ISSN 2663-1563 Vol. 6, Issue 3: 59-67, DOI: 10.25236/AJAGE.2024.060310

Study on the Position Determination Method of Landslide Sliding Surface Based on the Theory of Data Correlation and Information Fusion

Yu Shang[1,a,*]

[1]Guizhou Provincial Transportation Planning, Survey, Design and Research Institute Co., LTD, Guiyang, 550081, China
[a]252178416@qq.com
[*]Corresponding author

Abstract: *Sliding surface is one of the most important basic characteristics of landslide, but the determination of the specific depth position of landslide sliding surface is an important problem for the analysis of landslide characteristics. Firstly, the paper analyzes the depth position of the landslide sliding surface based on the survey method, the deep displacement monitoring method of rock and soil mass and the theoretical analysis method, and the data of the two methods are analyzed to avoid the influence of uncertain factors. Then it has established the parallel structure fusion network composed of three local detectors based on survey method, deep displacement monitoring method, and theoretical analysis method, and the detector has statistical independent and distributed observation under H0 and H1, it has established the parallel structure distribution detection model of information fusion theory according to the relevant data flow, and solved the Bayesian minimum risk criterion. The analysis result shows that: (1) Three detection methods, according to the Bayes risk function minimum rule, the "majority logic" rule is the best; (2) The three detection methods are analyzed by information fusion theory, and the sliding surface depth is distributed in 13-21.5m depth along with the terrain.*

Keywords: *Landslide; Sliding Surface; Information Fusion; Parallel Structure; Bayesian Minimum Risk Criteria*

1. Preface

Landslide is one of the most common geological disasters in China. The sliding body and the accumulation process form the sliding surface of the unchanged rock and soil mass below. The determination of the sliding surface ultimately affects the selection of rock and soil mass parameters and the size of the landslide volume, and ultimately affects the success or failure of the landslide treatment and the cost of the landslide treatment. Therefore, the determination of the sliding surface is the most critical link in the process of the landslide survey and treatment.

The systematic research on the landslide originated from Sweden. Before 1945, only the research staff of Sweden, the former Soviet Union and Norway National Institute of Geotechnical Research carried out separate small-scale research. After 1945, the research on the landslide in European and American countries gradually systematically deepened [1-4].

In the 1990s, with the rapid development of China's infrastructure, landslide geological disasters attracted more and more attention, and the research of sliding surface research is the key research object of geological scholars and engineers. Yang Jibao (1994) proposed a new method to determine the sliding surface of the landslide by using monitoring resources [5]; Zhao Fasuo (1999) analyzed the position and depth of bedrock landslide[6]; Yan Chunjie (2000) et al. studied the microstructural characteristics of the landslide sliding surface [7]; Ou Min (2005) proposed to use GeoCA and GIS technology to study the evolution law of landslide sliding [8]; Gan Youwen (2006) and others proposed the twist drilling method to determine the sliding surface of expansion soil landslide [9]; Lin Xiaosong (2011) proposed the spatial interpolation method to determine the landslide sliding surface [10]; Cheng Ke (2011) proposed the finite element strength subtraction to determine the sliding surface method [11]; Li Yangbo (2014) and others carried out the research on the maximum landslide thrust sliding surface of soil slope [12]; Xue Haibin (2015) studied the analysis method of multistage sliding surface of landslide by using the softening characteristics of geotechnical materials [13]; Lin Hui (2017) and others

ISSN 2663-1563 Vol. 6, Issue 3: 59-67, DOI: 10.25236/AJAGE.2024.060310

carried out the stability analysis and treatment scheme research of ancient landslide on multi-layer slide surface [14]; Gavering (2017) proposed the integrated C method and integrated φ method to determine the sliding surface; Jiang Xuezhong (2020) systematically studied the determination method of landslide sliding surface.

The general research on landslide sliding surface can be summarized into four categories:

(1) Observation method;

(2) Monitoring method;

(3) Comprehensive exploration method;

(4) Theoretical method.

As we research on the landslide system, due to the landslide sliding surface formation by terrain, hydrology, geology, meteorology, so the judgment with the research system more and more tend to parallel, but we often appear in practice a variety of methods results to determine the model and conditions have large error, so the sliding surface determination method of information fusion theory arises at the right moment. Taking the Xiangyang landslide of Moutai Group Co., Ltd. in Renhuai City, Guizhou Province, the landslide sliding surface is studied by drilling method, measurement method, wave speed test method, theoretical analysis method and information fusion theory method.

