PREVENTION OF DEBRIS FLOWS

DEBRIS FLOWS AND THEIR PREVENTION AND CONTROL IN JIUZHAIGOU SCENIC SPOTS OF HENGDUAN MOUNTAINS REGION

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INTRODUCTION

The Jiuzhaigou drainage area, of the Hengduan Mountainous Region, is beautiful. Its beauty is due to the rapids and waterfalls in the forest, the colourful lakes surrounded by dense woods, and the surrounding high mountains. Debris flow disasters pollute the lake water, make inroads on the blue lake, destroy the wonderful forest, block roads to scenic spots, endanger giant panda, and threaten the safety of tourists. If the disasters are not prevented, the lake in this area will be gradually silted up.

There are large natural debris flow gullies within the Jiuzhaigou area and also large and small artificial ones. Therefore, it is of great significance for the prevention and control of debris flows to safeguard the forest eco-system and natural enviornment.

Jiuzhaigou is one of the debris flow areas in the northeast part of Hengduan Mountainous Region. The drainage area covers 650.4 km^2 and its main gully is more than 50 km long in south-north direction. According to the physical geographic structure and scenic characteristics, the area is divided into six scenic spots (Shuzheng, Changhai, Rizhe, etc.).

There are 114 lakes (Haizi) in this area, and the largest and deepest one is named Changhai (long lake). The biggest waterfall is 130 m wide and more than 20 m high. There are also thick forests with more than 150 species of trees, mainly, fir and dragon spruce as well as Chinese pine, birch, oak, larch, maple, etc, and including the rare economic tree Chinese plumeyew.

THE DISTRIBUTION OF DEBRIS FLOW

Debris flows are widely distributed over this area, from the north Heye Gully, southeast to Changhai, and southwest to Xuanya-jianquan. There are 27 disastrous debris flow gullies. The distribution characteristics are as follows:

Topographically, most debris flows in this area developed in rocky mountains and on steep hillslides above the forest line. The ridge 4000 m above sea level, with exposed bed-rock and active soil slip and collapse, having been strongly weathered, becomes the original place of debris flow.

A rainstorm concentrates the distribution. For instance, there was a storm centre in Wesikahuang mountain range, 4192 m above sea level, on July 7, 1984. The fierce storm caused 3 debris flows on the west slope and four on the east slope, resulting in the most centralized distribution of debris flow in the region.

The debris flow mostly covers the forest cutting area, especially as some slope debris flows are formed by wood collecting.

The main debris flows occur between 2000 - 3000 m above sea level, and particularly between 2600 - 2800 m where there are two thirds of the total of 27 debris flow gullies.

In brief, the debris flows over the Jiuzhaigou region appear in belt-like distribution along the gully, and some in slice-like or dot-like distribution because of the effect of storms or human activity.

THE CAUSES OF FORMATION AND TYPES OF THE DEBRIS FLOW

Causes of Formation

The causes of formation of debris flows in Jiuzhaigou display a regular pattern; there must be abundant solid materials, a steep landform and plentiful rainfall. In addition, man's irrational economic activities also promote formation and activity.

Abundant materials: The mountain range in the Jiuzhaigou drainage area has great altitude differences. The exposed mountain body of weathered rock above the 3800 m forest line is mainly limestone, which has many joints and cracks. Where it is heavily exposed there often occur collapses and debris slips, providing abundant solid materials for the occurence of debris flows. On the forest belt below 3800 m, the thick brown earth and drab soil of the hilly area are developing into residual hillside deposits which become the material source of slope debris flows. Generally speaking, the abundance of solid materials in this area is favourable for the occurrence and development of debris flows.

Steep landform: This is an area of complex topography - steep slopes and big altitude differences (1500 - 2000 m) especially in the limestone area, where knife-back form or saw-tooth form ridges tower above hanging valleys. This is due to steep dip angles, flourishing cracks, frost weathering, eroding and denuding. The slope in the formation area is either between 60^0 and 70^0 or a sheer precipice with overhanging rocks. The gradient of gully beds is 200-600% and most of them appear steep in the upper reaches and gentle in the lower reaches with a broken-line form. Such features create favourable conditions for the formation and activity of debris flows.

