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THE CATASTROPHE FORECAST OF THE ANNUAL SIDEMENT TRANSPORT BY DEBRIS FLOW IN JIANGJIA GULLY, YUNNAN PROVINCE, CHINA

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ABSTRACT: On the basis of the observational data on the annual sediment transport by debris flow in recent 8 years, appling the catastrophe forecast method of Grey System Theory, this study has established the catastrophe model of the annual sediment transport by debris flow in Jiangjia Gully. It has forecasted the next potential catastrophic year in which the annual sediment transport will be over the catastrophic threshold 2 million m^3. Furthermore, it has introduced the "equal dimension–new information model", which makes the forecast be done continuously.

KEY WORDS: debris flow, annual sediment, catastrophic model, Jiangjia Gully

I. INTRODUCTION

The sediment transport by debris flow is one of the important evidences to evaluate the scale and the risk of debris flow. The volume of sediment transport is closely related to the preventive projects, especially the volume going beyond a threshold. This paper particularly emphasizes when the volume over the catastrophic threshold will occur.

The sediment transport by debris flow is the consequence of the comprehensive processes of the steep–slope, plentiful loose materials, and the certain intensity of rainfall in a gully. When the former two factors are specific, the latter factor–precipitation has a closer relationship with the sediment transport. In fact, the more rainfall, the more occurence times of debris flow, and the more the sediment transport by debris flow. Therefore, we can consider that the sediment transport has contained the influences of rainfall. For this reason, we suggest if the annual sediment transport can be obtained, it is more direct to forecast the catastrophic year with the annual sediment transport rather than yearly precipitation. But if there is no data of the annual sediment transport by debris flow, we can analyse the relationship between the sediment transport by debris flow and yearly precipitation in a similar region to find certain rules, and then use the precipitation over a catastrophic threshold to forecast the catastrophic year indirectly. Here we take Jiangjia Gully as an example (Fig.1), and directly use the annual sediment transport by debris flow to forecast the catastrophic year.

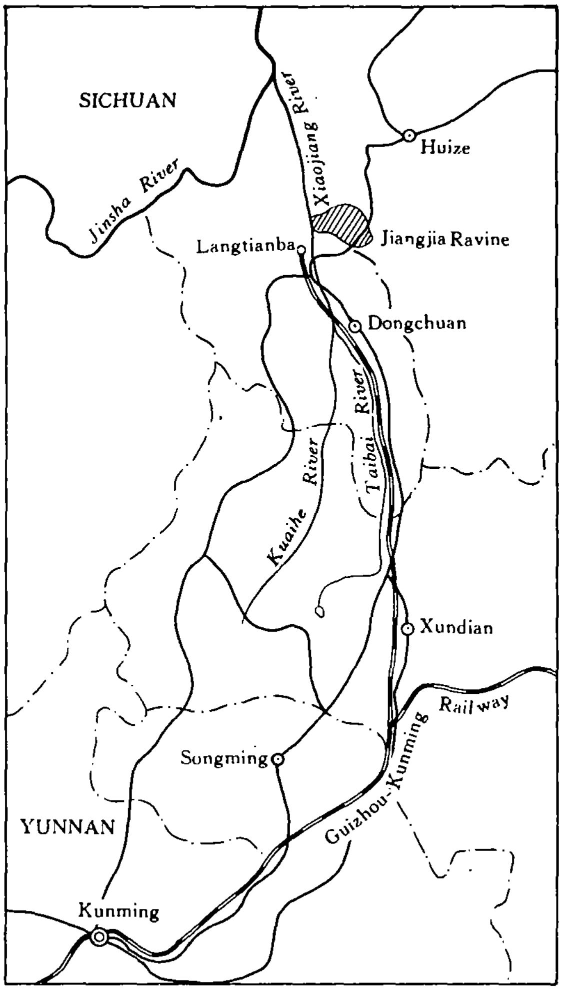

Fig.1 Location of Jiangjia Gully, Dongchuan, Yunnan Province

II. THE SURVEY OF JIANGJIA GULLY

Jiangjia Gully, a rainy debris flow gully, is situated in Dongchuan, Yunnan Province in southwest of China. It has a drainage area of 47.1 km^2,a length of 12.1 km, an average longitudinal gradient of 13.8%, as well as the unconsolidated materials of 123 million m^3.

At the upper section, the annual precipitation is 1200 mm, and at the middle section, the annual precipitation is 700–850 mm. From May to December is its rainy season. During rainy season, the precipitation accounts for 85% of the whole year's total and the dischange of water flow is 0.5–1 m/ s. From November to following April is its dry season. During dry season, the discharge of water flow is 0.1–0.5 m/ s. From 1965 to 1985, debris flows took place 256 times. The annual sediment transport by debris flow usually is 1–3 million m^3, mean 2 million m^3, the maximum up to 3.87 million m^3 in 1974[1,2].

III. THE CATASTROPHE MODEL OF THE ANNUAL SEDIMENT TRANSPORT BY DEBRIS FLOW

1. The Collection of Basic Data

The basic data to be used to establish catastrophe model are in Table 1[2,3].

