Risk Assessment of Debris Flow in Strong Earthquake Area

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Abstract. The construction and operation of the Jiuzhaigou County bidding section of the Jiumian Expressway is affected by debris flow disasters. It is important to scientifically and reasonably evaluate the debris flow risk in the engineering area. Therefore, according to the data of topography, meteorology, hydrology and regional geological structure of the project area, 12 influencing factors, such as regional geological disasters, loose material reserves along the gully and maximum punching amount at one time, are selected as the evaluation indexes of debris flow risk assessment. Based on the catastrophe progression method, a mutation model of debris flow risk assessment suitable for the project area was established. The debris flow risk assessment mutation model was used to evaluate the debris flow risk of 8 trenches in the project area, and the applicability of the model is verified by comparing the actual occurrence history of debris flow in the trench with the evaluation results. The analysis results show that the risk of debris flow in four gullies of Gangou and Xiaganzuo in the bid section project area of Jiuzhaigou County of Jiumian Expressway is extremely dangerous, and the debris flow risk of Shangganzuo gully is severe. These five debris flow gullies are the key objects of debris flow prevention and control during the construction and operation of Jiuzhaigou County bidding section of the Jiumian Expressway.

1. Introduction
Jiuzhaigou County bidding section of the Jiumian Expressway is located in the Wenchuan earthquake area, which contains a lot of favorable conditions (loose solid material and terrain conditions) conducive to the development of debris flow[1]. The sudden and destructive debris flow disaster is one of the main diseases faced by the construction and operation of Jiiumian Expressway. In the great mudslide accident of Dadu River in 1981, a bridge pier with a radius of more than 2m was cut off by the violent debris flow, and the train running on the bridge fell into the river, resulting in 275 deaths and huge losses[2]. The debris flow accident in Qingping township of Mianzhu City in 2010 killed and injured 47 people. The sudden debris flow destroyed the Nanhua tunnel section of S303 in Sichuan Province, causing traffic paralysis for nearly 20 days[3].

In order to clarify the degree of damage that may be caused by debris flow disasters in the various basins of the project area, and provide a basis for the prevention and control of engineering debris flow disasters, a large number of debris flow risk assessments have been carried out at home and abroad. Relying on the large and medium-sized hydropower projects in the upper reaches of the Minjiang River, Su Fenghuan studied the hazards of debris flow in 37 debris flow channels in the project area...
based on field investigation and remote sensing interpretation technology[4]. Aiming at Xiaojiagou on Wenchuan Provincial Highway 303, Xiang Lingzhi quantitatively analyzed the damage degree of Xiaojiagou debris flow to the national road based on geometric generalization method[5]. In view of the rapid increase of rainfall in dongmatun village, laomang mountain area in Northeast China, and the debris flow disaster has caused serious loss of life and property in this area, Shiwei Shen evaluated the debris flow risk in this area based on fuzzy comprehensive evaluation and analytic hierarchy process[6]. In view of the debris flow threat that may exist in the construction and operation of the Wudongde Hydropower Station reservoir area, Cencen Niu obtained the characteristics of the debris flow catchment area based on SPOT5 remote sensing images and digital elevation models, and evaluated the debris flow catchment area through fuzzy comprehensive evaluation and analytic hierarchy process[7]. The application of the above research results in engineering practice has achieved remarkable economic effects, but it must be pointed out that the current research on debris flow hazard assessment has regional characteristics[8], and there is no general debris flow risk assessment model. In view of the special terrain and geological conditions of Jiuzhaigou County bidding section of the Jiumian Expressway, there is no reference study on debris flow risk assessment at home and abroad.

Based on the field investigation, the data of topography, meteorology, hydrology and regional geological structure of the Jiuzhaigou County bidding section of the Jiumian Expressway are obtained. All kinds of signs show that the project area has the possibility of debris flow outbreak. In order to reduce the impact of debris flow disaster on the construction and operation of the project, corresponding prevention and control measures should be provided for different river basins in the project area Debris flow risk assessment. Therefore, on the basis of full investigation, according to the landform, meteorology, hydrology and regional geological structure data of each basin in Jiuzhaigou County bidding section of the Jiumian Expressway, 12 influencing factors, such as regional geological disasters, reserves of loose materials along the gully and maximum punching amount at one time, are selected as evaluation indexes for debris flow risk assessment. Based on the catastrophe model of debris flow risk assessment in the study area, the results of debris flow risk assessment are obtained, which provides scientific guidance for the construction and operation of Jiumian expressway.

