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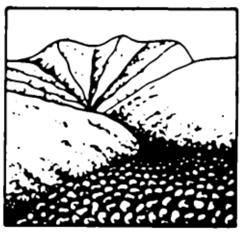

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При создании логотипа конференции использован рисунок из книги С.М. Флейшмана «Селевые потоки» (Москва: Географгиз, 1951, с. 51).
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Engineering control of debris flow in New Luding county, Hengduan Mountains, China

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Luding County is located in the transitional zone between the Tibetan Plateau and the Sichuan Basin, Sichuan Province, Southwestern China. Here is in the Hengduan Mountains in the eastern part of the Tibet Plateau and is an area prone to mountain hazards such as debris flows and landslides. Luding County New Town is located on the debris flow fan of Mohe Gully, a tributary of the right bank of the Dadu River. This is the deep valley of the Dadu River between Gongga Mountain and Erlang Mountain. The debris flow often occurs in the Mohe Gully and is located on the east slope of Gongga. The highest point of the basin is 5100 m, and the lowest point is only 1276.1 m. Within the horizontal distance of 22.7 km, the relative height is 3828.9 m. In order to prevent the damage of the Mohe Gully debris flow to the New Town, a debris flow project was implemented on the Mohe Gully. The main project included 7 gravity dams, 3 check dam and 2617.56 m long drainage canals.

debris flow, engineering control, China

Инженерная защита от селевых потоков в уезде Новый Лудин, горы Хэндуань, Китай

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Уезд Лудин находится в переходной зоне между Тибетским плато и Сычуаньской котловиной в провинции Сычуань, Юго-Западный Китай. Он расположен в горах Хэндуань и является районом, подверженным таким опасностям, как селевые потоки и оползни. Новый город Лудин расположен на селевом конусе выноса реки Мохэ, правобережного притока реки Даду. Река Даду на участке между горой Гунга и горами Эрлан протекает в глубокой долине. Селевые потоки часто формируются в долине р. Мохэ на восточных склонах г. Гунга. Самая высокая точка бассейна находится на высоте 5100 м, а самая низкая точка – на высоте лишь 1276,1 м. При горизонтальном проложении длины реки 22,7 км, относительное превышение истока над устьем составляет 3828,9 м. Чтобы предотвратить повреждение нового города Лудин селями, в долине Мохэ был реализован проект селезащиты. Основной проект включал 7 гравитационных плотин, 3 селезадерживающих плотины и 2617,56 м дренажных каналов.

сель, инженерная защита, Китай

Formation conditions and characters of debris flows in the Mohe Gully

Luding County, Ganzi Tibetan Autonomous Prefecture, Sichuan Province, China, is located in the east slope of the Gongga Mountain in the Hengduan Mountainous Area, which is in the eastern part of the Tibet Plateau. The local environment is characterized by high mountains and deep valleys, complicated geological conditions, frequent earthquakes and concentrated rainfalls. It is a place with frequent debris flows and landslides. Development of the Luding new county is experiencing threats from debris flows of the Mohe Gully, where preventing structures have been constructed.

Formation conditions of the debris flow

The Mohe Gully is frequently active in debris flows. It originates from the east slope of the Gongga Mountain and joins the Dadu River at the right bank, with elevation between 5100.0 m and 1276.1 m within 22.7 km, and streambed gradient of 107.8‰ (10.1°) (Fig. 1).

The Luding County lies in the subtropical zone and is climatically governed by the southeast and southwest monsoon, with altitude characteristics of subtropical zone, warm temperate zone, cold temperate zone, subfrigid zone and frigid zone successively from bottom to top of the valley. In particular, the Foehn effect has made a dry-hot valley in the Dadu River.