Strong storm: No practical observation information on this area has been gained until now. Observations made by the meteorological office in Nanpin County and Pinwu County, show plentiful rainfall and frequent strong storms in parts of the area which promote debris flows. As the dense forest regulates the rainfall, this factor is influential in causing debris flows, so the frequency of large scale debris flows is low and that of small ones higher in recent years.

Artificial factors: The formation of debris flows in Jiuzhaigou is strongly linked to the economic activities of the people. With the growth of population in this area, wood cutting and clearing for cultivation, livestock over-grazing, and excessive fuel collection have all increased. The results are exposed hillsides and gullies, and active collapse which promotes the occurrence and development of debris flows.

Types and Features of Debris Flows

In terms of the causes of debris flows in this area, they can be classified as either natural or artifical.

In the light of landform features they are classified as gully and slope types. Most natural ones are the gully type, while most artifical ones belong to the slope type. According to its own characteristics a debris flow can be classified as either thin viscous or low-viscous.

THE HARMFUL ACTIVITIES OF DEBRIS FLOWS

There is a long history about the activity of debris flows in Jiuzhaigou. Judging from their depositional fans in some branch gullies, several large-scale debris flows have occurred in the past. The extent of tree growth on the depositional fans, shows a history of more than one hundred years. For example, an investigation in 1983 indicates that Shuzheng, one of the branch gullies, once suffered a large-scale, disastrous debris flow which destroyed the village that was there at that time digging house foundations have uncovered clay basins and bowls, and a man's skull, etc.

Although debris flows occur more and more frequently in Jiuzhaigou, they are often on a small-scale with a volume of only several dozen cubic metres. A large one will have a volume of several thousand cubic metres and some more than ten thousand.

Jiuzhaigou is praised as a pearl on the plateau of Hengduan Mountainous Region for its mirror-like lakes, quiet and secluded mountains and dense forests. It not only has high value for viewers and admirers, but also is the field in which to do scientific research. The mountains, lakes, forests, and ecological environment remain a profound mystery for scientists.

Nevertheless, the debris flows strongly affect the lakes and forests. The main harm is that a great amount of silt and debris falls into the lakes and accumulates there, which reduces the lake area polluting the transparent lake water at the same time. Debris flows cause considerable damage to forests, threaten the safety of tourists and also block transportation routes.

The Prevention and Control of the Debris Flows

As the Jiuzhaigou scenic spots have won fame as "pearls","treasure places" and "some of the finest scenic spots in the world", the control of debris flows, protection of the natural ecological environment and the promotion of tourism must be the priorities.

In order to protect the natural environment and prevent the disasters, any scheme in this area, must stress the main points to avoid the strong debris flows and control the weak, and must be carried out in stages. The principles of a control scheme lie in: prevention combined with control, making a comprehensive list of key points, carrying out engineering works first, and combining short-term measures with long-term measures, debris flow control with environment beautification and nature protection. Using control measures, we hope to basically reduce the pollution of scenic spots and protect the environment. Short-term engineering, vegetative, and social measures should be determined according to the cause and formation conditions, and the type, pollution and damage extent of debris flow so that it can be controlled and the harm to environment and tourism can be reduced.

Engineering measures are very important and must be taken in the short-term. Vegetative and social measures are fundamental in debris flow control, and are also important in nature protection. However they are long-term, and therefore slow to take effect. This has been taken into account in the planning of a comprehensive scheme to control debris flows in scenic areas.