2. Overview of the study area
The Jiuzhaigou County bidding section of the Jiumian Expressway is located in Aba Prefecture of Sichuan Province. The overall landform is deep mountain and high mountain valley landform. The relative cutting depth is generally more than 1000m, and some parts are even more than 2000m. The geological structure is dominated by faults, mainly including Shaba Songbai lianhecun fault, banshantang yanziping fault and majiamo shagali weijiaba fault (Lianghekou fault). Affected by the earthquake, the integrity of rock mass in the study area is low, which provides a rich material source for the preparation of debris flow. The study area belongs to the Western Sichuan Plateau climate zone. The annual average precipitation is 567.3mm and the precipitation days are about 140 days. The rainfalls mainly occurred from May to September, accounting for 77.5% of the total year. The dry season rainfall (November to March) accounted for only 5.6% of the total year. The maximum daily precipitation over the years is 51.3mm (occurring in August), which provides abundant water resources for debris flow breeding.

Eight gullies, including Siren gully, Gangou gully and Xiaganzuo gully, are debris flow development gullies along the project line that may affect the route. The traffic location of the project is shown in Fig. 1 (a), and the debris flow trench in Gangou is shown in Fig. 1 (b). The debris flow along the line is mainly of medium and large-scale and gully type, with long hidden period, low frequency of outbreak and mainly triggered by heavy rainfall. Over the years, the Department of land and resources has successively implemented blocking and treatment projects for some debris flow gullies, effectively alleviating the threat of small and medium-sized debris flows and protecting the lives and property safety of villagers at the gully mouth. However, most of the blocking projects are out of repair for a long time, and their service functions are weakened. The ability to block large-scale
debris flows is limited. In case of extreme heavy rainfall, large-scale debris flow disasters are likely to occur. It is a threat to the proposed expressway.

Figure 1. Traffic location of the project and satellite map of Gangou debris flow gully.

3. Catastrophe model of debris flow risk assessment

Catastrophe progression method provides a scientific modeling method to describe the discontinuity phenomenon of mutation. This method is simple, easy and accurate, especially when there are many evaluation indexes, and it is difficult to determine the subjective weight of evaluation indexes, and the relative importance of each evaluation index is relatively clear. The model established by catastrophe progression method has the advantages that the grey correlation degree theory, set pair analysis and neural network methods do not have[9]. Sudden, randomness and danger are the typical characteristics of debris flow breeding. It is feasible to establish the risk assessment model of debris flow by using catastrophe progression method.

3.1. Selection of mutation index

There are many factors influencing the formation of debris flow. In order to reflect the principles of completeness, comprehensiveness, systematicness, sequence and qualitative and quantitative analysis, the paper starts from the internal and external factors that promote the formation of debris flow, and takes into account the particularity of debris flow breeding under the influence of strong earthquake area and tunnel excavation construction, and selects the risk assessment of debris flow from geological conditions, basin scale, basin morphology and inducing factors Price index. The selection basis of each evaluation index is as follows:

(1) Geological conditions

The geological condition is an important index to measure whether the region has the material source needed for the preparation of debris flow. The development of debris flow is often more active in areas with frequent rock fragmentation, collapse and landslide. The analysis of the causes shows that the poor geological conditions provide sufficient material source basis for the preparation of debris flow. Therefore, geological conditions have become the main factors of debris flow risk assessment, so regional geological disasters, loose material reserves along the gully, maximum punching amount at one time and regional structure are selected as evaluation indexes. Regional geological disasters can reflect the development degree of adverse geological phenomena such as collapse and landslide, which can directly provide material source conditions for the development of debris flow; The reserves of loose materials along the gully can reflect the material source conditions required for the development of debris flow. The waste slag from tunnel construction is the special material source for the development of debris flow in the area of Jiumian expressway; The maximum amount of one-time outflow is a direct indicator of the severity of the debris flow. The larger the amount of outflow, the greater the risk of the debris flow; Regional structure can show the active degree of crustal movement, and strong earthquake action will lead to rock fracture, thus providing loose solid material for the development of debris flow.
(2) Basin scale
The basin scale is an important index to evaluate the scale of debris flow. The basin area, the ratio of sediment supply length and the cutting density are selected as the evaluation indexes. The results show that the basin area can reflect the sediment yield and confluence conditions, which is closely related to the risk of debris flow; The ratio of sediment supply length along the way can be used to indicate the scope and amount of sediment supply, and the greater the ratio, the greater the risk of debris flow; The cutting density of drainage basin reflects the development degree of branch gully erosion, which is also positively related to the risk of debris flow.

(3) Basin morphology
The larger the relative elevation difference of the drainage basin and the steeper the longitudinal slope of the gully, the greater the kinetic energy of the debris flow development. At the same time, it is conducive to the concentration of water flow and provides water source conditions for the development of debris flow. Therefore, the relative elevation difference and longitudinal slope of the river valley are selected as the evaluation indexes.

(4) Inducing factors
The inducing factors refer to the triggering factors of debris flow, including daily maximum rainfall, vegetation coverage and population density, which are generally recognized in the risk assessment of debris flow. The maximum daily rainfall can reflect the sudden water source conditions required for the development of debris flow. Water is one of the essential conditions for triggering debris flow, and sudden rainstorm can also provide dynamic conditions for debris flow development. The vegetation coverage rate can show the regional inherent debris flow prevention and control ability. Vegetation can not only improve the geological conditions, but also contain water resources to prevent and control soil erosion, the population density can indirectly reflect the intensity of human activities in the region, and bad behaviors such as mountain opening and road building and forest felling will aggravate the development of debris flow.

3.2. Establishment of mutation model
Based on Liu Xilin's grey correlation degree method, the relative importance of each index at the bottom is determined[10]. Combined with the evaluation characteristics of catastrophe progression method evaluation system, an evaluation model of debris flow risk in strong earthquake area is constructed, as shown in Table 1. According to the rank of relative importance of each index in the bottom layer, the order of importance of middle layer index can be determined as follows: geological conditions > basin morphology > basin scale > inducing factors.

| Target layer | Catastrophe model | Middle layer | Catastrophe model | The bottom |
|--------------|------------------|--------------|------------------|------------|
| Debris flow risk prediction and evaluation index A | Butterfly type | Geological condition B1 | | Regional geological hazard C1 |
| | | | | Loose material reserves along the ditch C2 |
| | | | | Maximum punching amount at one time C3 |
| | | | | Regional tectonics C4 |
| | Butterfly type | Basin scale B2 | Swallow tail type | Drainage area C5 |
| | | | | Length ratio of mud sand replenishment along the way C6 |
| | | | | Watershed cutting density C7 |
| | Cusp type | Basin morphology B3 | Cusp type | Relative elevation difference C8 |
| | | | | Ditch longitudinal slope C9 |
| | Swallow tail type | Predisposing factor B4 | Swallow tail type | Daily maximum rainfall C10 |
| | | | | Vegetation coverage C11 |
| | | | | Population density C12 |
(1) Standardization of mutation index

For an evaluation model which contains quantitative and qualitative indicators, and the measurement standards of each index are very different, the catastrophe index must be standardized before using the catastrophe model to evaluate the regional debris flow risk, that is to say, the catastrophe index must be transformed into dimensionless data (0~1), otherwise, the debris flow risk assessment cannot be carried out according to the value of the catastrophe index.