Just in the dry-hot valley lies the downstream Mohe Gully, where mean annual rainfall is 645.9 mm, with 545.2 mm concentrated between May and September. The mean and extreme maximum daily rainfalls are 40.1 mm and 72.3 mm. Every year sees two days on average having rainfall of more than 50.0 mm. Rainfall increases with altitude and reaches more than 1 900 mm around 3 000 m. The annual rainfall between 2 800 m and 3 500 m is about 2.5~2.6 times of that in the valley. Rainstorms in rainy season are the very triggering water of debris flows.

Exposure rocks in the Mohe Gully are mainly hard rocks such as granite and diorite. Collapse and landslide are small and less developed. Only 8 landslides and 9 collapses are found in the gully, which, together with deposits over the gully, supplie 262×104 m^3 loose materials to debris flows.

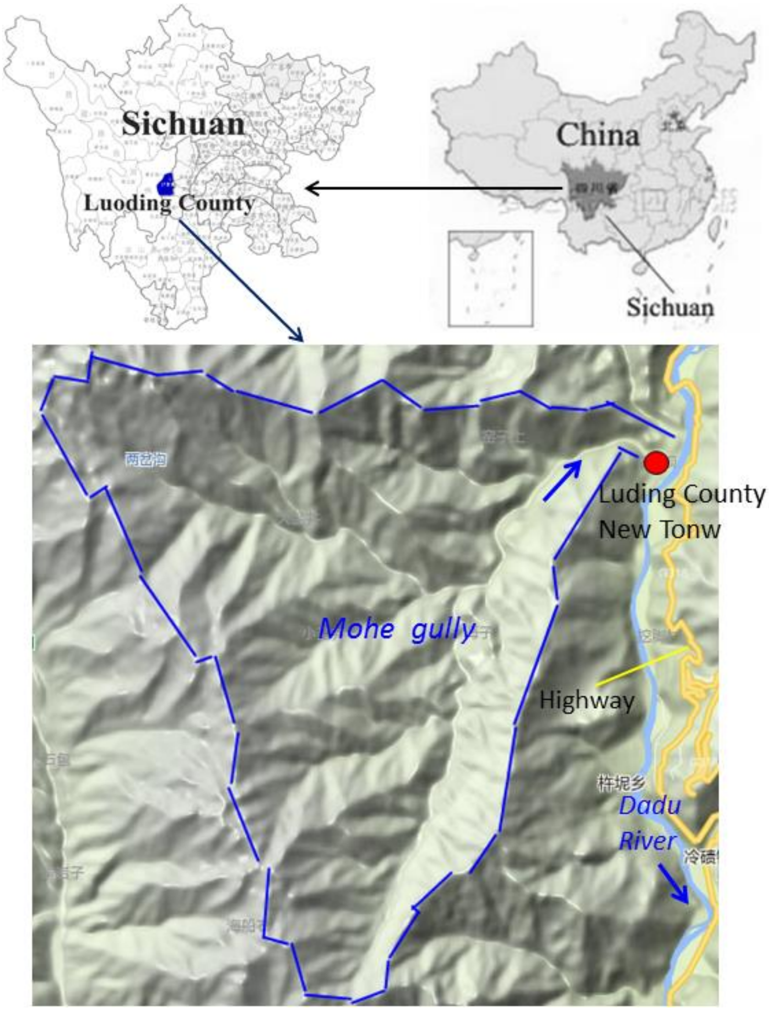

Fig. 1. The location map of the Luding new town.

Characteristics of the debris flow

Several debris flows occurred in the Mohe Gully in the last 100 years, among which the events in 1936, 1948, 1958, 1962, 1982, 2005, and 2009 caused huge disasters (Fig. 2).

a b

Fig. 2. (a) Debris flow destroys road; (b) debris flow destroys bridges.

Debris flows in the Mohe Gully have the following characters:

(1) The frequency of large-scale debris flows in the mainstream is low, nearly once every 50 to 60 years. Though the geographical conditions in favor of debris flows, storm floods with moderate scale cannot move massive gravels and rocks on river-bed. Only when rare

downpours and extraordinary rainstorms occur are flood able to activate sediments and to form debris flows.