2. Project Overview

The excavated slope on the right side of CK0 + 820~CK1 + 000 section of Songkan junction is 180m long, the maximum excavation depth of the axis is about 24.4m, and the right slope is 28.2m after excavation according to the designed slope rate (Figure 1). The soil layer on the slope area is composed of gravel clay, 0~2.0m thick and plastic. The strongly weathered rock mass is fragmented, and the rock mass type is ~V; the medium weathered rock mass is broken, the structural surface is generally combined, and the rock mass type is ~ V. After subgrade excavation, the slope rock mass is mainly composed of clay and strongly weathered dolomitic limestone conglomerate dolomite, which is like soil slope.

Figure 1: Landslide on the right of CK0 + 820~CK1 + 000 of Songkan Hub

The landslide is located within the range of 28~115m on the right side of C ramp baseline CK0 + 860~CK0 + 950, and the longitudinal length is about 90m and 87m wide along the baseline direction. According to the deep displacement monitoring, the sliding surface depth is about 15~21m, the landslide area is about 5000m2, and the landslide volume is about 70000m3, which is a traction medium-sized type landslide. The main manifestations are shown as follows (Figure 2):

(1), the original rear edge crack is expanded again, the sealing crack concrete appears obvious tensioning crack, the maximum width of the crack is about 5cm, the crack length has obvious outward expansion, the original crack length is 110m, the crack length is 130m.

(2) There are 4 vertical cracks in the pile wall, and the vertical cracks are staggered at CK0 + 940 and extend to the top of the pile. The average width of the pile top cracks is 3~7cm. According to the slope detection report, there are cracks in 8 # ~23 # anti-skid piles, and all 9 anchor cables failed.

(3) There are cracks in the upper platform of the pile wall along the route direction, and the cracks are 0~1.5cm wide.

(4) There are many cracks in the drainage ditch, with a width of 2~10mm.

ISSN 2663-1563 Vol. 6, Issue 3: 59-67, DOI: 10.25236/AJAGE.2024.060310

(5) No obvious deformation and cracking of the anchor cable frame beam and anchor cable of the sliding level 2 and 3 platform.

Figure 2: Landslide on the right side of CK0 + 820~CK1 + 000 section of Songkan Hub interchange

3. Survey Method

In order to determine the type of landslide and understand the landslide characteristics, the well exploration method is used to expose the landslide sliding zone, and the physical and mechanical tests of landslide soil are conducted by indoor tests. According to the exploration well has exposed slip belt for clay gravel, loose inclined structure, rock broken ~ broken, loose broken structure. The soil was water softening fast, expansion, and dry strength is higher, its poor mechanical properties, which was easy to form dry cracks, drilling to pressure before drilling. The leading edge of the sliding surface material for clay gravel, the shear strength of the soil was much higher than the central slip belt material strength.

According to the soil samples collected with the ring knife in the sliding belt, and the mathematical statistical analysis was conducted according to the experimental results. The analysis results are shown in Table 1 and Table 2.

Table 1: Mathematical statistics of indoor test results (saturation value)

Shear-resistance parameters of the sliding surface	Operating mode	Severe γ(kN/m^3)	Cohesive force C(kPa)	Internal friction angle φ(°)
	Natural	19	21	14
	Saturate	20	11	8

According to the drilling and exploration well, the buried depth of the landslide picture is about 14.2~20m, and the middle of the middle part is thick on both sides. The upper middle part is relatively thin.

4. Measurement method

Deep horizontal displacement measurement method is to use a servo of the gravity deformation of the deep horizontal direction of the rock and soil body. The mathematical model and data processing principle are as follows Figure 3:

Figure 3: Monitoring photo of the deep horizontal displacement of the landslide

(1) The measured value X is calculated according to the following equation. X0 is the measurement at the bottom point.

$$X = X_{positive} - X_{minus} \quad (1)$$

ISSN 2663-1563 Vol. 6, Issue 3: 59-67, DOI: 10.25236/AJAGE.2024.060310

(2) Calculation of horizontal displacement value Xi: (measuring the distance interval of 0.5m and 1m algorithm is different, 0.5m needs to be divided by 2)

$$x_i = X - X_0 \tag{2}$$

(3) Angle conversion

$$\theta = a\sin(x_i / l) * 180 / \pi \tag{3}$$

According to the analysis of 5 deep horizontal displacement measurement data in one hydrological year, as shown in Figure 4~ Figure 8:

Table 2: Deep level data indicate the depth position of the sliding surface

Hole number	Maximum deformation and buried depth of sliding surface (unit: m)
1#	13m
2#	13.5m
3#	21.5m
4#	11.5m
5#	4m

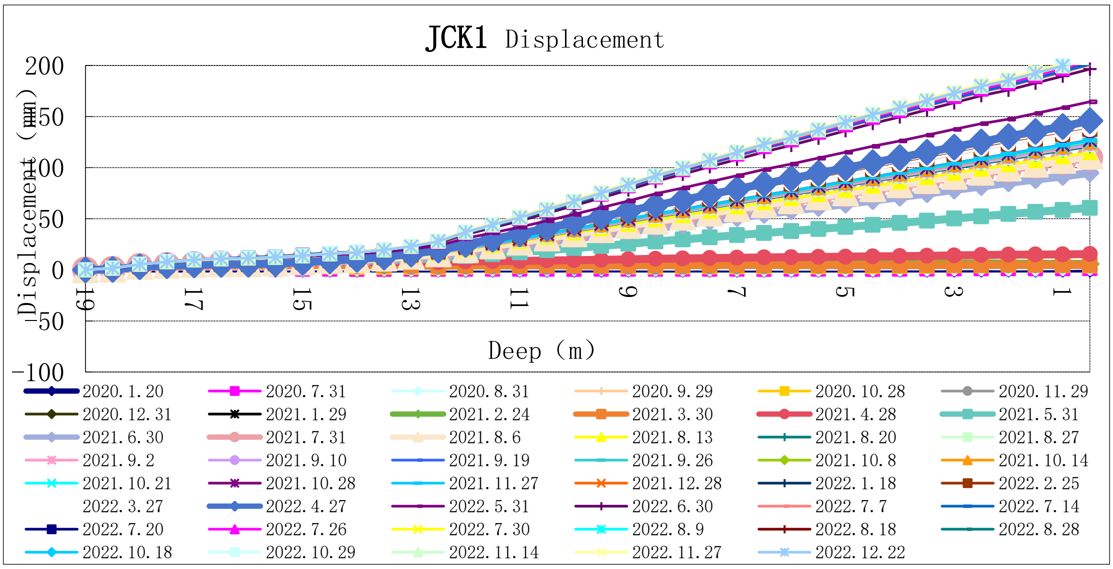

Figure 4: Measurement data diagram of deep horizontal displacement of hole 1 of landslide

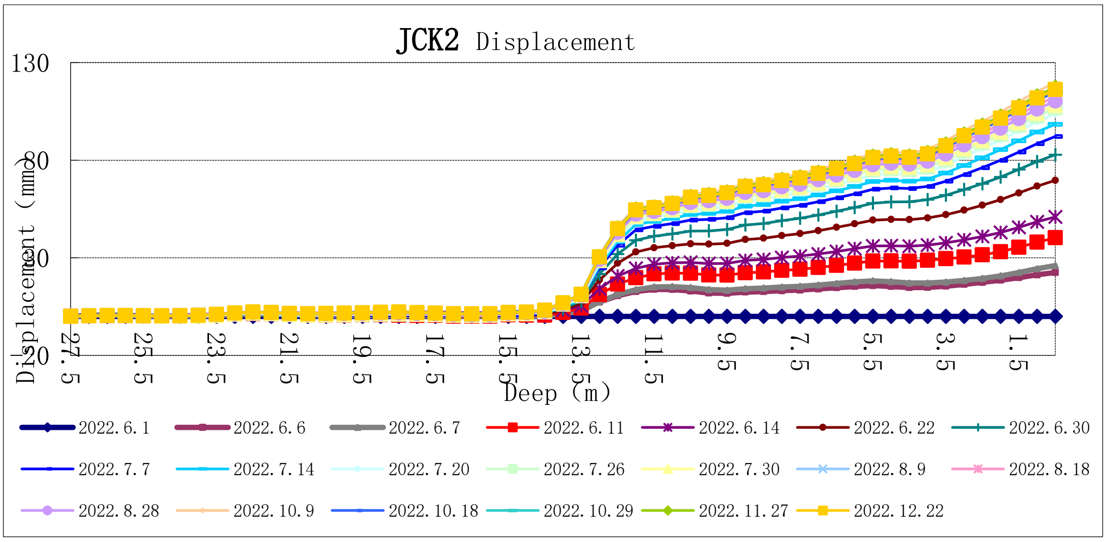

Figure 5: Measurement data diagram of deep horizontal displacement of hole 2 of landslide

