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# 土木研究所資料

中国鉄道部による鉄道が土石流地域を  
通過する場合の設計マニュアル(訳)

昭和63年9月

建設省土木研究所  
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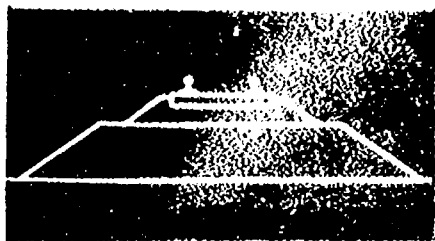
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## は　　じ　　め　　に

土石流災害は、我国のみならず世界的に土砂災害の主なものとして、その防止軽減策が研究されている。中国でも、鉄道部を中心に研究が行われているようである。このたび、中国の鉄道建設技術マニュアル、路基第4，特殊条件下の路基（鉄道部第1設計院，中国鉄道出版社，1978年1月）を入手した。その第13章は泥石流地区路基（The road bed in debrisflow area, 土石流地域の路盤）で鉄道が土石流地域を通過する場合の留意点，対応が記述されている。参考になると思われるので，土木研究所砂防研究室に滞在中の中国科学院成都地理研究所 胡 平 偉 氏 に翻訳して頂いた。中国語から英語への訳であるが，原文とともにとりまとめておく。

砂防研究室 室長　水　山　高　久

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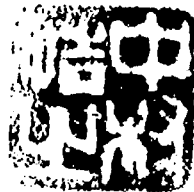
铁路工程设计技术手册

《路基》 第四篇

# 特殊条件下路基

铁道部第一设计院主编

中国铁道出版社



## 第十三章 泥石流地区路基

### 第一节 概 述

#### 一、基本概念

泥石流是在地质不良、地形陡峻的地区，由于降水（暴雨、融雪、冰川）而形成的一种含有大量泥砂石块等固体物质的特殊洪流。

当泥石流爆发时，一般发生时间短暂，来势猛烈，其前峰是一股浓浊粘稠而容重大的洪流，具有特殊的结构和浮托能力，既易于受阻落淤，又具有冲决阻碍夺路而出的巨大能量。它往往是前阻后拥，此塞彼溃，突然爆发，在很短时间内冲出数十万立方米以至数百万立方米的固体物质，能将数十吨、数百吨的巨石从山中冲到山外。泥石流常以强大的破坏力摧毁其前进途中的房屋、村镇、农田、森林、路基、桥涵和渠道，又能使河道受冲刷、淤积、改道，甚至堵断河流形成湖泊。在它落淤之处，又常掩埋大片土地及其上的建筑物和庄稼等，造成巨大的危害。

#### （一）泥石流流域区段

典型泥石流流域，从上游到下游一般可分为三个区段（图13—1）

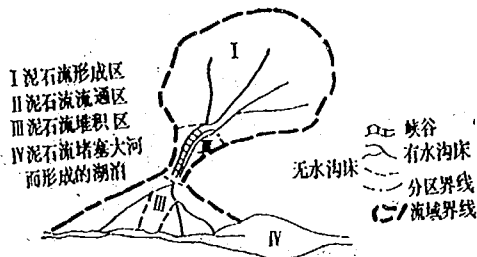


图13—1 典型泥石流流域示意图

泥石流形成区：一般位于流域的上游区段，多为高山环抱的山间盆地（低地），呈漏斗状，形成泥石流的固体物质和水源主要由此区段供给。这里滑坡、崩塌、岩堆等不良地质现象很发育，水土流失严重，山坡极不稳定。形成区的大小一般对泥石流的规模、性质及危害程度有重要的作用。

泥石流流通区：一般位于泥石流沟的中游地段，多为峡谷地形，谷坡陡峻，沟床纵坡比降大，多陡坎或跌水。故该区一般均较顺直而有显著的沟槽。

泥石流堆积区：是泥石流固体物质停积地段，位于泥石流沟的下游山口较平缓地区，多呈扇形或锥形，大小石块混杂堆积，地面垄岗起伏坎坷不

平。从堆积区的大小，一般可以看出泥石流规模的大小和危害程度。

上述区段的划分系大致的，有时可以缺少某一个区段，就地质历史时期和泥石流发育阶段来讲，这三个区段也并非固定不变，可以互相转化，如：早期泥石流的堆积区，在近期泥石流的活动过程中，可能转变为流通区或形成区，出现串珠状的洪积扇等。

#### （二）泥石流形成的基本条件

泥石流的形成同所在地区的自然条件和人类经济活动密切相关。地质和地形是泥石流发生的内因，而水则是外因。他们之间相互关系如图13—2。

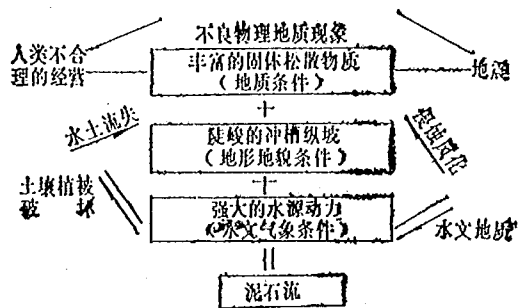


图13—2 泥石流形成条件的相互关系

#### 1. 地质条件

泥石流沟的地质特征，是地质新构造运动活跃，构造复杂，断裂、褶皱较多，地震烈度一般大于6度而频繁。这些条件导致岩层破碎，节理发育，特别是软岩层，软硬相间或老岩层出露较多的地区，因构造作用更易遭受破坏，为泥石流提供大量固体物质（以小崩塌、错落等方式补给泥石流）。

#### 2. 地形地貌条件

泥石流流域地形特征，是山高沟深，地势陡峻，沟床纵坡大，有利于水流的汇集和固体物质的搬运。

完整的泥石流流域，其上游多为三面环山，一面为瓢状或漏斗状围谷。山坡坡度多为 $30^{\circ} \sim 60^{\circ}$ ，坡面侵蚀及风化作用强烈，植被生长不良，山坡光秃破碎，沟道狭窄，在严重的坍方地段，沟谷横断面形状呈“V”形。其中游多为狭窄的峡谷，谷壁陡峻（坡度在 $20^{\circ} \sim 40^{\circ}$ ），沟谷横断面形状呈“U”形，通过坚硬的岩层地段，多陡坎或跌水。其下游

一般位于山口以外的大河谷地两侧，多呈扇形或锥形，是泥石流停积的场所。

### 3. 水文气象条件

一般说来，泥石流分布地区的雨型多为暴雨。暴雨量和暴雨强度愈大，所形成的泥石流规模也就愈大。

从泥石流的形成过程看，水的作用主要表现在两个方面：第一，对固体物质的浸润饱和作用。泥石流固体物质的储存地区，往往也是各种水源的汇集区，从而使固体物质大量充水，处于塑化状态，为泥石流的产生创造了条件。第二，对固体物质的侧蚀掏挖作用。湍急的水流从底部侧蚀掏挖沟底固体物质，发生崩塌滑坡，崩落下来的固体物质在急

流的推冲下形成泥石流。

### 4. 人类活动的影响

在山区建设中，不合理地破坏地表原有结构，造成山坡水土流失，提供大量固体物质，形成泥石流，或促使已趋稳定的泥石流沟复活。如：工程施工弃碴或山尾矿堆放不适当，引水渠道通过松散的边坡等，都会加剧泥石流的发生和发展。