Engineering measures: Because formation conditions are complex in this area, variety of features, types and advantageous dynamic conditions are exhibited by debris flows. Many debris flow gullies have a much larger starting flow and longitudinal slope than the common one. The debris flows have a strong effect, with rapid motive speed and short, steeply sloped gullies. The large falling difference, short flow process and narrow deposit area bring about some difficulties for the arrangement of the control engineering. So, the type in the engineering project design widely adopts the advanced one in and out of our country, especially the Sabo Project against debris flow in Japan's national parks. The adaption of these measures to the features of debris flow must be considered, attention paid to their appearance and viewing value, while protecting the original natural environment. Main measures are:

- Blocking project: To avoid polluting, and silting up lakes and destroying tourist attractions, by intercepting a debris flow in the gully, reducing the longitudinal slope and stabilizing the slope bottom on both banks, blocking partial solid materials of debris flows, and decreasing sand quantity, various measures have been taken: stone dams, iron rail dams, concrete rail dams, and gravity dams constructed with stone and concrete.

- Leading the debris flow: Although a dam can intercept a partial discharge from a debris flow, it is still possible for debris to flow into lakes and tourist spots, so a project has been adopted to guide the discharge which is not blocked, into a designated area.

- Sandpocket project: The combination of a leading project and a sandpocket in engineering, can silt up the discharge of the debris flow at the designated place, to prevent its overflow.

- Discharging project: Considering that some large gullies have had flowing-water all the year round, a discharging project must give the way to the discharge of the debris flow, so discharge channels are built to avoid flooding tourist areas. The project will be carried across highways, using surface water-flows and small bridges.

- Stabilization of gully and slope: The formation and activity of a debris flow is always related to the development of an unstable slope. Therefore, small-scale, low cost and effective measures to stabilize the slip at the foot of the slope can be used, such as building retaining and supporting walls, and slope projection.

Vegetation measures: Being a comprehensive control system in Jiuzhaigou drainage area, the forest vegetation has the functions of protection, recreation, sanitation and hydrology, water and soil conservation as well as the function to improve the local micro climate. For instance, it is common in this area that each type of debris flow formed above the forest line, stops and silts up along the gully due to inadequate water, which demonstrates the importance of water conservation by the forests. Therefore, expanding forests and strengthening their renewal has an important role in debris flow control.

- Plantation: Plantation on hillslides can bring slope debris flows under permanent control, and also reduces hydraulic waste. Larger saplings within the project should also be planted to block sand and debris in the gullies and on hillsides and the green tree variety can beautify the project and add to the scenic value of Jiuzhaigou.

- The tending of woods: Strengthening artificial and natural woods, flowers and plants, and promoting their growth, can increase water conservation and flow regulation.

- Closing-off hillsides: Every blade of grass and every tree in Jiuzhaigou must be protected and hillsides must be closed to facilitate afforestation and bush growth and to promote their renewal in order to maintain a balanced of ecosystem that is unfavourable for debris flow formation.

- Returning cultivated land to forest: The cultivated land near the lakes and on hillsides must be allowed to return to forest, bush and grass. Woods for protection and economy (the local tree varieties in this area) may be planted.

- Forbidding tree-felling: Timber used for building in Jiuzhaigou should not be cut from this area, especially in the debris flow gullies. Only sanitary lumbering (cutting down sick and indecorous, withered trees) can be permitted.

- Forbidding free livestock grazing: The young trees in Jiuzhaigou, and the flowers and plants along the roads have been seriously gnawed and trampled by livestock. The eight hundred or more head of cattle and more than one thousand goats must be kept in pens by local people and free and rotational grazing must be forbidden on hillsides. In addition, the development of stock-raising must be controlled and the number of cattle and goats must be decreased. There can only be decorative livestock around villages in Jiuzhaigou.

Social control measures: With the growth of population in Jiuzhaigou, economic activity has increased. If there were no measures to control it, the forest would gradually decline, and the beautiful lakes would be in danger of disappearing, so some social control measures are needed.

Control of the growth of agricultural population and migration: Jiuzhaigou got its name from the nine stockade visages in this area. With the growth of the agricultural population, the area of farmland has gradually expanded, but the 640 km^2 area of Jiuzhaigou is unable to expand. This inevitably causes a serious problem. Timber for building and cooking is increasingly needed, and the quantity of trees falls far behind the quantity consumed, which results in the slow destruction of the natural vegetation and wonderful scenery. So this problem cannot be neglected and it is necessary to control the growing agricultural population. Farmers living in debris flow gullies who are unable to change the direction of their production should be relocated.