ISSN 2663-1563 Vol. 6, Issue 3: 59-67, DOI: 10.25236/AJAGE.2024.060310

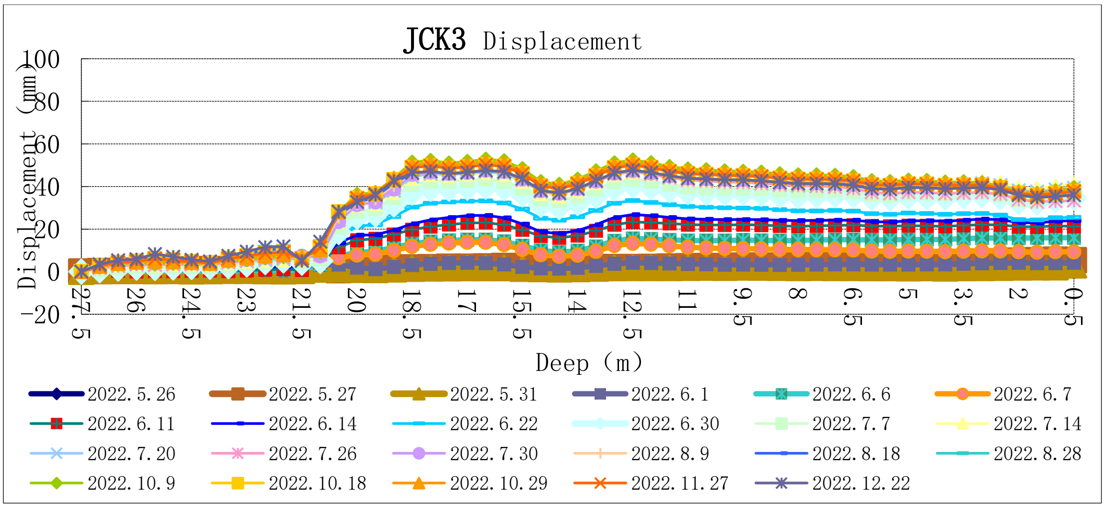

Figure 6: Measurement data diagram of deep horizontal displacement of hole 3 of landslide

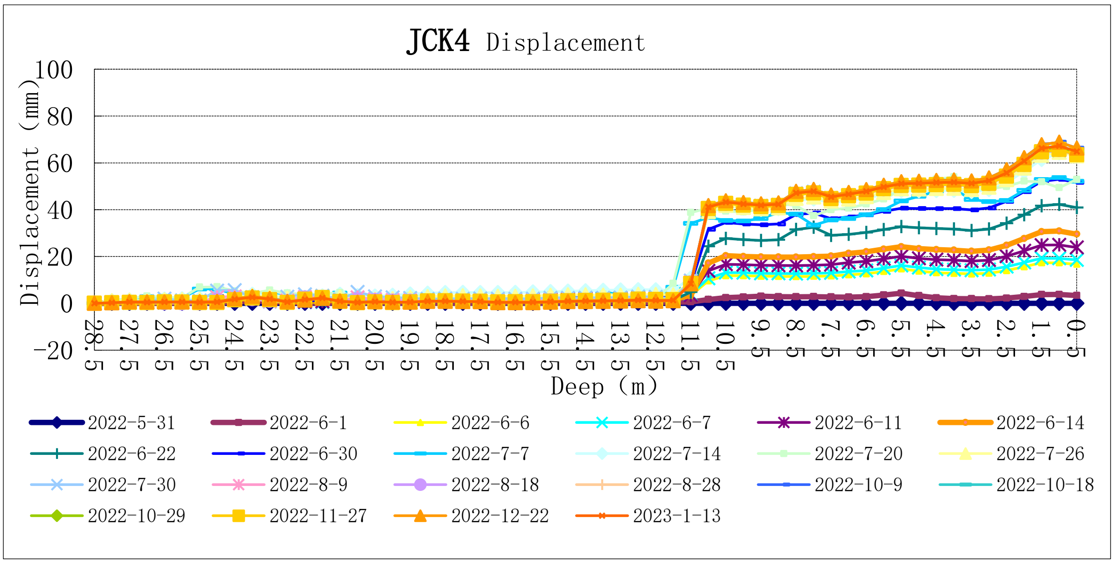

Figure 7: Measurement data diagram of deep horizontal displacement of hole 4 of landslide

