{pa} is the respective allowable values in the specification.

RSM in terms of the reliability index;

$$\eta_R = (\beta - \beta_a)\sigma_F + 1 \tag{5}$$

Where σ_F is the standard deviation of F; β is the calculated values of reliability index; β_a is the respective allowable values in the specification of GB50153.

Take Songta arch dam for example to illustrate the computational process of sliding stability safety factor of deterministic model.

Songta hydropower station is located in Chayu city of Tibet autonomous region of Linzhi. The arch dam is 314m high, granite body development dikes with M2 of the right abutment is the side surface, Moderate dip angle fracture with rock tendency is NE or NW, and inclination is NE or SE, which formed the bottom slip surface. Side surface and bottom slip surface has been constitutes the typical wedge failure mode of right abutment. The inclination of M2 is 243°∠85°, the M2 has distribution between elevation 1610.00 m and 1928.00 m; Moderate dip angle fracture with rock tendency is 105°∠25°. Figure 2 is the Songta arch dam right abutment geological map, the parameters for sliding stability analysis of arch dam abutment are shown in table 1, the standard value of material parameters is the 0.2 percentile value, the coefficient of variation V_f=0.2, V_c=0.35.

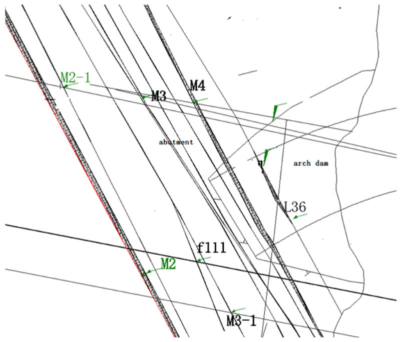

Fig.2 Songta arch dam geological plan of right abutment

Table 1 Sliding body parameters of Songta arch dam right abutment

item		parameters
volume /m^3		2467642
density / (kN/m^3)		27
bottom slip surface	area /m^2	64169
	mean value of strength parameter	f=0.894，c=592.9 kpa
	dip angle	105°∠25°
side slip surface	area /m^2	29848
	mean value of strength parameter	f= 0.209, c=42.35 kpa
	dip angle	243°∠85°
external force	fx/kn	-5173803.6
	fy/kn	-5852841.8
	fz/kn	-2346267.9
vector of ridge direction		（0.412，-0.864，-0.289）
slipping mode		double slide

According to the formula and the parameters can compute sliding stability safety factor of Songta arch dam abutment with the traditional deterministic model F=3.51.

Songta arch dam is class I hydropower project, γ_{m1f}=2.4，γ_{m1c}=3.0 are adopted to calculate safety factor by partial factor method; this safety factor must be greater than the minimum safety factor $F_{P,a} = \gamma_0 \varphi \gamma_{d_1} = 1.32$.

The formula for calculating the sliding stability safety factor of arch dam abutment by partial factor method is as follow:

$$F_p = \frac{\left(\frac{\sum f_1 N}{\gamma_{m_{1f}}} + \frac{\sum c_1 A}{\gamma_{m_{1c}}}\right)}{\sum T} \geq F_{p,a} = \gamma_0 \varphi \gamma_d \quad (5)$$

γ_0 is importance factor of structure, the security levels of structure is I, II and III, corresponding numerical value are 1.1, 1 and 0.9; φ is the factor of design condition, the design conditions are included persistent condition, transient situation and accidental condition, corresponding numerical value are 1, 0.95 and 0.85; T is a sliding force along the sliding direction ,the unit is 10^3 kN; f_1 is the friction coefficient of shearing; N is normal force which perpendiculars to the sliding direction, the unit is 10^3 kN; c_1 is the cohesion coefficient of shearing; , the unit is MPa; A is area of sliding surface,

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the unit is m^2; γ_d is the structure coefficient whose value is 1.2; γ_{m1f} and γ_{m1c} are partial factor of material properties, corresponding numerical value are 2.4 and 3.0.

According to the parameters in Table 1, the sliding stability safety factor of Songta arch dam abutment by partial factor method F_p=1.362.

From the above analysis that the sliding stability safety factor of traditional deterministic model of songta dam is 3.51, then, the traditional method calculated the ratio of safety margin η_F =1.003; similarly, the partial factor method calculated the ratio safety margin η_P =1. 032; from the above analysis the β=4.434, if we select the reasonable of allowable value for β_a, the value of η_R, η_p and η_F should be close.

Now, we choose allowable reliability index β_a=4.45 to compute the ratio safety margin of reliability method: $\eta_R = (\beta - \beta_a)\sigma_F + 1 = (4.4534 - 4.45)0.794 + 1 = 1.027$.

The allowable reliability index of abutment β_a = 4.45, which is different from 4.2 in the specification. As discussed in the introduction, in view of the complexity of abutment and safety requirements of abutment, so safety standards of arch dam need to be improved higher than gravity dam. According to the results, allowable reliability index of abutment 4.45with safety factor of traditional deterministic model 3.5.at the same level of risking control.

4. different variation coefficients of single model example

The anterior segment analysis is showing that the reliable index is a basic theoretical problem for the abutment slides stability, for example, when taking allowable reliability index of songta arch dam β_a = 4.45, the result of ratio safety margin is η_R=1.027, η_F=1.003, which shown β_a=4.45 and F_a=3.5 are at the same risk level, for this case, almost the 4.45 is a reasonable choice.

The question for further argument should be as flow: (1) using different strength index of rock whether the same result can be saw about η_R and η_F; (2) the other projects whether can get a similar result. \This section only uses a different parameters and coefficient of variation of songta arch dam to make a further research.