The previous economic structure should be changed and agriculture rationally change its direction: 805 people, 2000 mu land under cultivation, no less than 800 head of cattle and more than one thousand goats bred in Jiuzhaigou represent great danger to the woods and plants. Therefore, the farmers and herdsmen urgently need to change the direction of their production to forest protecting, and economic wood, fruit tree and medicinal material planting, or to gardening and tourism services.

Strengthening administration and guaranteeing the implementation of control schemes: Debris flow control in Jiuzhaigou should be combined with nature protection and be guaranteed by strong administrative measures. In addition, a unified administration organisation should be set up to strengthen the protection of natural environment.

Increasing scientific research on debris flows in Jiuzhaigou: Because these are the first debris flow control measures to be taken in this area and owing to the limitation of time, the research lacks systematization and depth, only part of the programme has been designed in this tentative scheme. To draw up a comphrehensive and rational control programme, it is necessary to do further scientific investigation and observation on the basic features of debris flows.

DEBRIS FLOWS AND THEIR PREVENTION

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INTRODUCTION

The Hengduan Mountain Region is located in the trasitional belt between Qinghai-Xizang Plateau and the Eastern hilly land. It is characterised by peculiar natural environment, complex geological structure, frequent earthquakes, steep topography and varied climate. Development of resources disturbed the mountain stability and ecological balance, facilitating the occurrence and increases of debris flow. In recent years debris flows have been becoming remarkably active and destructive, and have obstructed the economic development of the mountain region. Effective measures must be taken to control or restrain the occurrence and development of debris flow, and to facilitate the economic development in the mountain region.

DEBRIS FLOW DISTRIBUTION AND ACTIVITY CHARACTERISTICS

Distribution of Debris Flow

The Hengduan Mountains are one of the China's areas where debris flows are widely developed and distributed. The distribution characteristics are:

- Debris flows are concentrated in fracture zones, especially in seismic activity belts, such as the Anning River Fracture zone, the Heishui River Fracture Zone, the Jinsha River Fracture Zone, the Xiaojiang River Fracture Zone and the Xuanshui River Fracture Zone.

- Debris flows are largely distributed in river valley zones with 600-1000 mm of annual precipitation.

- Debris flows are largely distributed in deep-cut high mountain and middle mountains zones at 700-3500 m above sea level.

Activity Characteristics

- Debris flow activity fluctuates, sometimes strong and sometimes weak. For example, there are 40 or more debris flows in the Liusha River Basin, a tributary of the Dadu River. Debris flow activity since 1748 can be obviously divided into 4 active periods and 3 relatively quiet periods. The former occurred in 1819-1840, 1876-1894, 1922-1934, 1971-1974. Since 1980 debris flows have entered a fifth active period. In 1981 40 debris flows occurred in more than 30 ravines. There are 160 or more debris flow ravines along the Nujiang River (from the Nujiang River Bridge to the Gongshan). Since 1946 three active periods have occurred in 1947-1951, 1961-1966, 1967-1983. Activity in even one debris flow ravine fluctuates. In the Luhua Ravine of the Heishui River, since 1930, three active periods have occurred in 1930-1934, 1958-1969, 1976-1980. The active periods of debris flow are closely related to periodical changes in atmospheric circulation, the periodical activity of earthquakes and human economic activity.

- Obvious regional difference in Debris flow activity: Owing to the varied environment of the Hengduan Mountain Region, the formative factors of debris flows differ from place to place, and from ravine to ravine. Therefore, there is no correlation between the activity and scale of debris flows. Debris flows are very active in some sections of the Nujiang River, the Jinsha River, the Anning River and the Dadu River, including Gingshan, Fugong, Dequin, Dongchuan, Dukou, Xide, Hanyuan, Ganlo and other counties. As for each debris flow ravine, more than 10 debris flow occur in the Jiangjia Ravine of the Xiaojiang River every year; one debris flow occurs in the Luhua Ravine, Heishi every six years.