(2) Debris flows are mainly formed in the middle of the gully and the upstream is the water concentration area. Thus, preventing engineerings should be conducted in the middle or lower reaches.

(3) Controlled by the water level of the Dadu River and the landform of the outlet, the downstream Mohe is full of debris flow deposits. The depositional fan is as wide as 100~200 m, whereas its longitudinal slope is relatively small（6%~7%）. When debris flows occur, the major part can only reach to the middle and downstream of the river, with large amounts of gravel deposited in wide channels and low-density debris flows with fine grains or hyper-concentrated floods flow into the downstream. Thus, densities of mainstream debris flows change dramatically, with 1.9~2.2 t/m^3 in the middle and only 1.3~1.5 t/m^3 in the depositional fan at the outlet.

(4) According to grain composition (Table 1), density of the debris flow in the Mohe Gully is about 1.9~2.2 t/m^3.That is， the density is 2.0~2.2 t/m3 when debris flows are of 1% frequency and is 1.9~2.0 t/m^3 when debris flows are of 2% frequency.

Table 1. Grain composition of debris flow sediments in the Mohe Gully

Content (%) / Number	Grain diameter(mm)							Note
	0.005＜	**0.005～0.074**	**0.074～0.25**	**0.25～0.50**	**0.50～2.0**	**2.0～20**	**＞20**	
Mohe1	0	0	5.7	8.2	5.1	12.3	68.7	Small sample
Mohe 2	0	0	0.2	2.8	4.5	15.7	76.8	Small sample
Mohe 3	2.2	10.4	5.9	3.8	11.7	62.7	3.3	Small sample
Mohe 4	0	0.6	8.3	9.4	22.4	35.3	24.0	Big sample

Calculation of the debris flow discharge

There are no hydrologies or rainfall observational data in the Mohe Gully, design discharge of debris flow is derived from the corresponding peak discharge of flood plus the sediment yield rate with a certain coefficient. Calculating results are listed in the Table 2.

Table 2. Flux calculated value of debris flows in the Mohe Gully.

Calculating frequency P	**debris flows of 1% frequency (P=1%)**	**debris flows of 2% frequency (P=2%)**	**debris flows of 5% frequency (P=5%)**
Flux (m^3/s)	774	584	406

Prevention engineering structures

From April 2012 to June 2014, we have completed several preventing structures in the mainstream and tributaries, including gravity dams, check dams, and drainage canals.

Preventing goals and standards

The major preventing engineerings in the Mohe Gully contain gravity dams and drainage dams in the mainstream and tributaries.

Goals: preventing engineerings defend flash floods and debris flows from middle to large scales and can guarantee the safety of the Luding new town in downstream area; When debris flows with super design standard occur, these preventing engineerings alleviate hazards, reduce property losses and casualties to the lowest degree.

Preventing standards: main preventing engineerings in the mainstream are arranged to defend debris flows of 2% frequency (P=2%), and the check standard is setted due to debris flows of 1% frequency (P=1%); According to local geological conditions, projects are setted up to prevent earthquakes of intensity VIII.

Preventing engineerings in the mainstream

Preventing engineerings in the mainstream include one drainage canal and three gravity dams.

Drainage canals. The design standard of drainage canals is to drain debris flows of 2% frequency. The upside of the canal connects to the No.1 gravity dam retention basin dischargecanal, its downside connects to the Dadu River flood bank. Its overall length is 2 128.06 m, the upside and downside longitudinal slope are 6.24% and 6.29% respectively. The width of the upper and bottom part of the canal are 10.01 m and 9.5 whereas its depth is 4.6 m. The drainage canal is composed of walls on both sides and scour protecting boards in the middle of it (Fig. 3).

Fig. 3. Debris flow depositional fans and drainage canals in the Mohe Gully.

Gravity dam. Three dams from No.1 to No. 3 are all gravity dams.