Among the 12 indexes selected, regional structure and regional geological disasters are qualitative indicators, and the remaining 10 indicators are quantitative indicators. For qualitative indicators, the membership function value is constructed by using multi-phase fuzzy statistical method. Accordingly, the membership function values of regional geological hazard (C1) and regional structure (C4) are shown in Table 2. For quantitative indicators, standardized calculation formulas are used for processing, including loose material reserves along the ditch (C2), maximum punching amount at one time (C3), drainage area (C5), length ratio of mud sand replenishment along the way (C6), watershed cutting density (C7), relative elevation difference (C8), ditch longitudinal slope (C9), daily maximum rainfall (C10), and population density (C12) are positively related to the risk of debris flow. The standardized calculation formula is formula (1), and vegetation coverage (C11) is negatively related to the risk of debris flow, and the standardized calculation formula is formula (2):

\[
\begin{align*}
    x'_i &= \frac{x_i - x_{\text{min}}}{x_{\text{max}} - x_{\text{min}}} \\
    x'_i &= \frac{x_{\text{max}} - x_i}{x_{\text{max}} - x_{\text{min}}}
\end{align*}
\]

Where \( x_i \) is the evaluation index value, \( x_{\text{max}} \) is the maximum value of evaluation index grade threshold, \( x_{\text{min}} \) is the minimum value of evaluation index grade threshold, and \( x'_i \) is the standardized value of evaluation index. The correlation analysis of the evaluation index is based on the index data of 8 possible debris flow gullies along the Jiujiang expressway. Table 3 shows the evaluation index values of each basin, and the standardized results of evaluation indexes are shown in Table 4.

Table 2. Membership function values of qualitative indexes to debris flow.

| Indicator name | Membership function value |
|----------------|---------------------------|
| Regional geological hazard C1 | The gravity erosion such as collapse and landslide is serious, multi-layer landslide and large-scale collapse, loose surface soil and gully are very developed. | 0.8 |
| | Landslides, landslides, multi-layer landslides and small and medium-sized landslides, scattered vegetation cover, gully development. | 0.6 |
| | There are sporadic collapses, landslides and gullies. | 0.4 |
| | There is no collapse, landslide, gully or slight development. | 0.2 |
| Regional tectonics C4 | Strongly uplift area, earthquake area above M6, fault fracture zone. | 0.8 |
| | Uplift area, 4-6 magnitude earthquake area, with small and medium branch faults. | 0.6 |
| | Relatively stable area, earthquake area below magnitude 4, with small faults. | 0.4 |
| | Subsidence area, with little or no structural impact. | 0.2 |
Table 3. Risk assessment index values of debris flow.

| Basin name    | C1   | C2   | C3  | C4  | C5   | C6   | C7   | C8   | C9   | C10  | C11  | C12  |
|---------------|------|------|-----|-----|------|------|------|------|------|------|------|------|
| Siren gully   | 0.6  | 9.2  | 1   | 0.8 | 1.8  | 45   | 1.28 | 1500 | 336  | 51   | 40   | 17.8 |
| Gangou       | 0.6  | 2000.0 | 500 | 0.8 | 9.36 | 80   | 0.59 | 1788 | 306  | 55   | 40   | 4.5  |
| Xiaganzuo    | 0.4  | 420.0 | 550 | 0.8 | 23.55| 10   | 0.94 | 2137 | 243  | 50   | 45   | 5.8  |
| Shangganzuo  | 0.2  | 300.0 | 450 | 0.8 | 9.31 | 20   | 0.43 | 1816 | 394  | 48   | 45   | 35.7 |
| Lianghekou   | 0.4  | 6.0   | 16  | 0.8 | 2.78 | 25   | 1.10 | 1629 | 464  | 60   | 60   | 4.0  |
| Jitougai     | 0.4  | 2000.0 | 80  | 0.8 | 9.99 | 15   | 0.53 | 1589 | 240  | 56   | 40   | 30.9 |
| Pingpinggou  | 0.2  | 9.0   | 9   | 0.8 | 0.62 | 8    | 0.69 | 182  | 387  | 51   | 46   | 3.4  |
| Jiawugou     | 0.4  | 500.0 | 40  | 0.8 | 43.55| 30   | 0.26 | 1360 | 275  | 57   | 50   | 2.8  |

Table 4. Standardized data of risk assessment indexes of debris flow gullies.