Recent strong and frequent debris flow activity: Recent debris flow activity has been strong in the Hengduan Mountain Region. During the middle 70's and early 80's, debris frequently occurred in the vast area east of the Minjiang River and west of the Nujiang River. Not only are they widely distributed, but also concentrated in stretches and zones, and in great numbers. For example, in 1983 a rainstorm simultaneously caused ten or even one hundred debris flows in the lower reaches of the Sunshui River of the Anning River, the Heishui River of the Jinsha River, the upper reaches the Xiaojiang River, of the Dadu River (Dajinchuan), and the Nujiang (Njiang River Bridge-Gongshan). In 1981, 381 ravines gave rise to debris flows in 29 counties, in western Sichuan. In 1976 and 1979 debris flows took place in more than 100 ravines of 5 counties in the Nujiang River Basin. Large-scale debris flows from some of these ravines caused great disasters. Eamples include the 1976 debris flow in Lishadi, Fugong, Nujiang; the 1981 debris flow in the Liziyida Raivine, Ganlo, Dadu River; the 1983 debris flow in the Baishui River, Heishui River; the 1982 debris flow in the Hunshui Ravine, Anning River; and the debris flows the took place in the Guanmiao Ravine, the Bola Ravine, and the Zuoji Ravine of the Baishui River, the Luhua Ravine of the Heishui River, and the Ravine of the Zagunao River in 1984.

- Strong seasonal activity of debris flow: Most debris flows are caused by rainfall with obvious seasonal activity in May to October. Because there are double-humped rainfall and drought in the summer half season, two high tides can be found in debris flow occurrence in the summer half season, i.e. June, july and September.

HARMFULNESS OF DEBRIS FLOW

Numerous debris flows are distributed in the Hengduan Mountain Region, mainly concentrated in the valley zone in front of the mountains, which are densely-populated urban areas, so they are very harmful.

Since 1970, debris flows have occurred more and more frequently. There are many large or middle scale viscous debris flows of high velocity and large volume, with plenty of boulders, and a great impact force. The damaging pattern includes siltation, dash, impact, course change due to damming, bank denudation, upward breach of the natural dam. The most serious are the disasters caused by siltation, dash, breach of the natural dam and upward moves at the bend.

Siltation

This is the most common damage caused in the Hengduan Mountain Region. Its harmful affects cover wide areas, including farmland, villages, roads, water conservation and hydroelectric power works, cities and towns, as well as rivers and lakes. For example, in 1983, a rainstorm caused debris flows in 27 ravines of the Back Mountains, Xide County, Sichuan, burying more than 1000 mu of farmland, and a 4 km long section of highway. In 1972, a debris flow from the Hanlo Ravine, Mianning County, Sichuan buried the Xintiechuan Station of the Chengdu-Kunming Railway (four tracks), more than 100 mu of farmland and dozens of houses.

Dash

Debris flows have great dash power. When a large or middle scale debris flow occurs, all the facilities, roads and farmland in its path will be swept away, giving place to a rock sea. The following are two examples.

- On July 9, 1981, a disastrous debris flow occurred in the Liziyida Ravine which was bridged by the Chengdu-Kunming Railway. With velocity up to 13.2 m/s., volume weight 2.32 T/m^3, and tens of big boulders 8 m in diameter, this debris flow had great dash power. The bridge platform of the right bank was dashed, the pier No. 2 was sheared, and two beams were damaged, wrecking the train No. 422. This is a rare debris flow disaster in Chinese railway history.
- On July 18, 1984, a debris flow burst out

from the Guanmiao Ravine, Nanping County. This powerful debris flow had a velocity of 9.2 m/s., volume weight of 2.22 T/m^3, 430 boulders 2-5 m in diameter and 60 boulders 5-10 m in diameter. It cut away part of a three storey building. Big boulders smashed into the cemented-brick buildings and breached a 1 m thick concrete wall. As it came out of the ravine mouth, a highway was destroyed, pushing away the 1 m thick retaining wall on the left bank, and damaging a 14 m long opening.