### (三) 泥石流的类型与特征

根据泥石流的形成原因、形态、性质、规模、运动规律、危害程度和发育阶段等主要特点，结合防治措施的需要，将泥石流分类如图13—8，图13—4及表13—1。

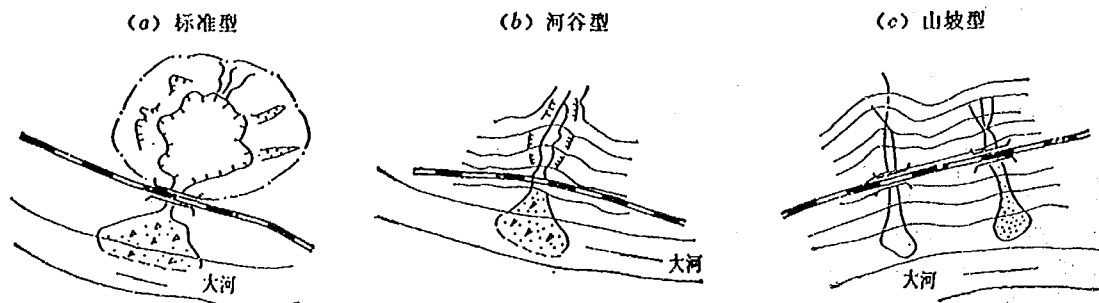


图13—3 山区泥石流示意图

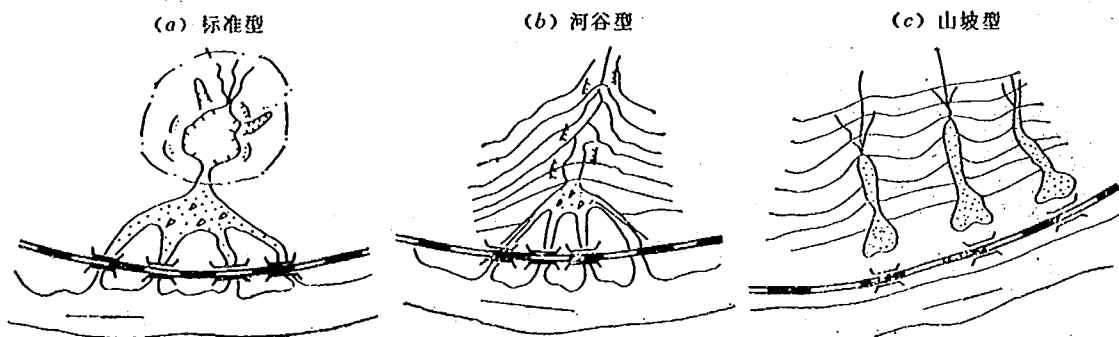


图13—4 山前区泥石流示意图

### 泥石流分类表

#### (1) 类——按水源补给形式分

表13—1 ①

| 类    | 暴雨       | 融雪      | 冰川       |
|------|----------|---------|----------|
| 特征   | 暴雨径流作用为主 | 雪径流作用为主 | 冰川径流作用为主 |
| 水源方式 | 暴雨径流作用为主 | 雪径流作用为主 | 冰川径流作用为主 |

#### (2) 区——按泥石流所处地貌位置分

表13—1 ②

| 区    | 山区                                     | 山前区                                        |
|------|----------------------------------------|--------------------------------------------|
| 特征   | 洪积扇分布在山麓大河的地带，扇缘侵入大河床内被大河切割成陡坎，不能充分发育。 | 洪积扇在山前较宽广的河流阶地上充分发育，扇缘距大河尚有一定距离，不受大河的切割作用。 |
| 地貌位置 |                                        |                                            |

## (3) 型——按流域形态特征分为三型

表13-1 ③

| 特 征  | 标准型                                                           | 河谷型                                                                                         | 山坡型                                                     |
|------|---------------------------------------------------------------|---------------------------------------------------------------------------------------------|---------------------------------------------------------|
| 形态特征 | 三个区段明显。形成区呈葫芦状，集流时间短，坍塌区较稳定，沉积区呈扇形，沉积物棱角明显，淤积速度快，破坏能力较强，规模较大。 | 流域多呈长条型，形成区分散在狭河谷的上、中游一带，上游成串珠状河段，河漫滩阶地明显，是松散物质分段搬运的结果。流通区较稳定，沉积物呈次棱角~浑圆状。破坏能力较强，周期较长，规模较大。 | 沟小流短，沟坡与山坡基本一致。形成区为塌滑山坡，无通区，沉积物棱角明显，直接沉积在坡脚，形成规模不大的洪积扇。 |

## (4) 性质——根据地质和水文性质分为两性

表13-1 ④

| 性 质     | 粘 性                                     | 稀 性                                  |
|---------|-----------------------------------------|--------------------------------------|
| 容 重     | 1.5~2.1(t/m <sup>3</sup> )              | 1.2~1.6(t/m <sup>3</sup> )           |
| 固 体 含 量 | 1000~1400(kg/m <sup>3</sup> )<br>40~80% | 50~700(kg/m <sup>3</sup> )<br>10~40% |
| 粘 度     | >3泊，含大量粘土粉土，形成粘稠的整体(泥石质或泥质)。            | <3泊，含粘土粉土较少，不能形成粘稠的整体(水石质或泥石质)。      |

| 性 质     | 粘 性                                                                                                 | 稀 性                                                                                                     |
|---------|-----------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------|
| 岩 性     | 形成区的岩层和土层，多为风化后成粘土、粉土的泥岩、页岩、粉砂岩、粘土、砂粘土等。                                                            | 形成区的岩层和土层多为玄武岩、石灰岩、石英岩、砂岩、角砾岩、卵石土、块石土等。                                                                 |
| 水 文 性 质 | 水不是搬运介质，固、液两相质体近于等速，呈层流运动，堆积过程中，固液两相不立即分开，无明显渗透，结构不变，滑移无分选，粗细混杂。沉积物疏水性能弱，洪水后不易干涸，干后成整体。流量沿程渗漏现象不明显。 | 水是搬运介质，且水分含量远大于固体物质，固、液两相为不等速运动，呈紊流性质，沉积时，固、液两相立即分开，沉积物有明显的渗透，粒度滑移由大到小分选，层次不明显。沉积物排水性强，干后松散。流量沿程渗漏现象严重。 |
| 破 坏 作 用 | 破坏能力最大                                                                                              | 破坏能力较大                                                                                                  |

## (5) 规模——按流域面积和储备量作为主要因素划分为三等

表13-1 ⑤

| 指 标 | 流域面积<br>(km <sup>2</sup> ) | 储备量<br>(万m <sup>3</sup> ) | 设计流量<br>Q <sub>泥100</sub><br>(m <sup>3</sup> /sec) | 沉积面积<br>(km <sup>2</sup> ) |
|-----|----------------------------|---------------------------|----------------------------------------------------|----------------------------|
| 大   | >10                        | >100                      | >100                                               | >1.0                       |
| 中   | 3~10                       | 30~100                    | 40~120                                             | 0.2~1.0                    |
| 小   | <3.0                       | <30                       | <50                                                | <0.2                       |