| Basin name    | C1     | C2     | C3     | C4     | C5     | C6     | C7     | C8     | C9     | C10    | C11    | C12    |
|---------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Siren gully   | 0.600  | 0.009  | 0.001  | 0.800  | 0.090  | 0.450  | 0.800  | 0.750  | 0.420  | 0.510  | 0.500  | 0.356  |
| Gangou       | 0.600  | 1.000  | 0.500  | 0.800  | 0.468  | 0.800  | 0.369  | 0.894  | 0.383  | 0.550  | 0.500  | 0.090  |
| Xiaganzuo    | 0.400  | 0.420  | 0.550  | 0.800  | 1.000  | 0.100  | 0.588  | 1.000  | 0.304  | 0.500  | 0.563  | 0.116  |
| Shangganzuo  | 0.200  | 0.300  | 0.450  | 0.800  | 0.466  | 0.200  | 0.269  | 0.908  | 0.493  | 0.480  | 0.563  | 0.714  |
| Lianghekou   | 0.400  | 0.006  | 0.016  | 0.800  | 0.139  | 0.250  | 0.688  | 0.815  | 0.580  | 0.600  | 0.750  | 0.080  |
| Jitougai     | 0.400  | 1.000  | 0.080  | 0.800  | 0.500  | 0.150  | 0.331  | 0.795  | 0.300  | 0.560  | 0.500  | 0.618  |
| Pingpinggou  | 0.200  | 0.009  | 0.009  | 0.800  | 0.031  | 0.080  | 0.431  | 0.091  | 0.484  | 0.510  | 0.575  | 0.068  |
| Jiawugou     | 0.400  | 0.500  | 0.400  | 0.800  | 1.000  | 0.300  | 0.163  | 0.680  | 0.344  | 0.570  | 0.625  | 0.056  |

(2) Correlation of mutation indexes

The system mutation progression calculation method includes "complementary" and "non-complementary". When each mutation index is basically uncorrelated, the "non-complementary" principle is used to determine the mutation series of the upper layer. When each mutation index is related, the "complementary" principle is used to determine the mutation series of the upper layer. The correlation coefficient of each mutation index was calculated based on Pearson product moment correlation coefficient method, and the correlation between each mutation index was determined according to the calculation results of correlation coefficient. The calculation results are shown in Table 5. But the reliability of using the correlation coefficient between statistical samples to determine the overall correlation of evaluation indicators needs to be verified. Therefore, the paper makes a significance test on the correlation coefficient between the calculated mutation indexes to make it more in line with the actual situation. T test was conducted on each evaluation index, assuming that the two mutation indexes were basically unrelated, and the significance level was 0.05. When \( t > t_{0.05(n-2)} \), \( p < 0.05 \), the original hypothesis was rejected, otherwise the original hypothesis was accepted, and the two evaluation indexes were basically unrelated. Table 6 shows the calculation results of T test for each index, and the distribution table of \( t \) test critical value \( t_{0.05(n-2)} \) is 2.45. It can be concluded that: for C1, C2, C3, C4, "non complementary" butterfly mutation model is adopted; for C5, C6, C7, "non complementary" cusp mutation model is used; for C10, C11, C12, "non complementary" swallow tail mutation model is used; for B1, B2, B3, B4, "non complementary" butterfly mutation model is used.

Table 5. Correlation coefficient of each evaluation index.

| Index  | C1     | C2     | C3     | C4     | C5     | C6     | C7     | C8     | C9     | C10    | C11    | C12    |
|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| C1     | 1.00   | 0.32   | 0.03   | 0.00   | 0.03   | 0.77   | 0.41   | 0.43   | -0.33  | 0.32   | -0.31  | -0.24  |
| C2     | 0.32   | 1.00   | 0.47   | 0.00   | 0.48   | 0.38   | -0.55  | 0.40   | -0.69  | 0.22   | -0.50  | 0.20   |
| C3     | 0.03   | 0.47   | 1.00   | 0.00   | 0.79   | 0.24   | -0.47  | 0.56   | -0.43  | -0.28  | -0.19  | -0.05  |
| C4     | 0.00   | 0.00   | 1.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   |
| C5     | 0.03   | 0.48   | 0.79   | 0.00   | 1.00   | -0.09  | -0.49  | 0.49   | -0.71  | -0.00  | -0.05  | -0.10  |
| C6     | 0.77   | 0.38   | 0.24   | 0.00   | -0.09  | 1.00   | 0.04   | 0.30   | -0.04  | 0.22   | -0.30  | -0.20  |
Table 6. T test results of debris flow risk assessment index.