Damming

When a debris flow occurs, if it is relatively large and crosses the main flow at right angles, the river is often dammed. Usually, the damming does not last long; with the rise of water level, overflowing will occur. Sometimes a lake may form and inundate farmland, villages and roads. If the dam breaks down, a more serious disaster will happen.

- Inundation: On July 18, 1984 a disastrous debris flow occurred in the Zuoji Ravine, Nanping County. Because the debris flow ravine crossed the main river at the right angles, the Baishu River was suddenly dammed, and the increased water volume and water level upstream resulted in the inundation of farmland and roads.

- Scour: On September 2, 1982 a debris flow from the Hunshui Ravine, Mianning county blocked the Anning river, strongly scoured the banks and channel, and formed high and steep slopes up to above 35°. On May 22, 1983 a debris flow from Geerzhai, Jinchuan County straight dashed to the Dadu River, and strongly scoured the valley. In addition the scouring of the opposite bank caused a new landslide.

- Breach: This is the most serious and damaging disaster in damming. The common mountain event affects wide areas and often brings about disaster. For example, on July 18, 1984 in the Guanmiao Ravine, Nanping county, the firest debris flow wavefront dashed into the Baishui River, and formed a dam. After about 30 minutes, the dam collapsed, creating a powerful special flood, which destroyed houses, farmland and roads downstream causing damage of more than 10 million Yuan. The sediment discharged into the river by the debris flow raised the river bed and changed the river course, bringing a damage to the production and construction on the river banks.

COUNTERMEASURES AGAINST DEBRIS FLOW

The occurrence of debris flows in the Hengduan Mountain Region has its internal natural factors. Their recent frequency and destructive capacity is mainly due to the irrational economic activity of man. For example, forcible deforestation, grass and shrub clearing for cultivation, road and canal construction, and excessive exploitation of bilogical energy resources will lead to the occurrence of debris flows which can destroy building construction, endanger cities and towns, bury farmland, damage industrial, agricultural, and hydroelectric facilities, stop transportation and communication, pollute rivers, and cause casualties.

The occurrence and development of debris flows in the region has a long history. The recent activity is so strong and frequent that it is very difficult to control. Furthermore, the debris flow areas are densely populated and economically developing. Accordingly, the control principle should be combined with the economic development, people's interest, and ecological and social benefits in the region. Debris flow countermeasures should include three compoenents: prevention, averting the hazardous area, and overall treatment.

Prevention

Protect the forest ecological system, strengthen artificial renewal and green the bare hills. Control the intensity of logging, improve logging patterns, facilitate natural renewal, recover the natural ecological balance, control the occurrence conditions and restrain debris flows.

- Sensitively develop and utilise natural resources, ensure the rational development of agriculture, forestry and animal husbandry, prohibit random reclamation, overgrazing and steep slope cultivation, and solve the contradiction between agriculture and animal husbandry to reduce the factors for debris flow occurrence.

- Improve the backward farming patterns, and give special attention to the irrigation canals that pass landslide zones or broken mountains so as not to add to the solid materials in debris flows. s flow occurrence.

- Proper measures should be taken in road construction, mining and waste disposal to prevent collapse, landslide and debris flow.

- In the densely populated areas with serious debris flow disaster and energy shortage, biological energy, such as successive fuel tree species, or water energy should be developed.

Averting the Hazardous Area

Most towns and villages of the Region are built on the old debris flow deposits, so they often suffer from the revival of debris flow. Averting disastrous debris flows and delineating the hazardous zone is necessary until debris flow countermeasures take effect. New villages, industrial facilities and the enlargement of towns should avert the debris flow hazard zone so as not be attacked by a debris flow.

Overall Treatment

Overall watershed treatment must be carried out in the towns, main roads and important factories and mines where debris flows are destructive. According to the formation, nature, activity characteristics and damage degree of debris flow, engineering measures with emphasis on checking, discharging and stabilising should be adopted for the present time; biological measures with emphasis on closing mountains to livestock grazing and fuel gathering, and on afforestation should be adopted in the long run. An overall treatment combining short-term and long-term measures, and engineering and bilogical measures could control debris flows and prevent disasters happening.