## (6) 发育阶段——按物理地质作用性质、坍塌程度及水土保持措施形态特征等分

表13-1 ⑥

| 发育阶段<br>指 标                             | 幼 年 期                            | 壮 年 期                            | 老 年 期                                  | 相 对 稳 定 期             |
|-----------------------------------------|----------------------------------|----------------------------------|----------------------------------------|-----------------------|
| 物理地质作用性质                                | 逐渐发育，以流水侵蚀，风化剥落为主。               | 严重发育，以坍塌崩塌滑坡等山坡物供给为主。            | 逐渐趋于稳定，以河床物供给为主。                       | 达到相对稳定状态。             |
| 活坍塌面积(%)                                | 1~8                              | >8                               | 1~8                                    | <1.0                  |
| 侵蚀模量(万m <sup>3</sup> /km <sup>2</sup> ) | 1~8                              | >8                               | 1~8                                    | <1.0                  |
| 坍塌程度系数(A)                               | 0.5~0.9                          | >0.9                             | 0.5~0.9                                | <0.5                  |
| 危害程度                                    | 一般                               | 最大                               | 较大                                     | 无                     |
| 沉积性质                                    | 沉积速度逐渐增大                         | 沉积速度最大而稳定                        | 沉积速度由大到小                               | 下切                    |
| 水土保持措施及植被情况                             | 水土保持遭受破坏，并向恶化方向继续发展。             | 童山秃岭，水土保持遭到严重破坏。                 | 封山育林，水土保持措施加强，植被情况有好转。                 | 水土保持措施植被情况良好。         |
| 形态特征                                    | 洪积扇逐渐形成而且正在发展壮大，整个扇面均很活跃、新鲜，淤积快。 | 淤积快，扇面规模淤积都较大，无槽、漫流严重。活坍塌达到极盛时期。 | 逐渐有下切现象，形成较固定沟槽，淤积减缓，扇面逐渐生长植物，死坍方迅速增多。 | 河床固定下切很深，扇面恢复耕植，土石变色。 |

(7) 泥石流强度——按流量、淤积厚度及水土百分比、粘土颗粒含量等特征分为三级

表13—1 ⑦

| 指<br>标<br>强<br>度 | 沉积区淤积厚度<br>(cm/年) | 设计流量<br>$Q_{泥100}$<br>( $m^3/sec$ ) | 水土百分比(体积比)或粘土颗粒占固体之重量比及所处的发育阶段。                                                                         |
|------------------|-------------------|-------------------------------------|---------------------------------------------------------------------------------------------------------|
| 强 烈              | $>5.0$            | $>120$                              | 1. 青壮年期切割剧烈。<br>2. 固体物含量 $>60\%$ , $\gamma_c > 1.63$ 粘土质颗粒 $>20\%$ 。                                    |
| 中 等              | $2 \sim 5$        | $40 \sim 120$                       | 1. 青壮年期向老年期过渡, 切割较剧烈。<br>2. 固体物含量 $30 \sim 60\%$ , $\gamma_c 1.4 \sim 1.8$<br>3. 粘土颗粒 $1.5 \sim 20\%$   |
| 微 弱              | $<2.0$            | $<60$                               | 1. 老年期向稳定期过渡, 旁侧为主下切轻微。<br>2. 固体物含量 $10 \sim 30\%$ , $\gamma_c 1.1 \sim 1.4$<br>3. 粘土颗粒 $1.5 \sim 20\%$ |

影响泥石流变化的因素很多。如固体物质补给来源的多少, 水量的变化及固体物质中细粒物质含量的改变等, 都直接影响泥石流的性质; 沟床的宽、窄、陡、缓等的变化也会引起泥石流性质的变化; 同一地区同一条沟, 如发生的时间不同, 有时也可能表现出不同的特性。对一定的泥石流流域来说, 在考虑防治措施时, 应以出现的性质和类型确定其整治方案。

## 二、泥石流对路基工程的危害

### (一) 冲刷

1. 线路横穿泥石流沟洪积扇, 常因桥涵跨度不够或导流建筑物失效, 主河槽改道, 使桥头路基被冲毁, 如图13—5。

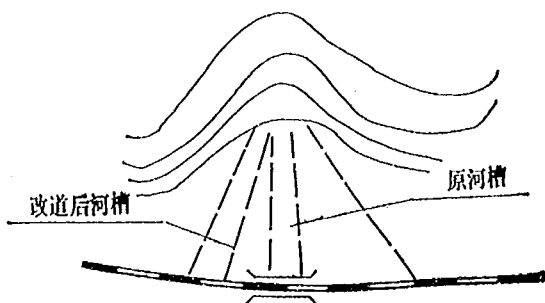


图13—5 主槽改道冲毁路基示意图

2. 沿河线主河流量不大, 而两岸泥石流相互交错发育之处, 两岸洪积扇常与河争地, 迫使主河床形成蛇曲, 主流在河床中摆动不定。当对岸泥石流发生时, 常迫使主河流改道冲刷路基, 如图13—6。

### (二) 淤埋

1. 线路横穿泥石流沟洪积扇, 当泥石流数量很大, 桥孔宣泄不畅时, 则常使桥头路基被淤埋。
2. 如主河流两岸泥石流沟发育, 而主河流的流量又不足以把流下来的泥石固体物质带走时, 则

大河往往把两岸全部大小泥石流沟发展的影响联系在一起, 使河床急剧上涨, 形成河宽滩浅。并行排列在主河一侧的泥石流沟, 随着一个个洪积扇的发展, 依次联接起来, 构成巨大的洪积扇群, 威胁沿河铁路, 甚至淤埋路基。

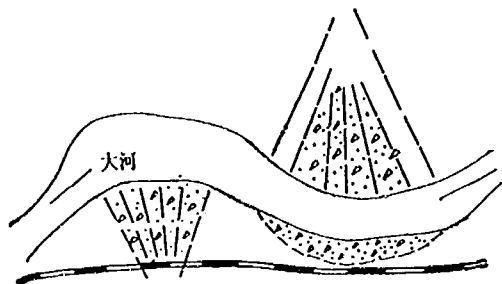


图13—6 对岸泥石流挤压河床路基冲刷示意图

### (三) 冲淤交替

泥石流沟往往是冲淤交替的, 有时是先有冲刷, 后又淤埋, 或这一次泥石流活动是冲刷, 而在另一次泥石流活动中则被淤埋。但更多的情况往往是既有冲刷, 又有淤埋, 即使在一次洪水中也出现冲淤交替的复杂作用。

## 三、泥石流地区路基设计的调查测绘

### (一) 综合调查

从地质和水文方面进行全面踏勘, 判明泥石流的区、型、性、规模和发育阶段, 对泥石流有一概括的认识, 作为拟定方案的依据。要着重了解泥石流区域的降雨时间与泥石流发生的历史, 地表切割、冲刷、水流方向, 固体物质运动情况, 沉积及分布范围, 洪水位置及壅水高度。特别还应调查了解受灾情况以及当地居民与泥石流作斗争的实际经验。

### (二) 泥石流的调查测绘

对泥石流的调查测绘, 必须掌握泥石流发生的全过程, 作为铁路建筑物设计的依据。

### 1. 对泥石流各区段的调查测绘

形成区：泥石流储备（松散物）的范围、厚度和数量，采取加固山坡增强其稳定性及调节地表水措施的可能性。

流通区：查明其长度、坡度，宜于设置工程和线路通过地段的工程地质条件。

沉积区：查明冲积物的形态特征，主流在洪积扇上发展的特征，切割淤积旁蚀现象，改道的可能性；沉积物的层序、级配、分选情况，移动方向、厚度、数量及最大一次淤积量；洪积扇与大河的距

离及过渡到主槽的形态。

### 2. 泥石流发展趋势的分析判断

调查泥石流利、流量、流速，以分析判断其可能发展的性质、规模、冲淤动向及范围，破坏程度，以便正确选择线路跨越的部位，确定跨越高度和处理方案，计算各种方案的结构物的需要强度。

### （三）泥石流状态的观测

对于某些严重的泥石流进行长期的观测工作，以与调查测绘的资料进行综合研究。

## 第二节 设计原则

### 一、线路位置选择

跨越泥石流地区的线路，由于其跨越区段位置的不同，可以路基、桥涵、隧道（或明洞）等不同建筑物通过。对比来说，路基是较易受破坏的，因此泥石流地区的线路应尽量避免以路基通过，而以桥、隧通过为宜。

