

# Prevention of debris flow disasters on Chengdu-Kunming Railway

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**Abstract:** Chengdu-Kunming Railway is an important transport line on southwestern China. However, this railway's safety is often threatened by debris flows. How to effectively forecast and alarm the debris flow disasters and reduce the losses is the aim to study the prevention system in this paper. The factors to cause or influence debris flow are divided into four parts—the basin environmental factors, the basin meteoric factors, the prevention work's elements and the flood-relief work's elements, and the prevention system is made up of three models—a judgment model to assess the debris flow gully's seriousness, a forecast model to predict the debris flow's occurrence and an alarm model to evaluate the debris flow's disaster. Afterwards, a concise structure chart is worked out and verified by the field data from Chengdu-Kunming Railway. This prevention system will provide beneficial reference for the debris flow's monitoring network to be executed on Chengdu-Kunming Railway.

**Key words:** debris flow disaster; prevention system; Chengdu-Kunming Railway

## Introduction

Chengdu-Kunming Railway Line is located on the mountain region of southwestern China. There are a lot of debris flow gullies spreading beside this railway line. On summer, the debris flow often bursts and threatens the safety of the railway transportation. In 1981, a large-scale debris flow occurred at Liziyida area on Chengdu-Kunming Railway, shattered the former Liziyida Railway Bridge and made a passenger train crashed, which is one of the most serious railway disaster brought about by debris flow in China. Therefore, in order to effectively prevent the debris flow disasters and reduce the losses on this railway, to set up a debris flow prevention system has important theoretical and practical significance.

## 1 Construction of debris flow database for Chengdu-Kunming Railway

To set up a debris flow database and constantly enrich it is an essential and important task for the debris flow prevention. However, because the factors to cause or influence debris flow disasters on Chengdu-Kunming Railway are numerous, the factors in the database must be chosen. According to the early researches by Shen *et al.* (Shen, 1991) and Wang *et al.* (Wang, 1996; 1997), the main factors can be divided into four parts—the basin environmental factors, the basin meteoric factors, the prevention work's elements and the flood-relief work's elements.

The basin environment factors are the important ones affecting the debris flow's burst and scope. The concerned data originate from three aspects: the technical archives (such as the regional formation, the lithologic character), the aero photographic data (such as the basin area, the vegetation cover rate) and the in-situ investigation (such as the bulk solid reserves, the stream blockage degree). The factors affecting the basin environment are numerous, impossible to adopt wholly. Thus, on the basis of a large number of investigation data, a counting analysis is conducted by the specialist-investigation-method. It is concluded that the 15 factors of three categories, which are mostly able to reflect the debris flow gully situation, can be selected as the basic ones of the basin environment and the main content of the basin environment database. The first category involves the factors reflecting the land surface feature: the vegetation cover rate, the mountain slope, the basin area, the relative elevation and the debris flow accumulation rate at a gully's mouth. The second category is the factors reflecting the loose material situation: the soil erosion degree, the regional formation, the lithological character, the length ratio of sediment supply along journey, the bulk material depth in the sediment production area and the bulk material reserve along a gully. The third category reflects the river condition, including the longitudinal slope of a river gully, the variation range in recent period, the cross-section of a gully and the blockage degree and so on.

The basin meteorological factors are the direct agent triggering the debris flow action. The seriousness of a debris flow gully is related with the regional meteorological feature, and whether the debris flow bursts out or not is affected by the rainfalls both in earlier period and in real-time. The prerequisite of debris flow forecast is the knowing of the rain events and the precipitation, and the real time rainfall process is the basis of a disaster alarm. The concerned data are obtained mainly through the historic archives of the meteorological station, the meteorological analysis of the satellite cloud mapping and the rainfall records in monitoring network.

The prevention works refer to the hydraulic works such as debris dams, drain-guiding ditches constructed in debris flow gullies used for reducing debris flow's destroying degrees, and the flood-relief works are the railway ones such as bridges and culverts constructed along a railway line for successfully releasing a debris flow. The hydraulic elements of these works are the important data reflecting its passage capability, which are obtained mainly by the design documents, the maintenance records

and the engineering return visits.