Table 1 The observational data of the annual sediment transport by debris flow in Jingjia Gully

Items	1	2	3	4	5	6	7	8
Year	1978	1979	1980	1981	1982	1983	1984	1985
Occurrence time	14	23	9	11	6	13	7	14
Sediment transport (million m^3)	2.27	3.76	1.50	2.18	1.07	2.08	1.69	3.15

2. The Establishment of Catastrophe Model

Accordind to the Grey System Theory[4,5], the catastrophe model can forecast when a disaster occur. Based on Table 1, the original number sequence $x^{(0)}$ is

$$x_{(0)} = \{x^{(0)}(1), x^{(0)}(2), \ldots, x^{(0)}(8)\}$$
$$= (2.27,\ 3.76,\ 1.5,\ 2.18,\ 1.07,\ 2.08,\ 1.69,\ 3.15)$$

Because the average annual sediment transport by debris flow in Jiangjia Gully is 2.00 million m^3, we designate the catastrophic threshold $\zeta = 2.00$. $x^{(0)}(i) > 2.00$ are arranged to form a new number sequence $x_\zeta^{(0)}$

$$x_\zeta^{(0)} = (2.27,\ 3.76,\ 2.18,\ 2.08,\ 3.15)$$
$$= \{x_\zeta^{(0)}(1), x_\zeta^{(0)}(2), x_\zeta^{(0)}(3), x_\zeta^{(0)}(4), x_\zeta^{(0)}(5), x_\zeta^{(0)}(6), x_\zeta^{(0)}(7), x_\zeta^{(0)}(8)$$

That is $P = \{p(1), p(2), p(3), p(4), p(5),$
$= (1,2,3,6,8)$

where P is the number sequence of the catastrophic years Make the first accumulated generating operation on P

$$P^{(1)}(1)=1$$
$$P^{(1)}(2)=P^{(1)}(1)+p(2)=3$$
$$P^{(1)}(3)=P^{(1)}(2)+p(3)=7$$
$$P^{(1)}(4)=P^{(1)}(3)+p(4)=13$$
$$P^{(1)}(5)=P^{(1)}(4)+p(5)=21$$

That is $P^{(1)} = \{P^{(1)}(1), P^{(1)}(2), \ldots, P^{(1)}(5)\}$
$= (1,3,7,13,21)$

Based on $P^{(1)}$ to establish Grey Model (1,1).

$$dP^{(1)}/\ dt + aP^{(1)} = u \qquad (1)$$

Marked a and u as the elements of parameter vector

$$\bar{a}=\{{a \atop u}\} = (B^T B)^{-1} B^T \qquad (2)$$

The solution of the differential equation 1 is

$$\bar{p}^{(1)}(i+1) = [p^{(1)}(1) - u/\ a]e^{-at} + u/\ a \qquad (3)$$

This is the forecast model we want.

In order to establish Grey Modol(1,), we construct the datum matrix B and Yn.

$$B = \begin{bmatrix} -0.5[P^{(1)}(1)+P^{(1)}(2) & 1 \\ -0.5[P^{(1)}(2)+P^{(1)}(3) & 1 \\ -0.5[P^{(1)}(3)+P^{(1)}(4) & 1 \\ -0.5[P^{(1)}(4)+P^{(1)}(5) & 1 \end{bmatrix} = \begin{bmatrix} -2 & 1 \\ -5 & 1 \\ -10 & 1 \\ -17 & 1 \end{bmatrix}$$

$$Y_n^{\bullet} = \begin{Bmatrix} P(2) \\ P(3) \\ P(4) \\ P(5) \end{Bmatrix} = \begin{Bmatrix} 2 \\ 4 \\ 6 \\ 8 \end{Bmatrix}$$

Then calculate $(B^T B)^{-1} B^T Yn$, we get

$$\bar{a}=\begin{Bmatrix} a \\ u \end{Bmatrix}=\begin{Bmatrix} -0.3980 \\ 1.7040 \end{Bmatrix}$$

That is: $a = -0.3980$, $u=1.7040$, $u/a= -4.2814$

Our needed catastrophe model is

$$\bar{p}^{(1)}(t+1) = 5.2814e^{0.3980t} - 4.2814 \quad (4)$$

3. The Test of Model Precision

The model precision directly affects the reliability of catastrophe forecast. We use the error test (Table 2) and the test of the remains difference (Table 3) to test the model precision. Here, we use $\bar{p}(t) = \bar{p}^{(1)}(t) - \bar{p}^{(1)}(t-1)$ to calculate the restored value of the catastrophe model.