Table 2 Ratio of safety margin conclusion table of abutment (V_c=0.3、V_f=0.2)

	η_F			η_R	
Condition	F_a=3.0	F_a=3.5	β_a=4.2	β_a=4.45	β_a=4.7
1	0.994	0.85	1.007	0.874	0.674
2	1.045	0.895	1.057	0.918	0.709
3	1.121	0.96	1.134	0.984	0.758
4	1.171	1	1.185	1.027	0.792

$\mu(1+2v)$, $\mu(1+v)$, μ and $\mu(1-v)$ are four different strength parameters are defined as the condition1, 2, 3, 4; the μ is mean value of strength parameters, V is variation coefficient of strength parameters.

The variation coefficients of strength parameters are V_c= 0.3, V_f=0.2, the results in Table 2, the ratio of safety margin conclusion of abutment is shown in Figure 3.

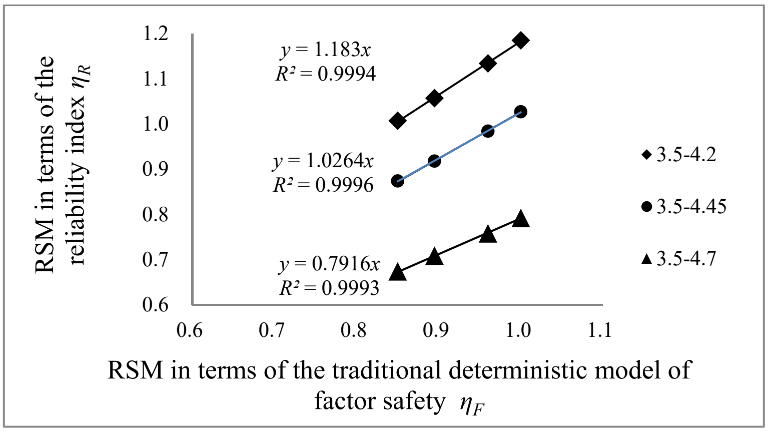

Fig.3 Regressions of ratios of safety margin about different β_a of songta arch dam(V_c=0.3、V_f=0.2)

Note: From left to right every point in the line shows different condition 1 to 4,3.5-4.2 is computing ratio of safety margin F_a=3.5,β_a=4.2

The fitting coefficient between η_F and η_R is 1.026 when minimum safety factor F_a =3.5 and allowable reliability index β_a=4.45, compared with the other two cases, this result is most closing to 1, which is showing F_a=3.5 and β_a=4.45 at the same level of risking control.

Table 3 Ratio of safety margin conclusion table of abutment (V_c=0.35、V_f=0.2)

	η_F		η_R		
Condition	F_a=3.0	F_a=3.5	β_a=4.2	β_a=4.45	β_a=4.7
1	1.17	1.003	1.204	1.05	0.779
2	0.876	0.75	0.98	0.782	0.55
3	1.464	1.254	1.49	1.292	1.02
4	1.758	1.506	1.799	1.475	1.281

In order to confirm the rationality of reliability index β_a =4.45, the variation coefficient V_c=0.35, V_f=0.2 are selected to do further investigated t, results in Table 3, the ratio of safety margin conclusion of abutment is shown in Figure 4.

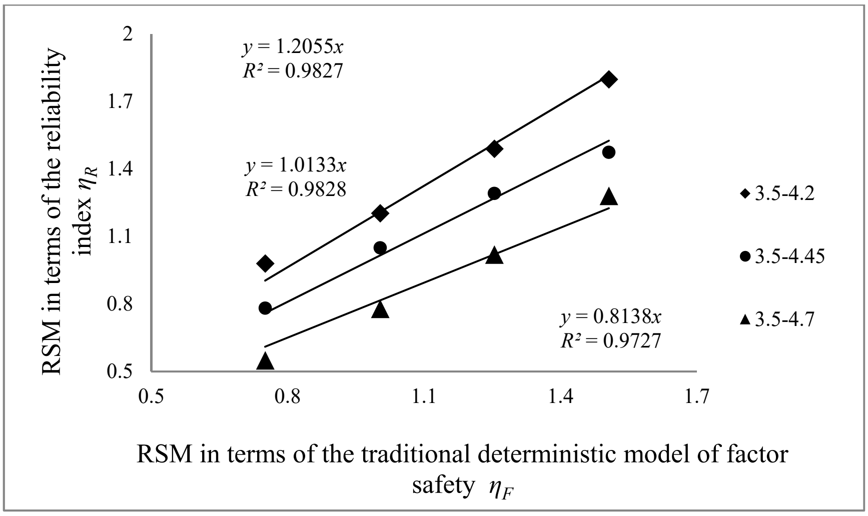

Fig.4 Regressions of ratios of safety margin about different β_a of songta arch dam(V_c=0.35、V_f=0.2)

The results are illustrated by Figure 5, the fitting coefficient between η_F and η_R is 1.013 when minimum safety factor F_a =3.5 and allowable reliability index β_a=4.45,

The fitting slope 1.013 is shown that F_a=3.5 and β_a=4.45 at the same level of risking control again.

5. Conclusion

Based on the method of ratio safety margin, according to the sliding bodies of songta arch dam, calculating the RSM under the condition of variation coefficient is V_c=0.3~0.35,V_f=0.2. The results show that the safety factor of traditional deterministic model 3.5and reliability index of reliability analysis method of 4.45 at the same level of risking control.

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