## 2 Establishment of prevention system for Chengdu-Kunming Railway

The debris flow gullies are successive one by one in the mountainous region along Chengdu-Kunming Railway, so it is impossible and unnecessary for us to bring all gullies under control. Therefore, the first work is to establish a judgment model to assess the seriousness of debris flow gullies. The judgment model used here is (Shen, 1991):

$$N = \sum_{i=1}^{15} (r_i p_i), \quad (1)$$

where  $r_i$ ,  $p_i$  are the weight and mark of each environmental factor respectively;  $N$  is the synthetic judgment value of a debris flow gully.

The seriousness of a debris flow gully is judged by the threshold (116, 86, 44) and divided into 4 judged results: serious, middle, slight and no debris flow gully.

The debris flow gully judged as serious ( $N > 116$ ) should improve its rainfall monitoring network as soon as possible and the debris flow prevention system must be conducted during heavy rainfall; the gully with the value between 86 and 116 should be monitored and guarded continuously; and the gully judged as slight ( $44 < N < 86$ ) or no debris flow gully ( $N < 44$ ) can be ignored temporarily.

The rainfall will result in a runoff and further form a mountain torrent. However, only the solid content in flood reaches a certain ratio, the torrent can be recognized as debris flow. The scale and destroying force of a debris flow is far more enormous than a torrent, so the forecast model must be established to judge if the debris flow burst out. The combined forecast parameter  $Y$  of a debris flow is determined by the dynamic function  $M$  of basin environment and the storm condition function  $R$  (Tan, 1991):

$$Y = MR, \quad (2)$$

in which

$$R = k_1 \left( \frac{H_{24}}{H_{24D}} + \frac{H_1}{H_{1D}} + \frac{H_{1/6}}{H_{1/6D}} \right);$$

$$M = k_2 (N_1 + N_2 + N_3 + N_4),$$

in which,  $k_1$  is the revision coefficient of the rainfall in earlier period,  $k_1 > 1$ ;  $H_{24}$ ,  $H_1$  and  $H_{1/6}$  are the maximum rainfall in 24 hours, 1 hour, and ten minutes respectively;  $H_{24D}$ ,  $H_{1D}$  and  $H_{1/6D}$  are the limited regional rainfall in 24 hours, 1 hour and ten minutes respectively, on Chengdu-Kunming Railway, they are 60 mm, 20 mm and 10 mm respectively;  $k_2$  is the basin erosion coefficient,  $0.01 \leq k_2 \leq 0.78$ ;  $N_1$  is the quantified value of the water collection and the sand storage synthetic parameter,  $0.30 \leq N_1 \leq 4.80$ ;  $N_2$  the quantified value of the runoff production and travel parameter,  $0.10 \leq N_2 \leq 1.60$ ;  $N_3$  the quantified value of the sand production parameter,  $0.35 \leq N_3 \leq 5.60$ ;  $N_4$  the quantified value of the debris flow transportation parameter,  $0.25 \leq N_4 \leq 4.00$ .

The debris flow bursting possibility is judged by the threshold (35, 25) and divided into 3 judged results: bursting, being able to burst and not bursting.

The basin judged as not bursting debris flow ( $Y \leq 25$ ) will be prevented according to an ordinary flood; for the basin judged as bursting ( $Y > 35$ ) or being able to burst ( $25 < Y \leq 35$ ) debris flow, their bursting scale should be estimated.

In order to obtain the clear water peak discharge in a debris flow process, a rationalized formula is used here (Wang, 1997):

$$Q_{fp} = \frac{1}{3.6} f \cdot r \cdot A, \quad (3)$$

in which  $f$  is the flow production coefficient,  $r$  is the maximum rainfall intensity and  $A$  is the basin area.

The debris flow peak discharge  $Q_{dp}$  can be estimated by the following formula (Wang, 1997):

$$Q_{dp} = Q_{fp} \cdot \frac{(\sigma - 1)(\operatorname{tg} \varphi - J)}{(\sigma - \rho)(\operatorname{tg} \varphi - J) - K_c \rho J} \cdot K_b, \quad (4)$$

in which  $\sigma$  is the debris flow solid density;  $\rho$  is the debris flow liquid density;  $\varphi$  is the solid-phase internal friction angle;  $J$  is the gully's slope;  $K_c$  is the boulder coverage coefficient and  $K_b$  is the debris flow blockage coefficient.

The existence of prevention works will reduce the debris flow's destroying capability, so the role of prevention works should be analyzed.