CONCLUSION

The natural environment of the Hengduan Mountains favour the activation of debris flows. In particular, mans' over-use and development of the rich natural resources (forest, mineral deposits, water energy and land, etc.), added to improper measures, and massive exploitation to obtain biological energy, have disturbed the natural ecological balance, which has led to the degradation of mountain ecological environment and the increasing frequency of debris flows. It is noted that since 1980 the activities of debris flows have been at a new high tide.

DEBRIS FLOWS AND THEIR COMPREHENSIVE CONTROL IN HEISHA RIVER, LIANGSHAN, SICHUAN, CHINA

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INTRODUCTION

The Heisha River is known as a catastrophic debris flow gully in the mountainous region of southwest China. It originates in the Luji Back Mountain Region, Liangshan, Sichuan, passes through the Luji Basin and the Qingtang Front Mountain, and empties into the Anning River. The whole course is 12.6 km, and the watershed has an area of 22.7 km^2. The River is composed of three gullies -- Heisha (main gully), Maidi and Madu, which join eachother at the col.

Before the programme was implementated, debris flows in the Heisha River were frequent. Debris flows of different scales took place almost every year, and a catastrophic debris flow occured every 8-10 years. During the last century debris flows have submerged five villages, and 3000 mu of farmland. A dispositional fan 3 km wide was produced. The Chengdu - Kunming Railway and the Sichuan - Yunnan Highway run through the middle of the fan. The communication and transport lines, factories, villages, and farmland, on the lower reaches, were often subjected to debris flow demage.

The Heisha watershed has a high and precipitous relief and deep-incised gullies. The relative height difference is 200 m; the hills slope at about 40^0. Weak Jurassic, black and purple shale, mudstone, and siltstone, interbedded with smut, predominates. Rocks have numerous joints and fissures due to the effects of faulting, folding, seismicity, and fossil landsliding. The loose soil material is more than 60 m thick as a consequence of heavy weathering. The dry and wet seasons are distinct. 93% of precipitation is concentrated in the rainy season between late May and early October. There are many rain storms in this period and the total rainfall of one event can exceed 160 mm. Forest cover has been lost leaving sparse grass cover.

The above-mentioned precipitious relief, loose soil material, and plentiful heavy rain provided favourable conditions for debris flow formation. The destruction of vegetation intensified soil and water loss through gully erosion, and accelerated the activity of landslides and the gully development. There are 180 landslides, slumps and falls, 135 debris flow branch gullies, and more than 26 million m^3 of loose materials. A powerful debris flow could burst out whenever the next heavy rain falls. The maximum debris flow discharge could reach 300 m^3.

PROCESS OF DEBRIS FLOWS

Types of Formation

There are two types of formation processes in the Heisha River: hydraulic and soil-mechanical (Tian, 1981). The former is due to the scouring of sloped surfaces, and eroding of the gully bed and loose deposits along gully banks by the forceful runoff. Such debris flows in the main gully of Heisha River resulted from the erosion of gully bed deposits, bank colluvial deposits, and slope wash on the middle reaches, added to debris flow deposits from branch gullies, that were initiated by floods originating in the Luji Basin on the upper reaches. A flow formed soil-mechanically occured when saturated slide deposits and other loose materials entered the gully under the stimulus of a rain storm. There have been many such debris flows in the branch gullies of Heisha River.

Types of Debris Flow

Debris flows in the Heisha River are of different types and have typical flow regimes, manifold effects and patterns.

According to the character of the flow, they can be further subdivided into: viscous, fluid, and plastic flows. The viscous type is the most characteristic debris flow. It has elements of both soil and water flows, as well as its own peculiar mechanical properties and movement laws. The specific gravity is 1.8-2.3 t/m^3; the viscosity and incipient static shear of slurry are 0.8-8.0 P and 0.2-100 mg/cm^2 respectively. The fluid debris flow is the transitional flow between sediment-laden water flow and viscous debris flow. It resembles a water flow in character. The specific gravity is 1.2-1.8 t/m^3; the viscosity and incipient static shear are 0.02-0.8 P and 0.2-100 mg/cm^2 respectively. The plastic debris flow is the transitional flow between viscous debris flow and sliding soil material. It has similar character to mass movement. The specific gravity is above 2.3 t/m^3; the viscosity and static shear are more than 8 P and 500 mg/cm^2 respectively.