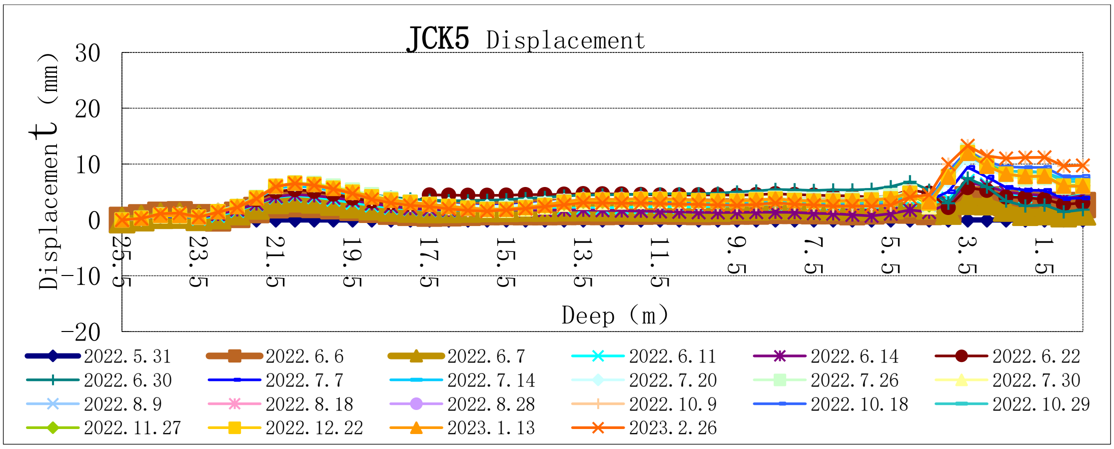

Figure 8: Measurement data diagram of deep horizontal displacement of hole 5 of landslide

According to the horizontal displacement measurement data of the deep rock and soil mass, the buried depth of the sliding surface is located in 4m~21.5m (Figure 9).

ISSN 2663-1563 Vol. 6, Issue 3: 59-67, DOI: 10.25236/AJAGE.2024.060310

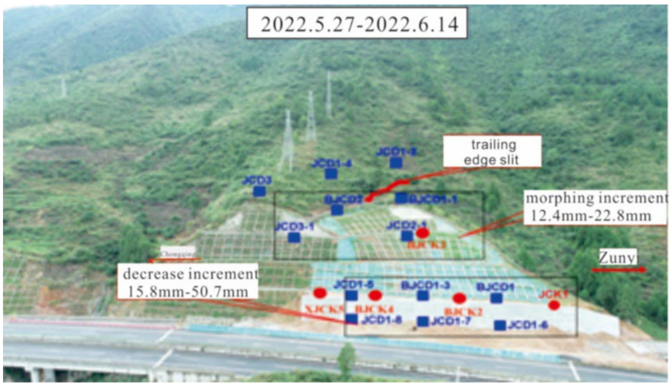

Figure 9: Distribution chart of horizontal monitoring holes of 5 landslide holes

5. Theoretical Analysis Method

In soil landslide, the inversion method is generally used to determine the landslide strength parameters and sliding surface position. Usually, the counteranalysis state is called the critical state. The critical state refers to the immediate state of the slope under the evaluation index of the determined working conditions, including slope surface shape, groundwater level, slip band occurrence conditions and external load and other factors. After determining the calculation state, the critical state factors of the slope should conform to the actual situation.

The stability evaluation index is mainly determined according to the macroscopic deformation of the slope and selected according to the actual situation. The stability evaluation index has a certain priori, so the correct choice can be made after considering the deformation nature of the slope at different development stages and surveying the deformation and terrain changes of the front and rear edge of the slope. In general inversion calculation of landslide stability coefficient, the square Bishop method, Sarma method, residual thrust method and other methods of limit balance theory are adopted. In this paper, the broken linear sliding calculation model is used for inversion analysis and calculation, and the calculation model is as follows:

$$K = 1 - \frac{\sum Q_i \cdot tg(\omega_i - \varphi_i)}{\sum Q_i \cdot tg\omega_i} + \frac{\sum c_i \cdot l_i \cos\omega_i}{\sum Q_i \cdot tg\omega_i} \tag{4}$$

Where: Qi——Slide power on the sliding surface of the i earth block;

i——The inclination Angle of the sliding surface of the ith earth block;

φ_i—— The friction angle of the ith earth block;

c_i—— The cohesion of the ith earth block ;

l_i—— Length of the slide surface of the i th earth block

The most dangerous sliding surface is selected to reverse the physical parameters of the landslide rock and soil (Table 3).