(1) The axis of the No. 1 gravity dam is 204.7 m as long and the top of the dam is 3.0 m as wide; The cross section of the overflow outlets is in compound trapezoid form with top and bottom width 20.0 m and 15.0 m respectively and with depth 4.0 m. The highest gravity dam reaches 20.2 m and the effective dam height is 16.2 five overflow canals are arranged in the middle of the gravity dam, they are setted in horizontal direction and are parallel to each other, centers of these canals are 3.0 m far away from each other; Drain canals are setted in the body of non-overflow dam with 2 m and 5 m longitudinally and horizontally far away from each other, the top hole is at the same height with the bottom of overflow canals. To prevent downstream erosion base being hollowed out, retention basins and discharge canals are constructed in downstreams. Drainage blind canals are setted every 5 meters from each other in the bottom of the retention basin to decrease uplift pressures the dam is experiencing. The downstream of the dam connects to drainage canals (Fig. 4).

Fig. 4. The No. 1 gravity dam in the Mohe Gully.

(2) The axis of the No. 2 gravity dam is 106.5 m as long and the top of the dam is 3.0 m as wide; The cross section of overflow outlets is in compound trapezoid form with top and bottom width 20.0 m and 15.0 m respectively and with depth 4.0 m. The highest gravity dam reaches 19.00 m and the effective dam height is 15.0 m; Five overflow canals are arranged in the middle of the gravity dam, they are setted in horizontal direction and are parallel to each other, centers of canals are 3.0 m far away from each other; the φ20 drain holes are setted in the body of the non-overflow dam with 2 m and 5 m longitudinally and horizontally far away from each other. To prevent downstream erosion base being hollowed out, apron is employed in downstream. The overflow outlets connect to the apron. To decrease uplift pressures the dam is experiencing, vertical drain holes are setted in the apron. φ50 drain-pipes are used and arranged in plum blossom form, gaps are both 1.5 m long in vertical and horizontal directions. The end of the apron connects to the scour prevention vertical wall, the wall is of gravity type and the vertical height is 5.5 m. The height and width of the wall toe are all 1 m. The width of the top and bottom of the preventing walls are 0.6 m and 2.23 m, whereas their height are 6.5 m. Drain-pipes are setted in a row and are arranged in plum blossom form in the wall with 1.5 m far away from each other (Fig. 5).

Fig. 5. The No. 2 gravity dam in the Mohe Gully.

(3) The axis of the No. 3 gravity dam is 99.50 m as long and the top of dam is 3.0 m as wide; The cross section of the overflow outlets is in compound trapezoid form with top and bottom width 20.0 m and 15.0 m respectively and with depth 4.0 m. The highest gravity dam reaches 16.00 m and the effective dam height is 12.0 m; Five overflow canals are arranged in the middle of the gravity dam, they are setted in horizontal direction and are parallel to each other, centers of outlets are 3.4 m far away from each other and are 3 m higher than the bottom of the overflow outlets. φ20 drain holes are arranged in the body of the non-overflow dam with 2 m and 5 m longitudinally and horizontally far away from each other, the top-hole lays 2.5 m

lower than the overflow bottom. To prevent downstream erosion base being hollowed out, apron is employed in downstream. The overflow outlets connect to the apron, the apron is 25 m long and 1m deep and the gradient is i=5%. To decrease uplift pressures the dam is experiencing, vertical drain holes are setted in the apron project. Drain-pipes are arranged in the plum blossom form, the gap is 1.5 m long in vertical and horizontal directions. The end of the apron connects to scour prevention vertical wall, which is 5.5 m as high and 1 m as wide and is in gravity mode. The side walls of the apron are in uniform gravity mode, the width and height of the barricade top is 0.5 m and 4.05 m respectively. The width and height of the unloading plat is 2.15 m and 1.2 m respectively. The barricade bottom is as wide as 1.63 m. Drain-pipes are setted in a row and are arranged in plum blossom form in the wall with 1.5m far away from each other (Fig. 6).

