Stability analysis of accumulation body based on monitoring results of deep displacement

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ABSTRACT. *The stability of accumulation body commonly adopts a qualitative and quantitative analysis method, which considers the geological boundary conditions, calculation model and mechanical parameters of rock mass and so on This causes the stability results be limited, so it is unlikely to make a real-time quantitative evaluation on the accumulation body. This paper proposes a method which avoids these problems, and timely evaluates the accumulation stability based on the monitoring results in the process of the deformation development. It involves two parameters, i.e. the integrity index S(i) and the destructive index S(d), used to evaluate quantitatively the dynamic change of accumulation body when the progressive destroy occurs from the bottom up. Take talus in front of the dam of Zippingpu hydraulic project as an example, this method not only measures the S(i) and S(d) during movements of its reservoir water level, but also evaluates the impact of Wenchuan earthquake on the accumulation body. it is proved by an example that this method is convenient, practical and feasible..*

RÉSUMÉ. *Afin d'analyser la stabilité du corps d'accumulation, généralement une méthode d'analyse qualitative et quantitative est adoptée, qui prend en compte les conditions des limites géologiques, le modèle de calcul et les paramètres mécaniques de la masse rocheuse, etc. Cela entraîne une limitation des résultats de stabilité, de sorte qu'il est peu probable qu'une évaluation quantitative en temps réel du corps d'accumulation soit réalisée. Cet article propose une méthode qui évite ces problèmes et évalue en temps voulu la stabilité de l'accumulation en fonction des résultats de la surveillance dans le processus du développement de la déformation. Il implique deux paramètres, à savoir l'indice d'intégrité S (i) et l'indice de destruction S (d), utilisés pour évaluer quantitativement le changement dynamique du corps d'accumulation lorsque la destruction progressive a lieu de bas en haut. En prenant comme exemple le talus devant le barrage du projet hydraulique de Zippingpu, cette méthode mesure non seulement les indices S (i) et S (d) lors des mouvements du niveau de son réservoir, mais évalue également l'impact du séisme de Wenchuan sur le corps d'accumulation. Un exemple montre que cette méthode est simple, pratique et réalisable.*

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KEYWORDS: *talus, stability, real-time quantitative assessment, deformation of landslide in depth, monitoring.*

MOTS-CLÉS: *talus, stabilite, évaluation quantitative en temps reel, deformation en profondeur du glissement de terrain, surveillance.*

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1. Introduction

The stability evaluation method for accumulation body includes qualitative analysis and quantitative analysis (Zhu and Hou, 2007; Zhang and Wang, 2009; Wang *et al*., 2014). The former includes the natural history analysis method (Duncan, 1996), the engineering geological analogy method (Chen and Liu, 2007), the graphic method (Xia and Li, 2002), It makes a judgement by intuition and experience, relying on the nature and the characteristics of the object to be analyzed including its past and present existence states, and its evolution law. The subjective judgment of the analyst is often one-sided to reflect local differences between things, thus fails to achieve a reliable and accurate result (Sun *et al*., 2014; Chen *et al*., 2001). The latter mainly includes the rigid body limit equilibrium method and numerical analysis method and probability analysis method (Martha *et al*., 2013). Although it comes to a more intuitive, simple and accurate result, it will be difficult to accurately quantify some correlation factors. Currently, the rigid body limit equilibrium method, as features intuitive physical significance and the simple evaluation method, is most widely applied in geotechnical engineering (Shi *et al*., 2016). However, it does not consider the anisotropy of the medium and its deformation (Cheng and Zhou, 2015), there is a certain defect in practical use. While a number of edges (slip) project examples prove that, in the deformation development stage, the accumulation landslide occues, the sliding surface gradually changes with gradual deformation of the sliding body (Yang *et al*., 2017). Therefore, the mechanical parameters about rock mass of accumulation landslide are also subject to change with sliding surface (Yin *et al*., 2016). The traditional rigid body limit equilibrium method (such as the internal friction angle φ and cohesion c) hardly reflects the changes of accumulation body in real time (Zhang, 2014).