Table 3: Invert the landslide slope stability state

Section number	Working condition state	Calculation condition	stability coefficient
Section 1	initial form	natural	1.05
		Full of water	0.95
Section 2	initial form	natural	1.05
		Full of water	0.95
Section 3	initial form	natural	1.05
		Full of water	0.95

The parameter change range is selected according to the statistical data, and the parameter change interval is $(\mu - 3\sigma, \mu + 3\sigma)$. The parameter sensitivity analysis is shown in Figure 10 and

Figure 11. According to the curve slope of the sensitivity analysis map, the ratio of the influence of cohesion and internal friction angle on the landslide stability within the homoscedesticity range is calculated $\eta_c:\eta_\phi$ =1:3.

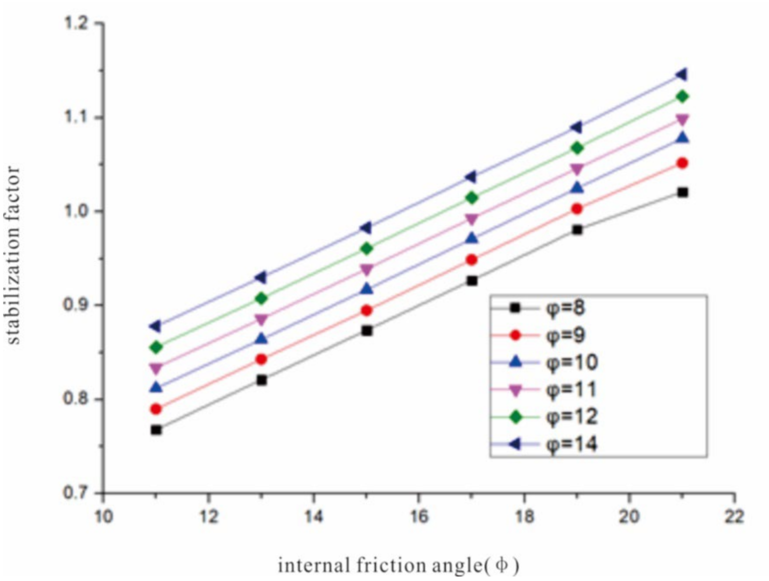

Figure 10: C- internal friction angle φ sensitivity analysis plot

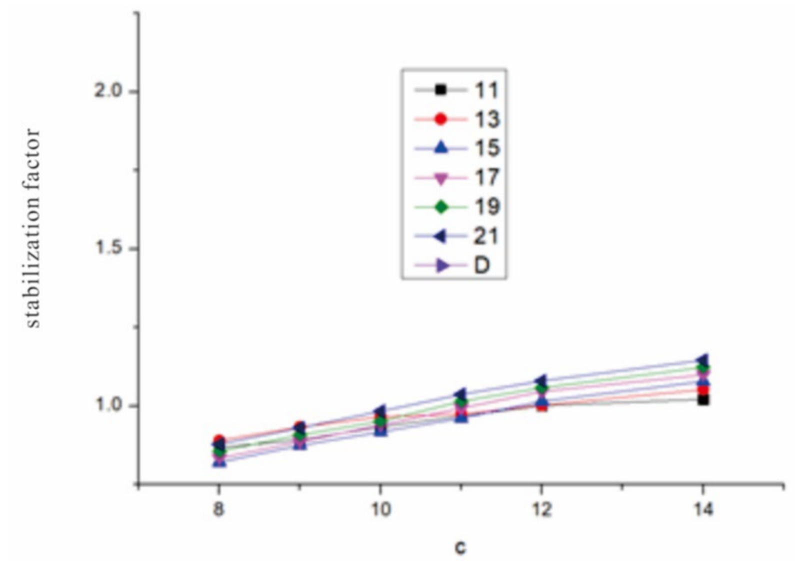

Figure 11: Analysis plot of the φ -C sensitivity of the internal friction angle

According to the stability evaluation index, the checking range of C value is determined, and a range of checking parameter values $c_1, c_2, \cdots, c_m$ is selected within this range, and then the corresponding series of ϕ values, namely $\phi_1, \phi_2, \cdots, \phi_m$, are obtained by reverse calculation. A series of shear strength parameters obtained by reverse calculation were compared with the statistical results, and the optimal parameters were selected as the intensity parameters for landslide stability calculation and design. The calculation formulas used for the comparison are as follows:

$$S_i=\eta_c\frac{|c_i-\mu_c|}{\sigma_c}+\eta_\phi\frac{|\phi_i-\mu_\phi|}{\sigma_\phi}$$

The smallest of the resulting comparison function values in Si is the optimal shear strength parameter of the sliding band soil, and Table 4 shows the resulting series of parameters and the corresponding comparison function values.

ISSN 2663-1563 Vol. 6, Issue 3: 59-67, DOI: 10.25236/AJAGE.2024.060310

Table 4: Inverse parameters and comparison function values

K=0.95	C(Kpa)	11	13	15	17	19	20	21
	φ(º)	8	9	10	11	12	13	14
	Si	1.614	1.606	1.608	1.609	1.601	1.798	2.206
K=1.05	C	11	13	15	17	19	20	21
	φ(º)	8	9	10	11	12	13	14
	Si	0.930	0.904	0.896	0.889	0.890	1.087	1.485

According to the comparative value of the reverse parameters, the sliding surface is selected as 13-21m depth position. At the stability coefficient K=1.0, the cohesion C and the internal friction angle φ of the slip soil are 17 and 11, respectively; at K=1.05, the cohesion C and the internal friction angle φ are 15 and 10, respectively.

6. Information Fusion Theory and Theoretical Method

Because different methods determine the position depth information of the sliding surface, in order to more accurate data judgment, assuming that each method is independent detector, all detectors detect the same phenomenon-sliding surface position depth, then each observer with local detector with *yi*(*i=1,2,...,N*), and their joint conditional probability density*f*(y_1,..., y_n |H*j*)(*j=0,1*) assume known (j=0,1), each observer makes a local judgment u_i(*i=1,2,……,N*). The fusion center receives the judgment vector $\boldsymbol{u}$=($u_1,u_2,……,u_N$), produces the global judgment u_0.Since several methods are parallel structure detectors, the purpose of Bayesian hypothesis testing is to obtain the average cost of minimizing the whole system operation $R(\Gamma)$, whose decision rule set $\Gamma = \{\gamma_0, \gamma_1, \ldots\ldots, \gamma_N\}$, where γ_0 represents the fusion rule.

The minimized Bayesian risk function (i. e. average cost) $R(\Gamma)$ can be expressed as

$$R(\Gamma) = \sum_{i=0}^{1}\sum_{j=0}^{1} C_{ij} P_j P_\gamma \, (Hi|Hj) \tag{5}$$

Then the minimum judgment rule is:

$$f(y_k|H_1)\sum_{\mu^\kappa}\int_{Y_\kappa} A(\mu^\kappa)\, C_D P_r(\mu^K|Y^K) f(Y^K|y^K, H_1)\, d\,Y^K \underset{\mu_{k=0}}{\overset{\mu_{k=1}}{\gtrless}} f(y_k|H_0) \tag{6}$$

In order to obtain fusion rules, it is necessary to minimize R(Γ). According to the PBPO method, fusion rules can also be expressed as:

$$\frac{P_r(\mu^*|H_1)}{P_r(\mu^*|H_0)} \underset{\mu_0=0}{\overset{\mu_0=1}{\gtrless}} \frac{C_F}{C_D} \tag{7}$$

N (formula 7) and 2^N (formula 8) are established to form non-linear joint cubic equations and are solved according to the binary problem Bayesian hypothesis and PBPO method.

The conditional probability of each local detector is assumed to be a Gaussian distribution with a variance of 1. In the H_0 and H_1 conditions, the fusion rule is "K-out-0f-N", and only the "with", "or", and "majority logic" rule are considered.