Table 2 The error test of the catastrophe model

Restored value	Original value	Absolute error	Relative error (%)
$\bar{p}(2) = 2.58$	P(2) = 2	q = −0.58	e = −29
$\bar{p}(3) = 3.85$	P(3) = 4	q = 0.15	e = 3.8
$\bar{p}(4) = 5.72$	P(4) = 6	q = 0.28	e = 4.7
$\bar{p}(5) = 8.52$	P(5) = 8	q = −0.52	e = −6.5

Table 3 The test of the remains difference of the catastrophe model

Grade of model precision	p	C
Good	> 0.95	<0.35
Qualified	>0.80	<0.50
Passable	>0.70	<0.45
Fail	<0.70	>0.65

Note: Based on Deng[4]

The ratio of the remains difference is

$$C=\frac{S_2}{S_1}=\frac{\sqrt{\frac{1}{4}\sum_{t=2}^{5}[q(t)-\bar{q}]^2}}{\sqrt{\frac{1}{5}\sum_{t=1}^{5}[p(t)-\bar{p}]^2}}=\frac{0.6336}{2.5612}=0.2474$$

The mini−error probability is

$$p=p\{|q(t)|<0.6745\,S_1\}$$

That is $p=p\{|q(t)|<1.7275\}$

From Table 2, we know all $|q(t)|$ are less than 1.7275. Therefore, $p=100\%=1$.

From Table 3, we know when $p>0.95$ and $c<0.35$, the model precision is good. Thus we can say thatthe catastrophe model 4 is reliable to forecast the annual sediment transport by debris flow in Jiangjia Gully.

4. The Result of Catastrophe Forecast

According to the catastrophe model 4, we can forecast the first catastrophicyear in which the annual sediment transport by debris flow over 2 million m^3 in Jiangjia Gully after 1985. We use catastrophe model 4 to calculate $\bar{p}^{(1)}(6)=34.35$ and $\bar{P}^{(1)}(5)=21.67$ and $p(6)=\bar{p}^{(1)}(6)-\bar{p}^{(1)}(5)=12.68$. Since $p(5)=8$, and from $t=8$ to count the difference between 12.68 and 8 is 4.68, this shows that the next year with sediment transport by debris flow over 2 million m^3 occur in 4–5 years later in Jiangjia Gully. That is, the catastrophic year occur in 1989 or 1990. In fact the sediment transport by debris flow in 1990 was indeed up to 3 million m^3. However, if we go on to forecast with catastrophe model 4, the next catastrophic year will occur in 1996, and again next catastrophic year will occur in 2005. Obviously, with the lapse of time, the weak trend of the activity of debris flow is not correspondent to the actual sitrction because there are lots ot loose materials in Jiangjia Gully. Therefore, we thick that the efficient result of catastrophe model 4 is only the first forecasted catastrophic year. It can only used to the short term forecast of the sediment transport by debris flow in Jiangjia Gully.

In order to solve the problem of the continuous catastrophe forecast. This study introduces the "equal dimension–new information model" which has the highest precision. When we add a new datum and delete the oldest datum, the quantity of the data is maintained to be equal. Thus we may build a new Grey Model (1,1) to forecast the next catastrophic year again.

If the forecast result is correct, we add the new year and build the new catastrophe model—equal dimension —new information model, so as to make thecatastrophe forecast have the highest precision all the time.

From 1986 to 1989, there were not extremely large scale of debris flow in Jiangjia Gully. In 1990, the sediment transport by debris flow went beyond the catastrophic threshold, which has been forecasted by the catastrophe model 4. Therefore, we may add the new year—1990 and delete the oldest year—1978.

Thus we get the equal dimension—new information number sequence

$$P = (1, 3, 5, 7, 12)$$

Again make the first accumulated generating opreration on p

$$p = (1, 4, 9, 16, 28)$$

Based on p to build the equal dimension —new information model

$$\bar{p}^{(1)}(t+1) = 5.1411e^{0.4401t} - 4.1411 \tag{5}$$

Then calculate $p(6) = \bar{P}^{(1)}(6) - \bar{p}^{(1)}(5) = 16.35$ with catastrophe model (5).

We know $p(5)=12$, and from $t=12$ to count, the difference between 16.53 and 12 is 4.53. Therefore the forecast result of catastrophe model 5 shows that the next catastrophic year in which the sediment transport by debris flow over 2 million m^3 will occur in 4–5 years later. That is, it will occur in 1994 or 1995.

IV. CONCLUSION

1) The founder of the catastrophe model believes that, with the lapse of time and with the enhancement of human's ability to resist disaster, the frequency of the disaster going beyond or beneath the certain catastrophic threshold will be lower and lower. However, for the special disaster—debris flow, so long as there are lots of unconsolidated materials in the gully, in a short time, the activity of the debris flows is impossible to become weak unless the strong counter—projects are implemented. Therefore, to forecast the middle and long—term catastrophe by one model it is not reliable. We should use the equal dimension model once again and again to make the short term forecast, which is a feasible method.

2) Because the $\bar{p}(t) = \bar{p}^{(1)}(t) - \bar{p}^{(1)}(t-1)$ are not all the integers, that is, the interval years between catastrophic years are little possible to be a interger.The forecasted catastrophic year by the catastrophe model is unavoidably tohave a scope, but usually it is not going beyond 2 years.

3) This research takes Jiangjia Gully as an exemple, and it has illustrated the main method of the catastrophe forecast of the sediment transport by debris flow in Jiangjia Gully. However, in the other rainy debris flow regions, we should consider the special conditions, redetermine the catastrophic threshold and establish a new catastrophe model and the equal dimension-new information model, then to begin the work of the practical catastrophe forecast.

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