Fig. 6. The No. 3 gravity dam in the Mohe Gully.

Preventing engineerings against tributary debris flows

The tributaries of the Mohe Gully watershed mainly develop on the left side of the mainstream. We have conducted preventing engineerings in tributaries, such as the Erping Gully, the Chejia Gully and the Xiao Gully, they are all on the left side of the main ditch. Those engineerings covering gravity dams, check dams and drainage canals. Among which, the design standard of the gravity dam is setted to defend debris flows of 5% frequency. The main purpose is to alleviate the risk of debris flows being blocked in tributaries.

Check dam project in the Chejia Gully. The main function of the check dam project is to stabilize gullies and slopes. The Chejia Gully is frequently active in debris flows. Three check dams are constructed in the middle and dowmstream of the Chejia Gully and all are in gravity structure. The axes length are as follows: No.1 13.6 m (Fig. 7), No.2 12 m and No.3 17.5 mother check dam is 6.5 m as high and thes effective height is 3.5~4.5 m， the basis burial depth is 2 m; The dam top is 1.5 m as wide.

Fig. 7. Check dam in the Chejia Gully.

Blocking and drainage engineerings of debris flows in the Erping Gully. Catchment of the Erping Gully area 2.9 km2 and gully length 2.7 km. The bottom of the gully is narrow, and it's mean streambed gradient is 449‰. Preventing engineerings include one gravity dam and one drainage canal.

The gravity dam has slits, with height and effective height 11.0 m and 6.0 m respectively, the dam axis is 26.4 m as long, the thickness of the top and bottom of the dam is 2 m and 6.1 m respectively. The gravity dam is setted in the middle and the downstream of the gully, thus gravel and grain materials are prevented to flow into downstreams and mainstreams. The drainage canal is 489.5 m as long and it's starting point connect the slit dam, whereas it's terminus is in the left part of the Mohe River. The side wall of the drainage canal is 0.5 m as wide and 3.0 m as high. Plus, its gradient is 116‰.

Projects focused on prevention in the Xiao Gully. The Xiao Gully is frequently active in debris flows, with longitudinal length and mean width of 6.2 km and 2.4 km respectively; The highest points in this drainage basin are 3 860 mother lowest points with elevation of 1 229 m and relative height difference of 2 631 m flow into the Mohe Gully.

Engineerings mainly focused on prevention and single-sided fending groyne is setted in the existence of the gully. Three gravity dams are arranged and among which the No.1 (Photo 8) and No.3 dam are grilled dams, the length of the dams' axes are 42.0 m and 29.5 m and their height are 10.5 m and 9.5 m respectivey.The effective dam height are 8 m and 7 m respectively, the thickness of the dam top are all 2 m while the thickness of dam bottom are 8.85 m and 8.15 m respectively (Fig. 8); The No.2 dam is entity dam of gravity type, the axis is 31.5 m as long and the dam is 12.5 m as high. The effective dam height is of 10.0 m and thickness of the top and bottom of the dam are 2 m and 10.25 m respectively; the basic buried depth of all those dams mentioned above are 3.0 m.

Fig. 8. The No.1 Gravity dam in the Xiao Gully.

Analysis of effectiveness of debris flow preventing engineerings

Debris flow preventing engineerings in the Mohe Gully was completed in the year June 2014 and has operated four Hydrological years. These well-protected engineerings guarantee the safety construction of the Luding new town. Their preventing effectivenesses are mainly in three following aspects.

Block to tributary debris flows

Debris flows in three tributaries, the Xiao Gully, the Erpingzi Gully and the Chejia Gully, are being managed. The area of the former three gullys' drainage basin is 10.4 km^2, 1.6 km^2 and 2.88 km^2 respectively and 14.88 in total, which accounted for 12.20% of the total. All gravity dams are designed as 5% debris flow standard and checked as 2% debris flow standard. These keep coarse particles within the tributaries and only high-sediment floods flow into the mainstream when debris flows occur. Thus, pressures of preventing engineerings in the mainstream can be reduced.