Most of the debris flow slurries of the Heisha River belong to Bingham fluid (Wu, 1981). Like debris flows, debris flow slurries can also be divided into fluid, viscous and plastic with different contact variabilities and laxation phenomena. All debris flow slurries have net-shaped textures. According to their character, they can be divided into four types: extremely close, close, relatively close, and loose. Debris flows may by considered as slurries containing a large number of rock fragments, and most of them belong to the pseudo-Bingham fluid with a lattice-like texture. There are four types: star-like suspended, supported, overlapped, and mounted.

Debris Flow Movement

The moving process of debris flows in the Heisha River varies with fluid properties. Generally, there are three categories: continuous, continuous-pulsating and pulsating. Usually, fluid debris flows are in the pulsating form. Debris flow regimes change with fluid properties and boundary conditions. Flow regimes can be classified as turbulent, disturbed, creeping, sliding, or waving. Debris flows of different regimes have different resistance laws and velocity formulae.

Debris flows of the Heisha River have a distinct impact that is abrasive and scouring, and they have deposition effects far more intense than that of floods with the same velocity. The flows not only have the capacity to cause major damage, but are also a great sculptural force. They can finish the morphodynamic process in hours, or even minutes, where it would take tens or hundreds of years for a water flow.

CONTROL OF DEBRIS FLOWS

A control programme was devised taking into account the formative mechanisms, activity laws, and damage patterns, of debris flows in Heisha River (Wu, 1983). Debris flows that occured in the main gully were the hydraulic type. They resulted from the powerful floods that originated in the Luji Basin on the upper reaches, scouring the loose deposits on the gully bed and banks, and receiving debris from branch gullies. The debris flows cut a course through the mountains and spread violently over the 3 km wide deposition fan with disasterous results. Therefore a control programme was devised: "A combination of engineering measures and biological measures, unified planning of the upper, middle, and lower reaches, and comprehensive management of mountain, water, forest and grassland" (CIG, 1981).

Concrete measures taken include:

- a flood control reservoir with a 22 m high dam, 540,000 m^3 capacity, and 12,000 mu of conservation forest on the upper reaches, to regulate floods and weaken the flood peak, to increase control of the hydrodynamics - the leading factor in hydraulic debris flow formation

- 7 silt arrest dams and 5 check dams

- 7 revetments and longitudinal dikes, backed by 6000 mu of soil and water conservation forests on the middle reaches, (Zhang, 1983) to arrest sediment, stabalize slopes, and weaken gully erosion in order to control the soil materials that gather to form debris flows

- a 5 km director dike, a drain ditch and 39 protecting forest belts to stabalize the gully bed and drain the floods, thereby reducing debris flow hazards.

All the properties and effects of the debris flows were taken into consideration in the design of each corrective engineering project. For example, the section, structure, and energy dissipation device of the silt arrest dams adopted, were a completely different form from the hydraulic check structures.

All the control measures were completed by 1978, and have successfully decreased the hazards of debris flows, and assured safety downstream. Since then the main gully has not seen a debris flow, withstanding the test of a rain storm with a 50 years recurrence. The amount of sediment transported out of the mountains after the treatment has been less than a quarter of what was transported out before under similar conditions. The peak discharge induced by a rain storm of 10 years recurrence has been one fifth of that before the treatment; in the main gully the peak discsharge induced by the same rain storm has been only one twentieth of that before. Not only have 2000 mu of farmland been recovered but crop yields have also increased. However, in recent years the reservoir and the director dike have had some siltation problems. In order to increase the effectiveness of the control programmes, aided by closing off the mountains to facilitate afforestation, management of the area must be strengthened.

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