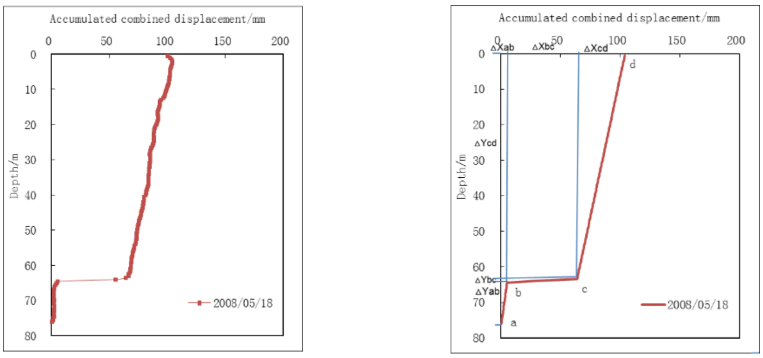
This paper applies a quantitative analysis of accumulation stability based on the monitoring results of the deep displacement to rapidly evaluate slope stability in the process of deformation (Sun *et al*., 2016). This method not only avoids error caused by geological boundary conditions, calculation model and the real-time change of mechanical parameters about rock, but also achieve real-time and quantitative analysis of the accumulation stability (Song and Song, 2017). The talus accumulation in front of the dam of Zipingpu hydraulic project is supposed as an example, the monitoring data of deep displacement was timely analyzed, thus the impact of Wenchuan earthquake on the stability of accumulation body is presented.

2. Generalization of monitoring results of deep displacement

Deep displacement, is one of the most commonly used means for the geotechnical engineering safety monitoring technology, which achieves deformation monitoring by measuring included angle between plumb line and inclinometer tube axis. The slope of the inclinometer tube is measured piecewise every 0.5m, so it is available for the horizontal displacement in the rock soil mass and the process that the displacement is subject to change with time interval. The potential sliding surface can be captured accurately, based on which to determine the size and direction of displacement caused by rock deformation, and the production parts. The displacement-time and displace rate-time relationship will be also available by monitoring work for a long time. It, by considering the changes of natural environment factors such as rainfall, groundwater level, etc., combined with the slope excavation, backfill, reinforcement and other construction factors, analyzes and judges the stability of various accumulation bodies, providing a real basis for design, construction, monitoring and early warning.

The comparative law is widely used for analysis of deep displacement, where the depth - accumulative displacement curve is dominant. The accumulation body takes potential sliding destruction such as on as a symbol; the slip zone takes destructions of sliding bed and slippery body as a symbol. The study shows that the deformation and destruction of the accumulation body occurs first in the slide bed and then gradually extends to the sliding body during the monitoring process.

The accumulative displacement of the earth surface is the sum of the relative deformations from the hole bottom to the slide bed, from the slip zone and the sliding body to the orifice of earth surface. In order to facilitate the analysis process, the displacement sum-time curve is plotted with 3-fold lines, as shown in Figure 1, the abscissa X represents accumulative displacement on the earth surface, the ordinate Y is the hole depth for monitoring deep displacement (from surface orifice to hole bottom), positive downward. The related components and meanings of the curve are as follows:



(a) Measured diagram (b) Generalization diagram

Figure 1. Accumulative displacement and hole depth distributionof deep displacement

(1) The X-Y plane coordinate system, the cumulative displacement-time relation curve (a) is mapped with three-fold lines, i.e. ab, bc and cd.

(2) In the map, the point a indicates bottom hole, as a deformation reference point (relative fixed point); b is sliding bed; c is junction between slide zone and sliding body; d is the earth surface orifice. Line ab represents the accumulative displacement of hole bottom (relative fixed point) to the sliding bed; line BC accumulative displacement of sliding zone; line cd accumulative displacement of sliding body to earth orifice.