|    | Index | C1  | C2  | C3  | C4  | C5  | C6  | C7  | C8  | C9  | C10 | C11 | C12 |
|----|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| C7 |       | 0.41| -0.55| -0.47| 0.00| -0.49| 0.04| 1.00| 0.09| 0.31| -0.03| 0.13| -0.19|
| C8 |       | 0.43| 0.40| 0.56| 0.00| 0.49| 0.30| 1.00| -0.28| 0.05| -0.07| 0.30|     |
| C9 |       | -0.33| -0.69| -0.43| 0.00| -0.71| -0.04| 0.31| -0.28| 1.00| 0.09| 0.62| -0.07|
| C10|       | 0.32| 0.22| -0.28| 0.00| -0.00| 0.22| -0.03| 0.05| 0.09| 1.00| 0.54| -0.39|
| C11|       | -0.31| -0.50| -0.19| 0.00| -0.05| -0.30| 0.13| -0.07| 0.62| 0.54| 1.00| -0.42|
| C12|       | -0.24| 0.20| -0.05| 0.00| -0.10| -0.20| -0.19| 0.30| -0.07| -0.39| -0.42| 1.00|

(3) Catastrophe risk assessment criteria

According to the national standard for debris flow prevention and control[11] and combined with the specific situation of the debris flow gully area, the debris flow risk is divided into four grades: mild, moderate, severe and extreme. The classification standard of debris flow risk in the study area is shown in Table 7. The normalized formula of catastrophe model is used to calculate the threshold value of single index risk classification, and finally the debris flow risk assessment standard based on catastrophe progression is obtained, as shown in Table 8.

Table 7. Classification standard of debris flow risk in study area.

| Mutation index | Risk level | Mild risk | Moderate risk | Severe danger | Extremely dangerous | Remarks |
|----------------|------------|-----------|---------------|---------------|---------------------|---------|
| C1             | 0.2        | 0.4       | 0.6           | 0.8           |                     | -       |
| C2             | 0~10       | 10~50     | 50~100        | 100~1000      | 1000 when more than 1000 |
| C3             | 0~10       | 10~50     | 50~100        | 100~1000      |                     | -       |
| C4             | 0.2        | 0.4       | 0.6           | 0.8           |                     | -       |
| C5             | 0~1        | 1~5       | 5~10          | 10~20         | 20 when more than 20 |
| C6             | 0~10       | 10~25     | 25~50         | 50~100        |                     | -       |
| C7             | 0~0.4      | 0.4~0.8   | 0.8~1.2       | 1.2~1.6       | 1.6 when more than 1.6 |
| C8             | 0~500      | 500~1000  | 1000~1500     | 1500~2000     | 2000 when it is more than 2000 |
| C9             | 0~200      | 200~400   | 400~600       | 600~800       | 800 when it is more than 800 |
| C10            | 0~10       | 10~25     | 25~50         | 50~100        | 100 when more than 100 |
| C11            | 50~80      | 25~50     | 10~25         | 0~10          |                     | -       |
| C12            | 0~1        | 1~10      | 10~25         | 25~50         | 50 when more than 50 |

Table 8. Risk classification of debris flow.

| Evaluation level | Catastrophe theory |
|------------------|-------------------|
| Mild risk        | 0~0.464           |
| Moderate risk    | 0.464~0.607       |
| Severe danger    | 0.607~0.681       |
| Extremely dangerous | >0.681         |
4. Debris flow risk assessment of Jiumian Expressway

4.1. Debris flow risk calculation

The calculation process of catastrophe progression of debris flow risk in Siren gully is shown as follows. Formula (3) gives the calculation process of bottom layer of catastrophe model, and formula (4) gives calculation process of intermediate layer of catastrophe model. Finally, $TA=0.422$. It can be seen from Table 8 that the risk of debris flow in Siren gully is mild risk. In the same way, the other sudden change series of grooves are calculated, and the final results are shown in Table 9.