The main role of a debris flow dam is to store sediments and reduce a flood peak, a debris flow's peak discharge released through a debris flow dam is (Wang, 1996):

$$Q'_{dp} = (1 - \eta C) Q_{dp}, \quad (5)$$

in which  $\eta$  is the sand retaining ratio of a dam and  $C$  is the debris flow's concentration.

The drain-guiding ditch changes the movable bed to a stable one, thus may heighten the debris flow's velocity and lower the debris flow's depth. The relationship between the flow depth  $h'$  in a drain-guiding ditch and the flow depth  $h$  on a primary riverbed is (Shen, 1991):

$$h' = (I_n / I_j)^{2/5} h, \quad (6)$$

in which  $I_m$ ,  $I_f$  are the debris flow's velocity coefficient in a movable bed and a stable bed respectively.

Whether a debris flow results in damage or not depends on both the disaster forming capability of a debris flow and the disaster resisting capability of the flood-relief works. The disaster resisting capability is mainly reflected on the maximum flow passage capability  $Q_c$  of bridges or culverts (Wang, 1997):

$$Q_c = (1/\alpha) m_c R_c^{2/3} I^{1/2} A_c, \tag{7}$$

in which  $\alpha$  is the resistance coefficient;  $m_c$  is the discharge coefficient;  $I$  is the bottom slope of bridge or culvert;  $A_c$ ,  $R_c$  are the effective cross-section area and the hydraulic radius of bridge or culvert respectively.

From the relation between the disaster resistance and the forming capability, the alarm model may be established (Wang, 1971). Let

$$K = Q_c / Q'_{dp}. \tag{8}$$

In accordance with the debris flow damage degree's classification requirement of the Chinese railway bridge and culvert at present, the threshold (1.35, 1.00) give the 3 safety classes of flood-relief works: safe ( $K \geq 1.35$ ), dangerous ( $1 \leq K \leq 1.35$ ), and very dangerous ( $K < 1$ ). Generally speaking, the smaller the  $K$  value, the bigger the possibility of debris flow disaster. On the basis of the alarm results and the in-situ situation, the corresponding engineering countermeasures should be made up respectively. The structure chart of the debris flow prevention system is shown in Fig.1.