(3) ΔXab, ΔXbc, ΔXcd, ΔXad respectively represent deep displacement of bottom hole (relative fixed point) to the sliding bed, the accumulative displacements of sliding zone and of surface bottom (relative fixed point) to earth surface orifice. There are:

$\Delta Xad = \Delta Xab + \Delta Xbc + \Delta Xcd$

(4) ΔYab, ΔYbc, ΔYcd respectively represent the hole depths from hole bottom part (relative fixed point) to the sliding bed, to sliding zone, and depth from sliding body to surface orifice.

3. Analysis principle of Si (Sd) index

Landslide takes shear destroy occurred in the sliding zone as a symbol, the process from evolution to destruction in landslide slip zone take a longer time. During landslide deformation and destruction, ΔXbc gradually increases, while ΔXcd, the landslide deformation above the landslide zone, gradually decreases. Therefore, a quantitative index is available for measuring the extent of landslide destruction, based on which to timely quantitatively evaluate the stability of the landslide.

$$S_i = \frac{\text{Accumulated displacement of sliding body to orifice}}{\text{Accumulated displacement of slide bed to orifice}} = \frac{\Delta X_{cd}}{\Delta X_{bc}+\Delta X_{cd}}$$

$$S_d = \frac{\text{Accumulative combined displacement of slip zone}}{\text{Accumulated displacement of slide bed to orifice}} = \frac{\Delta X_{bc}}{\Delta X_{bc}+\Delta X_{cd}} = 1 - S_i$$

The meaning and characteristics of Si (Sd) are as follows:

(1) Si, Sd respectively represent landslide integrity index and destructive index, the denominator is the accumulative displacements of sliding bed and earth surface orifice; Si molecules is the accumulated displacement of sliding body to orifice, i.e. accumulative displacement ΔXcd; Sd molecules is the accumulative combined displacement of slip zone, Xbc. When the sliding zone has not been produced, namely ΔXbc =0, Si=1, Sd=0, the sliding zone is complete; when the slip zone has been destroyed or cut out, namely ΔXcd =0, Si=0, Sd=1, thenthe sliding zone and landslide come up to destruction, Si, Sd variables fall in the [0-1] range.

(2) Si, Sd indexes have clear physical meanings, and the numerator and denominator are differences of two cumulative deformations. It can eliminate the same error occurred concurrently during observation, highlight =variables from slid zone and body to the orifice and the law of Si Sd changes.

(3) Based on the monitoring data from every borehole inclinometer, the Si and Sd can be calculated, and the stability of the landslide can be evaluated quantitatively and quantitatively by comparing the changes of Si and Sd.

(4) Compared with the traditional method, it avoids error caused by determining the landslide boundary, the calculation model, and facilitates the process. However, the current quantitative evaluation of landslide stability is required.

4. Engineering case

4.1. General situation

The accumulation body in front of the dam of Zipingpu Water conservancy project extents from the left bank to Hu Ping Dou Ping slope area where there is a giant loose accumulation. The dam of Zipingpu Project is about 618m, the diversion tunnel on the right bank imports at aabout 250m. In the front of the dam, there is a "chair" accumulation body shape in the plane. Tangjialin and Jiajiagou are located on both sides. The watershed near the trailing edge is about 1500m in the elevation. The length from its leading edge to the Minjiang River is about 1600m; the front width is between 300m~870m; the accumulation of the whole dam area is about 1.0km^2; the total volume is 3500×104m^3 to 4500×104m^3. The overall accumulation slope is relatively gentle at 20 degrees to 30 degrees, but the bedrock periphery is relatively steep, with the local slope up to 40 degrees; the frontier is relatively narrow, and became wider in the hill, mainly composed of 4 different elevation platforms and a steep slope 4 elevation platforms respectively are as follows: Hudouping is 800 ~ 820m, Dengzhanping is 960m, Baimiaozi is 1000 ~ 1040m, the Guanyinping is 1110 ~ 1150m. The monitoring equipment for dam accumulation deformation is mainly a borehole inclinometer, which is mainly used to measure the deformation, evolution and stability of its internal accumulation bodies and weak layers. Detailed arrangement and related information are shown in Fig 2 and in Table 1.