#### （一）线路横跨泥石流沟

线路横跨泥石流沟时，最好是在流通区用大跨度桥或隧道通过，使路基避开泥石流的威胁。若在洪积扇的尾部用长桥或多座桥梁通过，或不得已时在洪积扇的腰部以明洞通过，应充分考虑桥、洞两端路基的安全。

在尚处于活动阶段的泥石流洪积扇上，应避免作路堑通过；作路堤通过时，要按泥石流地区的具体情况，考虑到泥石流的淤积速度及铁路使用年限。

#### （二）狭窄河谷中的山区泥石流地区选线

在这种地段由于地形狭窄，一个个洪积扇逼近主河，发育极不完全，泥石流的淤积速度及冲击能力都比山前区泥石流严重，而选线又受地形限制。如线路靠近洪积扇尾部，既不能减轻淤积速度，又受到大河主流冲刷的威胁。因此，在这种地段的选线原则是：一般应当适当提高线路高度，用桥通过泥石流洪积扇的顶端，或用深埋隧道通过泥石流的形成区。

在泥石流主槽经常摆动不定的地段，及严重受两岸泥石流影响的山区泥石流主河之河滩上，均不宜作河滩路堤，不宜改河改沟，只能考虑用桥通过。

在受两岸泥石流影响的主河狭谷地段，其路基不宜侵占主河河床过水断面。

#### （三）开阔河谷中泥石流地区选线

线路沿泥石流沟汇集的开阔河谷前进时，线路可采用多次跨河办法，利用两岸洪积扇与洪积扇之间的阶地作路基（我国某线有成功的经验），选择不受泥石流或洪水顶冲的河湾地带设河滩路堤。但线路标高应高于在铁路使用年限内河床的总上涨高度。

#### （四）与其他工程交叉或平行时选线注意事项

1. 铁路与公路平行跨越泥石流沟者；铁路桥与公路桥相隔的距离宜稍远些，如相距过近往往因

下游公路桥阻水，而使铁路桥下淤积加快（特别是河床坡度较平缓的地段），或因上游的公路桥被泥石流冲毁危及铁路路基的安全。

2. 灌溉渠在泥石流区通过时，常因渗漏作用而加剧泥石流的发展危害下游铁路，选线时应注意这个因素。

### 二、路肩设计标高的确定

路肩设计标高，关系到铁路路基的安全、稳定、造价及使用年限，同时也涉及到前后地段的大型建筑物，因素较为复杂。在泥石流地区影响路肩设计标高的主要因素是泥石流的淤积速度和泥石流水位，对此要通过周密调查及多种计算办法互相印证确定。

#### （一）河床的淤积计算

在研究淤积时，要特别注意淤积时间（过去、现在、将来）、地点（所处部位）、速度（泥石流沟发展趋势）以及河相因素（河床宽窄、坡度、缓急、淤积范围）等具体情况，用多种方法互相参证，选取比较符合实际的结果。

#### 1. 多年平均淤积值计算

$$(1) \text{ 调查法 } h_{\text{平}} = \frac{\sum h}{n} \quad (13-1)$$

式中  $h_{\text{平}}$ ——多年平均淤积值（m），  
 $\sum h$ ——调查（挖探、钻探、观测）年限淤积总值（m），  
 $n$ ——调查年限的年数（年）。

$$(2) \text{ 成因分析法 } h_{\text{平}} = \frac{H}{N} \quad (13-2)$$

式中  $N$ ——设计年限（年），  
 $H$ ——设计年限内总上涨数（m）

$$H = \frac{W - Nw}{A}$$

$W$ ——全流域在设计年限内可能补给的松散物质的储备量（ $\text{m}^3$ ），

$w$ ——估算每年随水冲走的固体物质体积数（ $\text{m}^3$ ），

$A$ ——沉积范围的面积（ $\text{m}^2$ ）（要注意冲积扇被切割的变化情况），

$h_{\text{平}}$ ——年平均上涨值（m）。



5. 路堤填料应就地取用渗水土, 无渗水土时可用粘性土, 其中最好用粘土填筑。

6. 填筑路堤取土, 应使取土坑对泥石流能起因势利导的作用, 不宜集中挖掘过深, 也不宜顺路基方向挖取; 在沟中取料时, 要注意避免引起河床粒径细化, 以免加剧冲刷而对建筑物基础产生不良影响。

7. 泥石流地区的山坡, 大部分是不稳定的, 岩层风化破碎, 因此路堑天沟需浆砌, 边坡要加固。路堑切割穿过小型泥石流沟时, 不宜采用吊沟

或顶顶改沟等办法, 最好用渡槽引渡泥石流。

8. 排水沟的横断面和纵坡要适当加大加深, 并不宜改沟并流。

9. 泥石流地区应尽量不采用涵管, 而采用桥梁。桥梁应有足够的净空和长度, 同时桥的上下游需设置适当的导流防护工程, 不致形成桥下淤积或主流改道而威胁路基的安全。

10. 明洞和隧道也应有足够的长度, 不使泥石流淹没和倒灌入洞口及破坏两端路基。

### 第三节 泥石流水文计算

#### 一、泥石流流速计算

##### (一) 稀性泥石流流速计算公式

##### 1. 西南地区现行公式

$$V_c = \frac{M_c}{\alpha} R_c^{2/3} \cdot I^{1/2} \quad (13-8)$$

式中  $V_c$ ——泥石流断面平均流速 (m/sec);

$R_c$ ——泥石流水力半径 (m);

$\alpha$ ——阻力系数,  $\alpha = [\psi \cdot \gamma_H + 1]^{1/2}$ ;

$\psi$ ——泥石流修整系数,  $\psi = \frac{\gamma_c - 1}{\gamma_H - \gamma_c}$ ;

$M_c$ ——泥石流沟糙率系数 (查表13-2);

$\gamma_c$ ——泥石流容重在1.0~2.3t/m<sup>3</sup>之间;

$\gamma_H$ ——泥石流固体物质的比重, 一般取2.4

~2.7, 为了简化计算手续, 已知

$\gamma_c$ 、 $\gamma_H$ 后,  $\alpha$ 、 $\psi$ 可直接从表13-

3中查得;

$I$ ——泥石流水面或沟床坡度 (%)。

##### 2. 西北地区现行公式

$$V_c = \frac{M_0}{\alpha} R_c^{2/3} \cdot I^{3/8} \quad (13-9)$$

式中  $M_0$ ——未考虑泥石流特征的糙率时铁道部第一设计院根据统计结果推荐15.3;

$V_c$ 、 $R_c$ 、 $\alpha$ 、 $\psi$ 、 $\gamma_c$ 、 $\gamma_H$ 、 $I$ 意义同前。

3. 在等速运动条件下的山区、半山区紊流类泥石流根据动能平衡原理推导, 国外有人建议用下面公式:

$$V_c = \frac{M_0}{\alpha} R_c^{2/3} I^{1/4} \quad (13-10)$$

式中  $M_0$ ——山区河道糙率系数 ( $M_0=6.5$ ), 其它各符号意义同前。

泥石流沟糙率系数 ( $M_c$ )