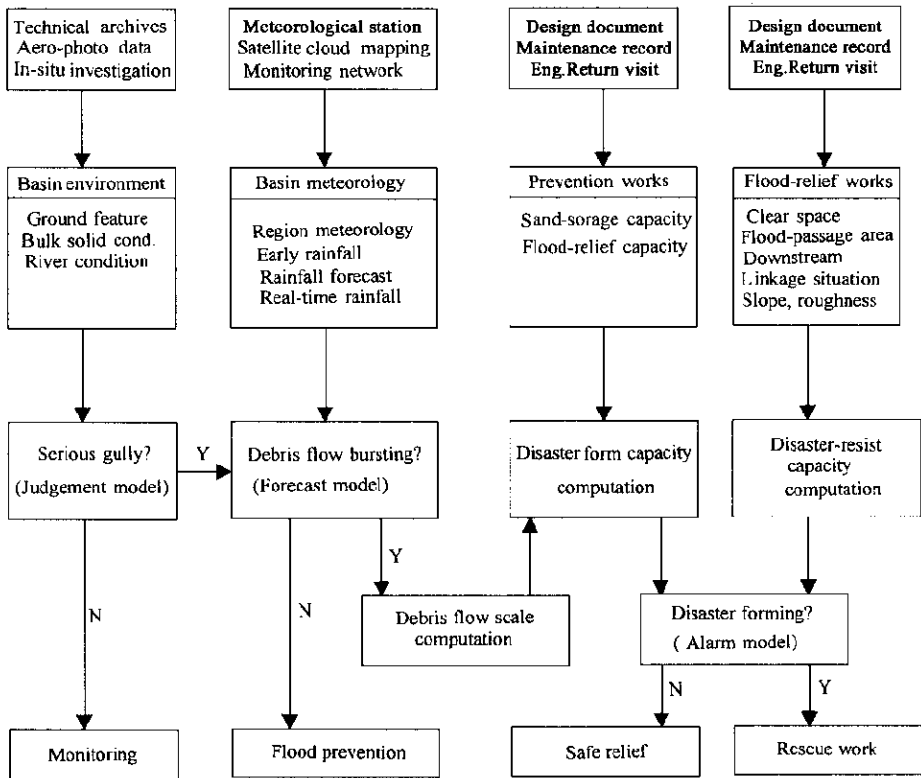


Fig.1 Debris flow prevention system on Chengdu-Kunming Railway

### 3 Verification of prevention system on Chengdu – Kunming Railway

The 41 km long debris flow test zone from Wusihe to Canluo on Chengdu-Kunming Railway was set up in 1988 and since then the abundant rainfall and disaster data have been accumulated. However, it is a pity that the data satisfying all the conditions needed by the prevention system are not so rich. Only the lacking of one simple factor will make the data useless in these models. Therefore, in order to verify the prevention system in this paper we have to pick up these data complete to our models from the debris flow archives. The plenary verification needs a more research in the future.

#### 3.1 Verification of judgment model

In the light of the present debris flow database, the assessment mark and the judgment result for part of the debris flow gullies in the test zone by Equation (1) is shown in Table 1.

**Table 1** Verification of judgment model

Gully name	Assessment mark	Judgment result
Luoso Gully	113	Middle
Zaiban Gully	127	Serious
Leri Gully	95	Middle

zone, and debris flow burst in many gullies. Based on the archives data the comparison of the forecast results given by Equation (2) with the practical situation is shown in Table 2.

As shown by the verification results, except Laguzi Gully, the forecast results of other debris flow gullies well coincide with the practical situation.

Statistically speaking, the verification results by all useful data from the test zone can be concluded (Table 3).

**3.3 Verification of alarm model**

The test zone was hit by a storm in July 11—12, 1990, with the rainfall  $H_{1/6} = 12.6$  mm,  $H_1 = 23.2$  mm, and  $H_{24} = 94.9$  mm at Maguzu Gully, and  $H_{1/6} = 13.8$  mm,  $H_1 = 44.8$  mm,  $H_{24} = 83.6$  mm at Zanban Gully. The debris flow burst in both gullies. From Equation (3)—(8) in combination with the archives data, the corresponding disaster forming capability, disaster resisting capability and alarm result can be obtained (Table 4).

The practical situation that time is: the debris flow in Maguzu Gully successfully passed the downstream railway bridge; but the culvert in Zaiban Gully was slightly overflowed due to locally choking up.

It is noted that, due to the lacking of the disaster data in the test zone, the statistical analysis for the alarm model can not be given at the present time. The work of data collection should be enhanced in the future.

**4 Conclusions**

The paper briefly describes the debris flow prevention system for Chengdu-Kunming Railway, verifies and compares it with the archive data. Under the support of the Geographical Information System, this system is on trial at the test zone. Along with the further improvement of the facilities-monitoring network in the test zone, the system, as a disaster-resisting software, will play its proper role and gain further enrichment.

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The above-indicated judgment results basically coincide the present situation of these gullies. Farther, according to the researches by Shen and Tan, the correct ratio of the model's judgment results with the experts field judgment results along Chengdu-Kunming Railway is more than 95% (Shen, 1991).

**3.2 Verification of forecast model**

During July 26—27, 1989, it rained widespread at the test

**Table 2** Verification of forecast model

Gully name	Rainfall observation value, mm			Forecast result	Practical situation
	$H_{1/6}$	$H_1$	$H_{24}$		
Xinzaizi	9.0	20.0	68.0	Burst	Burst
Longmen	11.0	25.6	55.4	No burst	No burst
Leguluoduo	15.8	36.0	69.0	Burst	Burst
Zaiban	3.4	10.9	32.2	No burst	No burst
Laguzi	10.3	19.1	42.1	Burst	No burst
Erdulu	3.6	15.6	47.8	No burst	No burst
Yanren	10.6	30.6	59.6	Burst	Burst

**Table 3** Statistical results for the forecast model

Y	Total,	True,		False,	
	Gully number	Gully number	Percentage	Gully number	Percentage
< 25	36	36	100	0	0
25—35	19	12	63	7	37
> 35	9	8	89	1	11
Total	64	56	87	8	13

Note: The correct ratio can reach 87%

**Table 4** Verification of alarm model

Gully name	Disaster forming capability	Disaster resisting capability	Alarm result
	Inflow discharge, m <sup>3</sup> /s	Flow passage discharge, m <sup>3</sup> /s	
Maguzu Gully	386.4	838.3	Safe
Zaiban Gully	528.4	613.4	Dangerous