Block to mainstream debris flows

Through former investigation, the overall amount of solids in debris flows of 1% frequency in the Mohe Gully is 144×104 m^3,among which, gravel diameters over 20 mm account for 78% and their overall volume are about 112×104 m^3.Seven gravity dams and three check dams are constructed in the mainstream and tributaries in order to prevent debris flows of volume as high as 140×104 m^3,which hold up coarse particles in debris flow of 1% frequency to the upstream of the dam and gurantee the safety of the Luding new town. Gravity dams are all designed in the comb shape and with large discharging holes. This certain kind of shape let sediment laden flows enter into drainage canals and refuse coarse particles in huge debris flows. When common debris flows occur, large amounts of deposits are unlikely occur. Reservoirs are advised to keep empty to fight against debris flows characterized by low frequency and large scale.

According to practical measurement in December in the year 2014, the reservoir capacity of three gravity dams in the mainstream are as follows: No.1, 247 874 m^3; No.2, 78 748 m^3; No.3, 69 695 m^3; 396 281 m^3 in total. That is the gravity dam which can prevent volume of coarse particals as high as 40×104 m^3 each time, which limits debris flows within the Mohe Gully. In this way, threats to the Luding new town from debris flows of 2% frequency can been eliminated.

Drainage of mainstream debris flows

Drainage canals in the Mohe Gully are designed and checked according to debris flows of 2% and 1% frequency respectively. After blocks from three gravity dams in mainstream, large particles in the debris flow are being held up in the upstream. The flow evolves into dilute debris flows or hyper-sediment concentrated floods with density lower than 1.3 t/m^3. Correspondingly, the designed flux and checked flux are $Q_{2\%}$=223 m^3/s and $Q_{1\%}$=257 m^3/s respectively. The upside of the drainage canal connects to the retention basin discharge chute of the No.1 gravity dam and its downside connects to the bank of the Dadu River. The width of the top and bottom of the dam are 10.01 m and 9.5m, its depth is 4.6m. After the accomplishment of the drainage canal construction, we reexamined it's drainage capacity. We found out that when the debris flow reached it's checked flux $Q_{1\%}$=257 m3/s, the drainage canal can be as deep as 3.3 m. When drainage canal is full of water, the depth of water reaches 4.6m and the flux is of 411 m^3/s which is 1.6 times the amount of debris flows of 1% frequency. (Fig. 9, 10).

Fig. 9. Houses located on the edge of the debris flow drainage canal in the new town.

Fig. 10. Drainage canals and rib ridges.

Therefore, when debris flows of 1% frequency or lower occurs, preventing engineerings can guarantee the safety of the Luding new town. This has positive meanings to the development of the Luding County where the available land resources in the deep valley are relatively limited.

Conclusions

(1) The Hengduan Mountains Area is located in the east part of the Tibet Plateau and is characterized by high mountains and deep valleys. Effective preventing measures are able to prevent frequent debris flows and to guarantee the safety of new projects. The new town of Luding County is a perfect example.

(2) In areas like the Luding new town characterized with high mountains ,deep valleys and large scale debris flows, main preventing engineerings (such as gravity dams and drainage canals in the mainstream) must be strong enough to block and drain debris flows effectively in order to control mountain hazards;Meanwhile,corresponding blocking engineerings must be setted in main tributaries in order to prevent their flowing into the mainstream and to decrease pressures that main engineerings are experiencing.

(3) In area like the Luding new town where huge debris flows occur, engineerings are not enough to gurantee absolute safety in this area, warning and monitoring of debris flows should also be conducted. When debris flows over the designed standard occur, people in dangerous area should be arranged in safety area to avoid dangers.

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