表13-2

| 组 别 | 沟 槽 特 征                                                           | M <sub>c</sub> 值 |       | 坡 度         |
|-----|-------------------------------------------------------------------|------------------|-------|-------------|
|     |                                                                   | 极 限 值            | 平 均 值 |             |
| 1   | 沟槽糙率很大, 槽中堆积不易滚动的砾石和大块石, 并被树木严重阻塞, 无水生植物。沟底呈阶梯式降落。                | 3.9~4.9          | 4.5   | 0.375~0.174 |
| 2   | 沟槽糙率较大, 槽中堆积有大小不等的石块, 并有树木阻塞, 槽内两侧有草木植被。沟床坑洼不平, 但无急剧突起, 沟底呈阶梯式降落。 | 4.5~7.9          | 5.5   | 0.199~0.067 |
| 3   | 较弱的泥石流沟槽, 但有大的阻力。沟槽由滚动的砾石和卵石组成, 常因有稠密的灌木丛而被严重阻塞, 沟床因有大石块突起而呈凹凸不平。 | 5.4~7.0          | 6.6   | 0.187~0.116 |
| 4   | 在山区中下游的光滑的岩石泥石流沟槽, 有时具有大小不断的阶梯跌水的沟床, 在开阔河段有树枝、砂不停积阻塞, 无水生植物。      | 7.7~10.0         | 8.8   | 0.220~0.112 |
| 5   | 在山区或近山区的河槽, 由砾石、卵石等中小粒径和能完全滚动的物质组成, 河槽阻塞轻微, 河岸有草木及木本植物, 河底降落较均匀。  | 9.8~17.5         | 12.9  | 0.090~0.022 |

##### (三) 粘性泥石流流速计算公式:

##### 1. 西藏古乡粘性泥石流经验公式:

$$V_c = K_1 \cdot K_2 \cdot V_0 = 0.46 V_0 \quad (13-11)$$

式中  $K_1$ ——表面平均流速 ( $V_{pi}$ ) 与表面中泓流速 ( $V_0$ ) 之比。

$$K_1 = \frac{V_{pi}}{V_0} = 0.60;$$

$K_2$ ——垂直方向流速分布系数取  $K_2 \approx 0.77$ ;

$V_0$ ——中泓流速 (m/sec), 根据实验资

料得,

$$V_c = \frac{1}{n} R_c^{3/4} I^{1/2}$$

 $n$ ——泥石流糙率, 一般取0.45;

 $R_c$ ——泥石流流体水力半径 (m);

 $I$ ——泥石流水面纵坡 (%);

 $V_c$ ——泥石流流速 (m/sec)。
 $\gamma_c$  值与  $\alpha$  值对照表

表13-3

| $\gamma_c$<br>$\gamma_H$ $\psi \cdot \alpha$ |          | 1.0 | 1.1   | 1.2   | 1.3   | 1.4   | 1.5   | 1.6   | 1.7   | 1.8   | 1.9  | 2.0  | 2.1  | 2.2  | 2.3  |
|----------------------------------------------|----------|-----|-------|-------|-------|-------|-------|-------|-------|-------|------|------|------|------|------|
| 2.4                                          | $\psi$   | 0   | 0.077 | 0.167 | 0.272 | 0.400 | 0.556 | 0.750 | 1.00  | 1.33  | 1.80 | 2.50 | 3.67 | 6.00 | 13.0 |
|                                              | $\alpha$ | 1.0 | 1.09  | 1.18  | 1.29  | 1.40  | 1.53  | 1.67  | 1.84  | 2.05  | 2.31 | 2.64 | 3.13 | 3.92 | 5.68 |
| 2.5                                          | $\psi$   | 0   | 0.071 | 0.154 | 0.250 | 0.364 | 0.500 | 0.667 | 0.875 | 1.14  | 1.50 | 2.00 | 2.75 | 4.00 | 6.50 |
|                                              | $\alpha$ | 1.0 | 1.08  | 1.18  | 1.28  | 1.38  | 1.50  | 1.63  | 1.79  | 1.96  | 2.18 | 2.45 | 2.81 | 3.32 | 4.15 |
| 2.6                                          | $\psi$   | 0   | 0.067 | 0.143 | 0.231 | 0.333 | 0.454 | 0.600 | 0.778 | 1.00  | 1.28 | 1.67 | 2.20 | 3.00 | 4.33 |
|                                              | $\alpha$ | 1.0 | 1.08  | 1.17  | 1.26  | 1.37  | 1.48  | 1.60  | 1.74  | 1.90  | 2.08 | 2.31 | 2.55 | 2.96 | 3.50 |
| 2.7                                          | $\psi$   | 0   | 0.063 | 0.133 | 0.214 | 0.308 | 0.416 | 0.545 | 0.700 | 0.890 | 1.12 | 1.43 | 1.83 | 2.40 | 3.25 |
|                                              | $\alpha$ | 1.0 | 1.08  | 1.17  | 1.26  | 1.35  | 1.46  | 1.57  | 1.70  | 1.84  | 2.01 | 2.21 | 2.44 | 2.74 | 3.13 |

## 2. 福列什曼实验公式:

$$V_c = V_B (1 - a) \quad (13-12)$$

式中  $a = 0.09 \sqrt{n_c - n_0} + b(\gamma_c - 1)$ 

$$b = \lg(3n_c)^\circ;$$

$$V_c = V_B [1 - 0.09 \sqrt{n_c - n_0} + \lg(3n_c)^\circ \cdot (\gamma_c - 1)];$$

 $V_c$ ——泥石流流速 (m/sec);

 $V_B$ ——清水流速 (m/sec) (按照公式13-11);

$$10V_B = \frac{1}{n_B} \cdot R_B^{3/4} \cdot I^{1/2}$$

 $n_B$ ——清水运动时水流速度;

 $n_c$ ——估计有效粘度 (泊), 按实测泥石流的粘度 (泊) 或按表13-4;

 $n_0$ ——粘性泥石流最小粘度取为8泊;

 $\gamma_c$ ——泥石流容重 (t/m<sup>3</sup>)。
泥石流稠度与有效粘度 $n_c$ 对照表

表13-4

| 边坡土特性           | 轻质砂粘土 | 粘土及重质砂粘土 | 粉土及重质砂粘土 | 粉土及重质砂粘土 | 粘土    |
|-----------------|-------|----------|----------|----------|-------|
| 泥石流稠度           | 稠浆状   | 稀泥状      | 稠浆状      | 稀泥状      | 稠浆状   |
| 估计有效粘度( $n_c$ ) | 3—8   | 3—8      | 9—12     | 12—25    | 10—20 |

## 3. 莫氏公式

$$V_c = K_c \sqrt{gh(i - i_0)} \quad (13-13)$$

式中  $V_c$ ——泥石流流速 (m/sec);
 $K_c$ ——在已知流量下最大能量损失的参数, 与泥石流流体中固体物质的相对稠度 ( $e$ ) 有关, 即:

$$K_c = \frac{2}{\sqrt{3 \cdot e}} \sqrt{\frac{(1-e)^3}{1-e/2}}$$

 $e$ ——石块 (泥砂) 的平均粒径 ( $D_s$ ) (m) 与泥石流流体深度 ( $h$ ) (m) 之比。

$$e = \frac{D_s}{h}$$

 $g$ ——重力加速度;

 $i$ ——泥石流沟床纵坡;

 $i_0$ ——泥石流发生运动时的最小坡度, 无资
料时可选用  $i_0 = 0.05 \sim 0.06$ 。

上述各公式在实际应用中, 最好都用来进行计算, 而选择其中较满意的结果。

## 二、泥石流流量计算

## (一) 形态调查法 (形态勘测法)

$$Q_c = W_c V_c \quad (13-14)$$

式中  $Q_c$ ——泥石流流量 (m<sup>3</sup>/sec);
 $W_c$ ——根据按形态调查确定的泥石流最高洪水水位来计算的泥石流横断面面积 (m<sup>2</sup>);