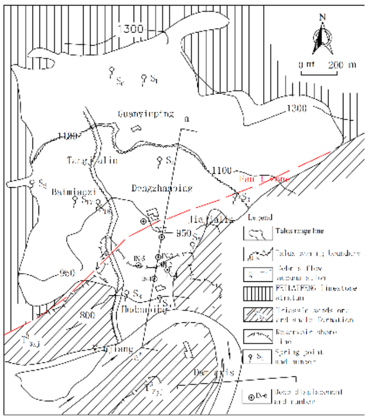


Figure 2. Monitoring plan of deep displacement of dam accumulation body

Table 1. Dam accumulation inclinometer monitoring arrangement

Number	Elevation (m)	Depth (m)	Hole bottom elevation (m)	Base surface elevation (m)	Location
IN-1	847	50	797	812	leading edge of Dengzhanping
IN-2	890	78	812	825	
IN-3	929	110	819	831	Central section of Dengzhanping
IN-4	891	66	825	836	
IN-5	889	86	803	809	
IN-6	942	126	816	825	Back of Dengzhanping
IN-7	944	120	824	841	

4.2. Si (Sd)data processing

The time relation curves Si (Sd) for each deep displacement monitoring are shown in Table 2 and in Fig 3~7. We can see from time analysis, the deep displacement Si(Sd) still has three time periods obviously, and is divided into two parts:

Table 2. Statistics of Si (Sd) characteristic values of change in accumulation body before dam

Monitoring point Date	IN-2	IN-4	IN-5	IN-6	IN-7
2006/10/12	0.99 (0.01)	0.99 (0.01)	0.94 (0.06)	0.98 (0.02)	0.97 (0.03)
2007/08/10	0.92 (0.08)	0.93 (0.07)	0.94 (0.06)	0.97 (0.03)	0.96 (0.04)
2008/05/05	0.85 (0.15)	0.82 (0.18)	0.94 (0.06)	0.96 (0.04)	0.86 (0.14)
2008/05/18	0.38 (0.62)	0.53 (0.47)	0.65 (0.35)	0.95 (0.05)	0.83 (0.17)
2009/09/07	0.32 (0.68)	0.55 (0.45)	0.65 (0.35)	0.94 (0.06)	0.82 (0.18)
2010/09/10	0.32 (0.68)	0.58 (0.42)	0.67 (0.33)	0.95 (0.06)	0.82 (0.18)
2011/09/09	0.31 (0.69)	0.57 (0.43)	0.67 (0.33)	0.96 (0.04)	0.83 (0.17)
2012/10/20	0.30 (0.70)	0.53 (0.47)	0.65 (0.35)	0.96 (0.04)	0.81 (0.19)

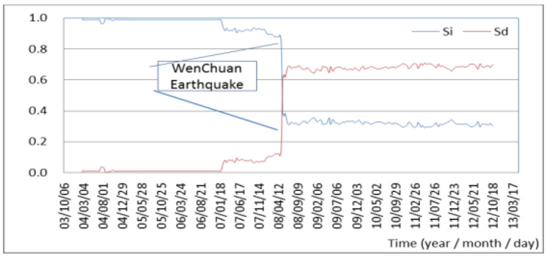


Figure 3. Si (Sd) - time relation (IN-2)

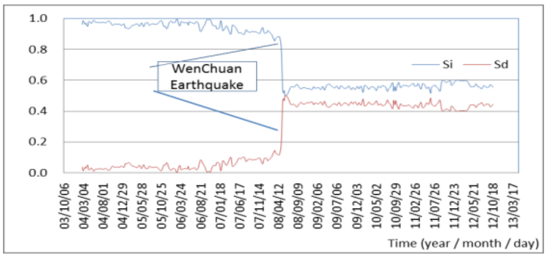


Figure 4. Si (Sd)-time relation (IN-4)