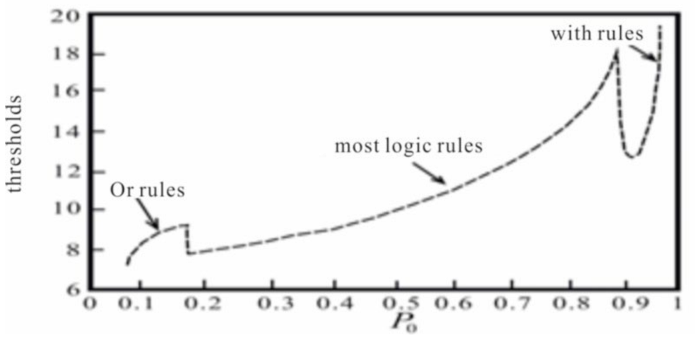

Figure 12: Results of fusion rule calculation

The results show that the detector "majority logic" rule is the best, that is, the sliding surface depth is distributed 13-21.5m depth with the terrain (Figure 12).

ISSN 2663-1563 Vol. 6, Issue 3: 59-67, DOI: 10.25236/AJAGE.2024.060310

7. Conclusion

Subject using drilling and well exploration, measurement, inversion analysis method shows that the sliding surface depth minimum value of 4m, the maximum value of 21.5m, in view of the different methods and means error more than 5%, according to the statistical theory, there are significant error, so in order to accurately determine the sliding surface depth, using the information fusion theory of parallel structure distribution detection theory of four methods to detect data information fusion processing, test results show that:

(1) Three detection methods, according to the minimum rule of the Bayesian risk function, indicates that the "majority logic" rule is the best;

(2) Three detection methods, the sliding surface depth are distributed at 4-21.5m depth along with the terrain.

References

[1] Matsuura S, Asano S, Okamoto T, et al. Characteristics of the displacement of a landslide with shallow sliding surface in a heavy snow district of Japan[J]. Engineering Geology, 2003, 69(1):15-35.
[2] Nakamura H, Shimizu K. Soil Tests for the Determination of Shear Strength along the Sliding Surface [J]. Journal of the Japan Landslide Society, 2011, 15(2):25-32.
[3] Mohammad A M A E K, Uchiyama N, Sano S. Energy Saving in Feed Drive Systems Using Sliding-Mode-Based Contouring Control With a Nonlinear Sliding Surface[J]. IEEE/ASME Transactions on Mechatronics, 2015, 20(2): 572-579.
[4] Holambe P, Dambhare S. Sensorless Robust Controller for Buck Converter using Modified Fast Terminal Sliding Surface[C]. 2021 IEEE Kansas Power and Energy Conference (KPEC). IEEE, 2021.
[5] Yang Jibao. A new method to determine the sliding surface of a landslide with monitoring resources [J]. Disaster ology, 1994, 9(2): 5.
[6] Zhao Fayuo, Mao Xinhu, Luo Lijuan, et al. Study on the total mineral analysis method of the bedrock landslide slip surface [J]. Journal of Xi'an University of Science and Technology, 1999, 19 (0z1): 23-26
[7] Yan Chunjie, Sun Yunzhi, Tang Huiming. Microstructural characteristics of the landslide sliding surface [C]. The 31st International Geological Congress. 2000, 37(8): 3.
[8] Ou Min, Zhang Yongxing, Hu Juyi, et al. Study on the evolution of landslide based on GeoCA and GIS [J]. Hydrogeology and Engineering geology, 2005, 32(1): 4.
[9] Gan Youwen, Ji Jianjiang, Chen Ping. Research and application of determination method of expanded soil landslide [J]. Water conservancy and hydropower technology, 2006, 37(12): 3.
[10] Lin Xiaosong, Xu Jiang. Study on interpolation of buried depth space [J]. Subgrade works, 2007, (6): 3.
[11] Cheng Ke. Study on the method of landslide landslide [J]. Shanxi Architecture, 2011
[12] Li Yangbo, Chen Wensheng, Liu Longwu, et al. Study on the maximum landslide thrust sliding surface of soil slope [J]. Chinese and foreign highway, 2014, 34(1): 4.
[13] Xue Haibin, Dang Faning, Yin Xiaotao, et al. Study on the analysis method of landslide based on the softening characteristics of geotechnical materials [J]. Rock and soil Mechanics, 2015, 36(11): 9.
[14] Lin Hui, Liu Daiwen, Lin Zhiping. Stability analysis and treatment scheme of multi-layer slip surface [J]. Highway traffic Technology: Application Technology Edition, 2017, (5): 2.