 $V_c$ ——泥石流流速 (m/sec), 按照泥石流的类型分别选用泥石流流速计算公式确定。

(二) 配方法: 此法根据泥石流流体中水和固体物质的比例, 用在一定设计标准下可能出现的洪

水流量, 加上按比例所需的固体物质体积配合而成的泥石流流量。

$$Q_c = Q_b(1 + P) \quad (13-15)$$

式中  $P$ ——考虑到土的天然含水量而引进的泥石流修正系数。

$$P = \frac{\gamma_c - 1}{\frac{\gamma_H(1+W)}{W\gamma_H + 1} - \gamma_c}$$

$W$ ——土的天然含水量(%)；

$Q_b$ ——清水流量( $\text{m}^3/\text{sec}$ )；

$Q_c$ 、 $\gamma_H$ 、 $\gamma_c$ ——意义同前。

此法适宜于西北地区泥石流的流量估算。

### (三) 雨洪修正法

#### 1. 东川经验公式:

$$Q_c = Q_b(1 + \phi) D_u \quad (13-16)$$

式中  $D_u$ ——泥石流堵塞系数。

根据东川在七年中40个观测资料验证,  $D_u$  值在1.0~3.0之间并与堵塞时间的长短成正比, 与产生泥石流的大小成反比, 即:

$$D_u = 0.871^{0.24} \quad D_u = 5.8 / Q_{\text{泥}}^{0.21}$$

因此, 在确定堵塞系数时要综合考虑, 进行具体分析。 $D_u$ 在1.0~3.0范围之内也可按下表选用。

$$\phi \text{——泥砂修正系数} = \frac{\gamma_c - 1}{\gamma_H - \gamma_c},$$

$\gamma_c$ ——泥浆容重, 可根据化验求得( $\text{t}/\text{m}^3$ )；

$Q_c$ 、 $Q_b$ ——意义同前。

实测堵塞系数表

| 堵塞程度  | 最严重堵塞   | 较严重堵塞   | 一般堵塞    | 微弱堵塞    |
|-------|---------|---------|---------|---------|
| $D_u$ | 2.6~3.0 | 2.0~2.5 | 1.5~1.9 | 1.0~1.4 |

#### 2. 斯氏(60年)公式

$$Q_c = Q_b \frac{(1 + \phi)^{7/16}}{(\phi \gamma_H + 1)^{1/14}} \cdot D_u \quad (13-17)$$

式中所有符号意义同前。

#### 3. 赫氏公式:

$$Q_c = Q_b \cdot \alpha \cdot D_u = Q_b \left[ \frac{P}{\gamma_H(100 - P)} + 1 \right] \cdot D_u \quad (13-18)$$

$P$ ——泥石流固体物质含量百分比(按重量)；

$\gamma_H$ 、 $Q_b$ 、 $D_u$ 、 $Q_c$ ——意义同前。

#### 4. 拉氏公式:

$$Q_c = Q_b \cdot e^{0.05 \left( \frac{\gamma_H}{\gamma_b} - 1 \right)} \cdot D_u \quad (13-19)$$

式中  $e$ ——自然对数=2.718；

$\gamma_b$ ——水的容重一般以 $\text{t}/\text{m}^3$ 计；

其它符号意义同前。

以上雨洪修正法公式中的2、3、4式是引进国外的, 经过在我国西南的东川、西昌、西宁等地的25条泥石流沟的实测资料验证, 斯氏(60年)公式, 较为符合实际, 与东川公式较为接近。拉氏公式偏大, 赫氏公式则有大有小(-14.4~23.2%)。由于目前对泥石流的内在规律的研究和认识还比较肤浅, 泥石流流速及流量计算尚无较完整统一的计算公式。在运用上述公式时, 需进行深入细致的调查研究和测绘, 正确选用公式和有关参数, 将计算的结果互相验证, 作出较切合实际的结论。

### 三、土的侵蚀速度及坍塌储备量的计算

(一) 土的侵蚀速度, 可参考表13-5 (不包括大量崩塌作用)。

土的侵蚀速度 表13-5

| 土的侵蚀程度 | 土的侵蚀速度 ( $\text{m}/\text{年}$ ) |
|--------|--------------------------------|
| 微弱的    | 0.02~0.05                      |
| 中等的    | 0.06~0.15                      |
| 强烈的    | 0.16~0.30以上                    |

#### (二) 储备量计算:

$$W = V \times F \quad (13-20)$$

式中  $W$ ——年供给储备总量( $\text{m}^3$ )；

$V$ ——土的侵蚀速度( $\text{m}/\text{年}$ )；

$F$ ——坍塌面积( $\text{m}^2$ )。

如土的侵蚀强度不同, 则可用加权平均计算。

(三) 资料整理及分析: 根据调查的结果, 作出各种图表并计算有关数据(汇总地质、水文数据)作为处理措施中的依据。

## 第四节 泥石流的防治措施

泥石流的发生和发展其原因是多方面的, 但在大多数情况下, 产生泥石流重要原因之一就是天然植被的破坏。泥石流的发展是一个长期过程, 一般泥石流从发生到大规模发展, 再到衰退以至停止, 少则几十年多则几百年。再者由于它的规模比较大, 单纯依靠工程措施来治理, 往往工程巨大, 若用生物法恢复其植被, 则需要较长的年限才能收效, 因此, 对待泥石流要综合整治。一方面要治山

治水, 逐步减轻泥石流的危害程度; 另一方面要采取工程措施, 提高铁路建筑物本身的坚固性以抵抗泥石流的破坏。

### 一、预防泥石流发生的措施

#### (一) 水土保持措施

1. 封山育林、植树造林包括分水岭防护林, 护坡林; 在梯田、地坎、沟谷、冲积扇上植树造林

等。封山育林不仅保护了森林,且使草皮也有生长的机会。树根和草皮可以巩固种植土不受冲刷,保护其下面的岩层不受或少受风化营力的作用。不过树木的生长需要一段时间,所以在铁路修建的初期,造林的同时还要采取适当的工程措施,否则铁路仍将遭受近期泥石流的危害。

2. 植树的种类——视当地具体条件,通过调查选用,最好是根深枝叶繁茂和耐旱的树种。乔木与灌木要互相间植,草皮绿苔等应加以保护。常用的乔木树种有洋槐、榆树、云南松、合欢、栓皮栎、杜梨等;灌木有紫穗槐、鼠李、密柚子、木豆、马桑、胡枝子、大麻子树等都是较适宜的。

### (二) 农牧技术措施

田间工程方面有梯田截水坑,梯田截水沟,水簸箕,软埝等;耕作方面有轮作、间作、套种、混种、横耕、沟垄耕、停耕、区田、水平防冲沟等;牧业方面有牧场合理利用,封坡育草等。

### (三) 水土保持工程措施

1. 治理地表水和地下水,疏干土壤,以稳定山坡。可修建山坡截水沟、蓄水沟、鱼鳞坑,填挂补缝,边坡渗沟,支撑渗沟等工程。

2. 稳定山坡的工程措施,有沟头防护,护岸稳坡,封面固坡,分洪蓄石,调洪淤沙等。如果泥石流系由于滑坡雪崩等活动引起的,可以适当做些支挡工程。

## 二、泥石流输、导、滞、拦建筑物

对流出山口的泥石流,可采用输排、利导、滞流,拦截等综合治理措施,而以排导为主。

### (一) 泥石流排洪道

泥石流排洪道是排泄泥石流常用的一种建筑物,能起到顺畅排泄泥石流的作用。它的设计与一般排水的渠道不同,主要是从泥石流的特征和类型加以考虑。现分述如下:

1. 排洪道的平面布置。泥石流特别是粘性泥石流,在转弯处有较大的超高和爬高能力,截弯取直性能很强,同时也容易受阻停积。粘性泥石流流经沟床弯道时截弯取直有两种情况:

(1) 凹岸泥石流流速大,凸岸流速小,结果凹岸冲刷,凸岸淤积如图13—9,使沟出现截弯取直现象。

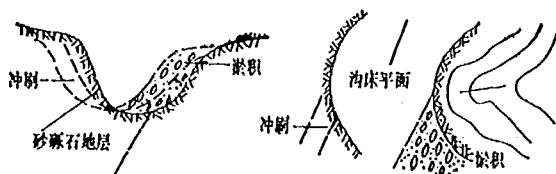


图13—9 粘性泥石流在沟床弯道上运动时的冲刷淤积情况示意图

(2) 当泥石流前峰部分在凹岸受阻挡,跟踪而来的泥石流主体无法从上超越时,就会改变流动

方向,呈现出凹岸淤积凸岸冲刷的另一种截弯取直现象。如图13—10。



图13—10 粘性泥石流在沟床弯道上运动时凹岸受阻冲淤情况示意图

因此要使排洪道尽量做到不淤积不冲刷,不漫流或决堤等,应尽可能直线布置。如因地形限制必须转弯时,稀性泥石流排洪道的弯道半径要大于一般排洪道底宽的8~10倍。粘性泥石流排洪道的弯道半径要大于一般排洪道底宽的20倍左右。

为了便于大河带走泥石流宣泄下来的固体物质,排洪道出口与大河交接处以锐角为宜,其角度应在45°以下,使排洪道保持良好的宣泄性能。

2. 排洪道与大河交接处,其标高应高于同频率的大河水位,至少也应高出20年一遇的大河洪水。否则会由于大河顶托而导致排洪道发生淤积。另外排洪道与桥孔相接时,其断面应与桥孔断面一致,排洪道与桥头锥体连成一体。在桥孔处,排洪道不宜突然放大或收缩,以免引起桥下的淤积和冲刷甚至影响到排洪道本身安全。

3. 排洪道纵坡:合理选择排洪道的纵坡,最好的办法是对天然或人工河道进行观测而确定,中国科学院冰川冻土沙漠研究所推荐的排洪道纵坡如表13—6。

人工铺砌排洪道

纵坡参考表

表13—6

|    | 容重<br>(t/m <sup>3</sup> ) | 物质组成    | 最小纵坡(%)  |
|----|---------------------------|---------|----------|
| 稀性 | 1.3~1.4                   | 泥流, 泥石流 | 2.5, 3.5 |
|    | 1.4~1.5                   | 泥流, 泥石流 | 3.0, 4.0 |
|    | 1.5~1.6                   | 泥流, 泥石流 | 3.5, 4.5 |
| 粘性 | 1.6~1.8                   | 泥石流     | 5~7      |
|    | 1.8~2.2                   | 泥石流     | 8~15     |

一般可根据当地的调查资料选定设计纵坡,并注意下列各点:

(1) 洪积扇的坡度与设计纵坡大致相符,只有局部地段需要挖深或填高时,纵坡不宜变坡,而要一坡到底;如因地形限制必须变坡时,也只能以利于泥石流排导为前提,从上游往下游应由缓变陡。

(2) 洪积扇较平缓,不能满足设计纵坡的要求时,可在上游采用拦蓄停淤或引水淡化措施,使泥石流在较小纵坡下亦能顺利排走。

(3) 洪积扇纵坡比设计纵坡大得多时, 主要是如何防止冲刷, 目前在这方面多采用加深防护堤的基础或加大护底厚度等方法来解决, 也有用横向堆坡拦墙的办法, 解决基础冲刷问题。

上表提供的设计纵坡, 只能适用于冲淤变化能保持在不影响安全排泄的范围内。但由于大多数泥石流流域不是产生单一类型的泥石流, 其流量、流态、容重及物质组成等是不断发生变化的, 就一次泥石流而言, 其流态特征也不是一致的, 所以设计时必须考虑到这些情况。

4. 排洪道的基础埋深: 泥石流不仅有快速的淤积作用, 其冲刷作用也很强烈, 有时一次泥石流就可以将沟床冲刷 1~3 米或更深。例如, 某某线在一次泥石流中分别将沟下切 3 米及 6 米, 在某支线基础埋置 2 米深的工程, 几乎都因泥石流的冲刷而毁坏。因此对泥石流沟护坡基础的埋深, 必须考虑泥石流的冲刷作用, 特别是对凹岸的冲刷。影响泥石流冲刷深度的因素很多, 通常用实际观测和调查访问的资料作为设计的依据。对于稀性泥石流可参考下面的冲刷公式, 与调查结果相互印证。

在直槽中:

$$h_p = \frac{0.1q}{\sqrt{d_{pi} \left( \frac{H}{d_{pi}} \right)^{1/6}}} \quad (13-21)$$

式中  $h_p$ ——冲刷后泥深 (m),  
 $q$ ——单宽流量 ( $\text{m}^3/\text{sec}$ ),  
 $d_{pi}$ ——泥石流固体物质平均粒径 (m),  
 $H$ ——原泥深 (m)。

在弯道凹岸处, 冰川冻土沙漠研究所推荐:

$$h_p = \frac{0.17q}{\sqrt{d_{pi} \left( \frac{H}{d_{pi}} \right)^{1/6}}} \quad (13-22)$$

式中  $h_p$ 、 $q$ 、 $d_{pi}$  及  $H$  意义同前。

5. 排洪道的弯道超高: 由于泥石流的容重大, 其运动时的惯性也大, 因而它的外侧超高比清水要大得多, 在设计中应特别加以注意。弯道外侧超高可根据现场调查和访问的资料确定, 也可用下列公式进行计算。

$$\Delta h = \frac{2.3V_c^2}{g} \cdot \lg \frac{R_s}{R_i} \quad (13-23)$$

式中  $\Delta h$ ——弯道外侧超高 (m),  
 $V_c$ ——泥石流流速 ( $\text{m}/\text{sec}$ ),  
 $g$ ——重力加速度 ( $\text{m}/\text{sec}^2$ ),  
 $R_s$  和  $R_i$ ——分别为弯道凹岸和凸岸的曲率半径 (m)。

6. 排洪道的断面形式: 常见的有梯形断面, 矩形断面, 复式断面和锅底形断面等四种, 见图 13-11 a、b、c、d。

断面形式的采用, 要根据泥石流通过地段的地形, 保护工程建筑的要求以及排洪道本身的结构来确定。一般来说, 需要改道或重新开挖的排洪道的流量不大, 多采用梯形或矩形断面; 按原沟床或加

高河堤的排洪道, 而且通过的流量又较大者, 一般采用复式或锅底形断面。

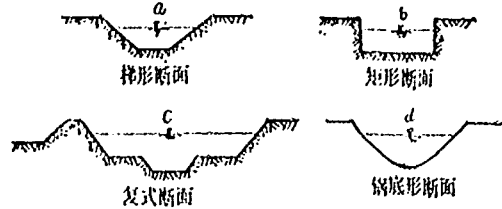


图 13-11 排洪道断面形式

7. 排洪道的断面尺寸: 在设计中通常是已知设计流量 ( $Q_c$ ), 纵坡 ( $i$ ), 容重 ( $\gamma_c$ ) 及固体物质比重 ( $\gamma_n$ ), 据以选定断面形式和底宽 ( $B$ ), 确定排洪道的泥深 ( $h_c$ )。选定的断面形式及底宽 ( $B$ ), 泥深 ( $h_c$ ) 应满足下述公式:

$$Q_c = W_c V_c$$

式中  $Q_c$ ——设计流量;  
 $W_c$ ——泥石流过流断面 ( $\text{m}^2$ ),  
 $V_c$ ——泥石流流速 ( $\text{m}/\text{sec}$ )。