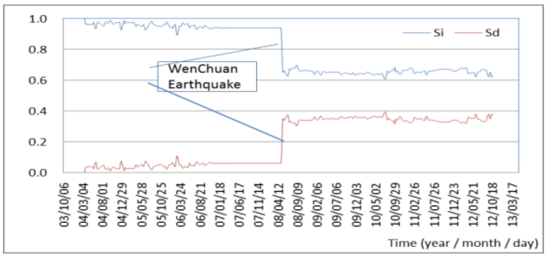


Figure 5. Si (Sd)-time relation (IN-5)

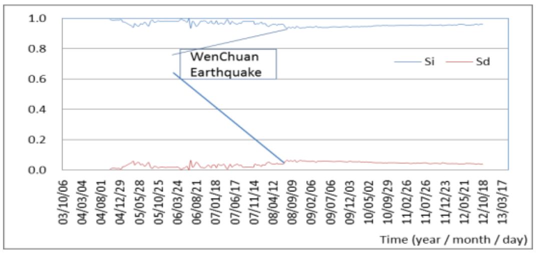


Figure 6. Si (Sd)-time relation (IN-6)

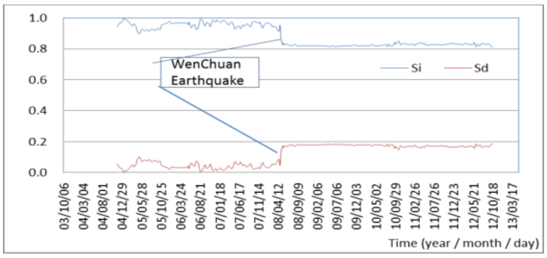


Figure 7. Si (Sd)-time relation(IN-7)

4.3. Analysis of Si (Sd)results

(1) Before the Wenchuan earthquake occurred, the monitoring site is better with integrity, but the integrity of the monitoring time lacks. The Si of IN-4 monitoring sites reaches 0.82, the lowest, the Sd is increased over time at the rate of 0.18; but the highest Si of IN-6 reaches 0.96, the Sd is 0.04.

(2) During the period of Wenchuan earthquake, the integrity of the monitoring site of the deep displacement has been reduced to some extent due to the impact of the Wenchuan earthquake, and its destructiveness has increased. The Si of monitoring site IN-2 was lowest, decreased to 0.38, but its Sd increased to 0.62. The integrity of monitoring site IN-6 was least affected by the Wenchuan earthquake, i.e. its Si decreased to 0.95, and its Sd increased to 0.05.

(3) After the Wenchuan earthquake occurred, the integrity and destruction of the surface and slip surface of each deep displacement monitoring site fluctuated steadily over time.

(4) As the elevation of deep displacement monitoring site is reduced, the impact of the Wenchuan earthquake on its integrity is gradually increased, so that the integrity has gradually decreased, the integrity of accumulation at the 845m of center pressure heavy platform in front of the dam body from the frontier of Dengzhanping declines most, this is the key control areas.

5. Conclusion

(1) Based on the deep displacement monitoring results from the quantitative analysis of the accumulation stability, the deformation evolution process and the stability of the accumulation body can be evaluated in real time.

(2) Si (Sd) evaluation method avoids the errors caused by the real-time change of geological boundary conditions, defining the calculation models and mechanical parameters of rock and soil, which is easy to operate and more practical.

(3) In the process of reservoir level fluctuation, the destroy process of body sliding zone may be very long. Through the analysis of the relative elevation in the slip

deformation process, the early warning can be issued, so as to start the emergency plan concurrently, thus to reduce or avoid losses caused by geological disasters.

(4) Continuously observe deep displacement, if the abnormal situation occurs, it should be repaired or rebuilt in time, constantly evaluate the stability of accumulation and monitor landslide for the safety.