$$\begin{align*}
TB_1 &= \min \{TC_1, TC_2, TC_3, TC_4\} \\
&= \min \{\sqrt{C_1}, \sqrt{C_2}, \sqrt{C_3}, \sqrt{C_4}\} = 0.178 \\
TB_2 &= \min \{TC_5, TC_6, TC_7\} \\
&= \min \{\sqrt{C_5}, \sqrt{C_6}, \sqrt{C_7}\} = 0.300 \\
TB_3 &= \min \{TC_8, TC_9\} \\
&= \min \{\sqrt{C_8}, \sqrt{C_9}\} = 0.749 \\
TB_4 &= \min \{TC_{10}, TC_{11}, TC_{12}\} \\
&= \min \{\sqrt{C_{10}}, \sqrt{C_{11}}, \sqrt{C_{12}}\} = 0.714 \\
TA &= \min \{TB_1, TB_2, TB_3, TB_4\} = 0.422
\end{align*}$$

Table 9. Debris flow risk assessment results

| Groove name    | Catastrophe theory | Risk level         |
|----------------|--------------------|--------------------|
| Siren gully    | 0.422              | Mild risk          |
| Gangou         | 0.880              | Extremely dangerous|
| Xiaganzuo      | 0.774              | Extremely dangerous|
| Shangganzuo    | 0.669              | Severe danger      |
| Lianghekou     | 0.426              | Mild risk          |
| Jitougai       | 0.729              | Extremely dangerous|
| Pingpinggou    | 0.456              | Mild risk          |
| Jiawugou       | 0.795              | Extremely dangerous|

4.2. Result verification

The prediction results are in good agreement with the actual history of debris flow, and the established debris flow risk assessment model is suitable for the Jiuzhaigou County bidding section of the Jiumian Expressway. For example, on July 25, 2016, a huge debris flow disaster occurred in Ganzuo gully with the highest mutation level, forming a barrier lake near the mouth of the gully, blocking the tangzhu River, resulting in the disconnection of S205 provincial highway, the destruction of 19 villagers’ houses, and huge economic losses. Another example is the extremely dangerous Xiaganzuo gully. Small and medium-scale debris flows occurred in 1964, 1976, 1986 and 2001, and the debris flow broke out again on July 25, 2016. The effluent formed a "ji"-shaped accumulation area with a length of about 1000m and a width of 20–120m at the mouth of the ditch. The accumulated material reserves were about $28\times10^4m^3$. 1.8km village road was submerged and destroyed, 150m provincial highway was occupied, 3000m drinking water pipeline was damaged, and the forest farm offices on both sides of the gully were also destroyed.

5. Conclusion

(1) Based on the control of internal and external factors of debris flow disaster in engineering area, a
A catastrophe model of debris flow risk assessment suitable for engineering area is established. The model includes 12 catastrophe indexes, involving geological conditions, basin shape, basin scale and inducing factors.

(2) The catastrophe model of debris flow risk assessment is used to evaluate the debris flow risk of 8 debris flow gullies in the project area. The results show that the debris flow risk of Gangou and Xiaganzuo in the Jiuzhaigou County bidding section of the Jiiumian Expressway is extremely dangerous, and the debris flow risk of Shangganzuo gully is severe. These five debris flow gullies are the key objects of debris flow prevention and control during the construction and operation of Jiiumian expressway.

(3) By comparing the actual occurrence history of debris flow in 8 gullies with the evaluation results, it is considered that the catastrophe model of debris flow risk assessment can accurately reflect the debris flow risk of gully debris flow along the Jiuzhaigou County bidding section of the Jiiumian expressway, and the assessment results can provide basis for debris flow prevention and control in construction and operation of Jiiumian expressway.

Acknowledgements:
The work is supported by the National Natural Science Foundation (51978265), the Key Young Foundation of Jiangxi Province (20181BAB216028), the Department Foundation of Transportation of Jiangxi Province (2018H0042), and project (20181BCB24011).

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