Reference

Chen H. J., Liu S. H. (2007). Slope failure characteristics and stabilization methods. *Canadian Geotechnical Journal*, Vol. 44, No. 4, pp. 377-391. http://doi.org/10.1139/t06-131

Chen Z. Y., Mi H. L., Wang X. G. (2001). A three-dimensional limit equilibrium method for slope stability analysis. *Chinese Journal of Geotechnical Engineering*, Vol. 23, No. 5, pp. 525-529. http://doi.org/10.3321/j.issn:1000-4548.2001.05.001

Cheng H., Zhou X. P. (2015). A novel displacement-based rigorous limit equilibrium method for three-dimensional landslide stability analysis. *Canadian Geotechnical Journal*, Vol. 52, No. 12, pp. 2055-2066. http://doi.org/10.1139/cgj-2015-0050

Duncan J. M. (1996). State of the art: limit equilibrium and finite-element analysis of slopes. *Journal of Geotechnical Engineering*, Vol. 22, No. 7, pp. 577-596. http://doi.org/10.1061/(ASCE)0733-9410(1996)122:7(577)

Martha T. R., Roy P., Govindharaj K. B., Kumar K. V., Diwakar P. G., Dadhwal V. K. (2015). Landslides triggered by the June 2013 extreme rainfall event in parts of Uttarakhand state, *Landslides*, Vol. 12, No. 1, pp. 135-146. http://doi.org/10.1007/s10346-014-0540-7

Shi X. G., Liao M. S., Zhang L., Balz T. (2016). Landslide stability evaluation using high-resolution satellite SAR data in the Three Gorges area. *Quarterly Journal of Engineering Geology and Hydrogeology*, Vol. 49, No. 3, pp. 203-211. http://doi.org/10.1144/qjegh2015-029

Song D. Q., Song H. Q. (2017). stability studies of reservoir landslide under reservoir water level fluctuation. Dongbei Daxue Xuebao. *Journal of Northeastern University*, Vol. 38, No. 5, pp. 735-739. http://doi.org/10.3969/j.issn.1005-3026.2017.05.026

Sun G. H., Zheng H., Tang H. M., Dai F. C. (2016). Huangtupo landslide stability under water level fluctuations of the Three Gorges reservoir. *Landslides*, Vol. 13, No. 5, pp. 1167-1179. http://doi.org/10.1007/s10346-015-0637-7

Sun S. R., Xu P. L., Wu J. M., Wei J. H., Fu W. G., Liu J., Debi P. K. (2014). Strength parameter identification and application of soil–rock mixture for steep-walled talus slopes in southwestern China. *Bulletin of Engineering Geology and the Environment,* Vol. 73, pp. 123-140. http://doi.org/10.1007/s10064-013-0524-1

Wang N. Q., Xue Y. Q., Yao Q. Y., Yu Z., Feng X. (2014). Review of landslide stability analysis method. *Advanced Materials and Technologies*, Vol. 1004, pp. 1541-1546. http://doi.org/10.4028/www.scientific.net/AMR.1004-1005.1541

Xia Y. Y., Li M. (2002). Evaluation method research of slope stability and its developing trend. *Chinese Journal of Rock Mechanics and Engineering*, Vol. 21, No. 7, pp. 1087-1091. http://doi.org/10.3321/j.issn:1000-6915.2002.07.031

Yang B. B., Yin K. L., Xiao T., Chen L. X., Du J. (2017). Annual variation of landslide stability under the effect of water level fluctuation and rainfall in the Three Gorges Reservoir. *Environmental Earth Sciences*, Vol. 76, No. 16, pp. 12665-12681. http://doi.org/10.1007/s12665-017-6898-9

Yin X. M., Yan E. C., Gao X., Li X. W. (2016). Stability reliability analysis of precipitation-induced landslide based on monte carlo method-example: Xiaozai landslide in China. *Electronic Journal of Geotechnical Engineering*, Vol. 21, No. 16, pp. 5331-5350.

Zhang X., Tan J. H. (2014). Research on Majiagou landslide stability analysis and control design. *Lecture Notes in Electrical Engineering*, Vol. 163, pp. 595-602. http://doi.org/10.1007/978-1-4614-3872-4_76

Zhang Z. Y., Wang S. T., Wang L. S. (2009). Principles of engineering geology. *Beijing: Geological Publishing House*, pp. 154-165.

Zhu B., Hou K. P. (2007). Summarize of slope stability study. *Express Information of Mining Industry*, Vol. 23, No. 10, pp. 4-8.