设计底宽 ( $B$ ) 和泥深 ( $h_c$ ) 的最佳情况, 是与该段稳定的天然沟床  $B/h_c$  之比值相近, 如果条件不能满足, 其设计之  $B/h_c$  比值应小于 5~7。

8. 排洪道深度 ( $h$ ) 的确定

直槽中为  $h = h_c + h_1$  (13-24)

弯道处为  $h = h_c + h_1 + \Delta h$  (13-25)

式中  $h$ ——排洪道深度 (m),  
 $h_c$ ——泥石流设计深度 (m),  
 $h_1$ ——安全高度, 一般取 0.2~0.5 (m),  
 $\Delta h$ ——弯道超高 (m)。

除了用公式计算外, 也可采用校核流量的办法来确定排洪道的深度。例如设计流量为百年一遇, 可视工程建筑物的重要性, 采用二百年或三百年一遇的流量来校核设计的排洪道深度。

9. 排洪道的结构形式和尺寸: 排洪道的两侧常采用的有三种形式: 护坡、挡土墙和堤坝。护坡和挡土墙, 多用于下挖的排洪道, 堤坝的形式多用于填方的排洪道。护坡的稳定边坡和挡土墙的合理断面尺寸, 可根据土的物理力学指标大致确定。由于泥石流挟有泥砂石块, 具有比清水大得多的拖动力和冲刷能力, 故对土质护坡或护堤来说, 多采用铺砌加固沟底。但对沟道宽、护底造价太高者沟底可不进行铺砌, 而采用两种办法来解决基础冲刷: a、加深护堤铺砌基础, 并加横向堆坡拦墙 (见图 13-12), 维持沟底的一定纵坡, 加强排洪道的整体性。如西南某市的泥石流排洪道, 在未加堆坡拦墙以前每年都有基础冲刷需要维修, 后在一次洪流中, 排洪道溃堤, 冲毁了一个菜场和几个商店。经 68 年加设堆坡拦墙以后, 经历次泥石流的考验, 基础再无冲毁现象, 效果很好。

堆坡拦墙的底部, 同排洪道的边墙基础砌成一体, 拦墙顶与沟底平, 间距 8~16 米, 或由下式

计算决定,

$$L = \frac{H - \Delta h}{i}$$

式中  $L$ ——栏墙间距 (m);  
 $i$ ——排洪道纵坡;  
 $H$ ——栏墙全高 (m);  
 $\Delta h$ ——安全高, 采用 0.3~0.5m, 见图13—12之 A—A 剖面。

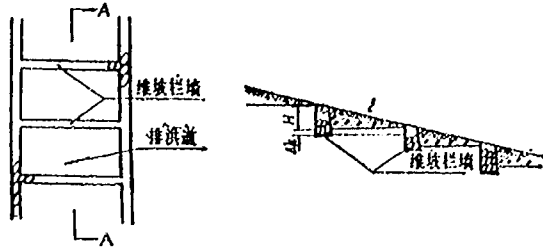


图13—12 排洪道图

栏墙厚 0.5~1.0m, 一般在排洪道纵坡  $i > 5\%$  时才使用堆坡栏墙。

#### 10. 泥石流的其他排输措施

泥石流排洪道跨越铁路时常采用以下几种结构形式:

(1) 泥石流渡槽。对于一些储量及流量有限的小型泥石流, 如地形许可, 下游有淤积场地, 或者宣泄下来的固体物质, 大河可及时带走, 不致从下游回淤淹埋路基者, 可考虑渡槽方案。目前渡槽所排泄的泥石流流量一般不超过  $30 \text{ m}^3/\text{sec}$ 。其结构形式有棚洞式和明洞式两种。渡槽常作成急流式的, 其纵坡在  $8 \sim 15^\circ$  之间, 在西南等铁路上, 按上述条件采用的渡槽效果均很好。

(2) 急流槽。是用增大纵坡和压缩断面的办法使泥石流形成急流下泄的工程建筑物, 以防止桥孔的淤积和堵塞。为了防止急流槽的冲刷, 一般把它全部砌成光滑的槽子, 急流槽的首尾连接处设有裙墙。急流槽的断面形式有梯形、矩形、复式形、三角形等, 其中复式和三角形断面利于小水时集中排泄, 免于淤积。急流槽还要有适当的断面宽度和比较均匀而足够的排水纵坡, 急流槽的最小坡度一般是参照该泥石流天然沟槽的不淤最小坡度来选择。如图13—13, 分别绘出天然不淤沟段与急流槽的  $V = f(Q)$  曲线, 使急流槽的  $V_2$  大于天然不淤河段的  $V_1$ 。急流槽要避免转弯, 当非设弯道不可时, 外侧应超高, 还要考虑泥石流冲起高度以及爬升作用的影响。

(3) 引水输砂工程, 在条件许可之处, 可将其它清水沟常流的水引到排洪道、渡槽、急流槽之前, 使泥石流稀释, 以利排泄, 防止淤堵。

#### (二) 导流堤

导流堤一般是修建在冲积扇上, 或在路基及其它铁路建筑物受到泥石流威胁的范围内, 使泥石流能顺利排走, 以确保路基等建筑物的安全。它的高

度应是使用年限内的淤积厚度与泥石流的泥深之和。受淤积控制的导流堤, 可考虑分期分批的加高。

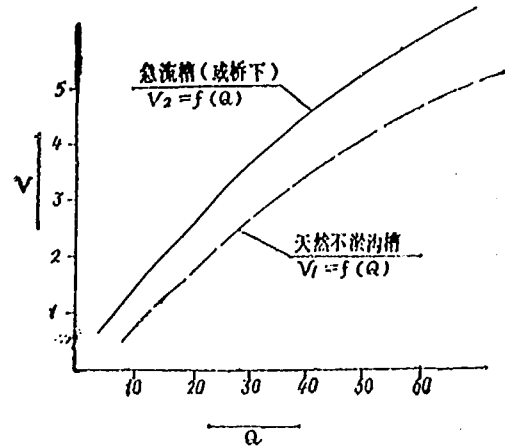


图13—13

导流堤堤顶标高由下式计算:

$$H_p = h_p + \Delta x + C \quad (13-26)$$

式中  $H_p$ ——导流堤堤顶标高 (m);  
 $h_p$ ——设计年限淤积高+设计水位 (m);  
 $\Delta x$ ——桥前壅水高度 (m);  
 $C$ ——安全值, 上游用 0.5m, 下游用 0.25m。

在泥石流可能受阻的地方或弯道处, 还应加上冲起高度和弯道超高。冲起高度可以调查访问得出, 也可以按公式进行估算。

$$\Delta h = 0.1 V_c^2 (1 + \cos \alpha) \quad (13-27)$$

式中  $\Delta h$ ——冲起高度 (m);  
 $V_c$ ——泥石流流速 (m/sec);  
 $\alpha$ ——沟岸顺泥石流方向的夹角 (度)。

导流堤的基础埋置深度参照前述排洪道的基础埋置深度办理, 导流堤的断面尺寸按土的力学指标计算。

#### (三) 滞流措施

泥石流的滞流建筑物, 通常是在泥石流沟中修一系列的低矮拦挡坝, 俗称谷坊坝, 泥石流可以漫过坝顶。坝的作用有三: ①、拦蓄泥沙石块等固体物质减弱泥石流的规模; ②、固定泥石流沟床, 防止沟床下切和谷坡坍塌; ③、平缓纵坡, 减小泥石流流速。一般来说, 拦挡坝的回淤坡度 ( $i$ ) 都小于原沟床纵坡 ( $i_0$ )。对于泥石流规模小、无经常水流作用的泥石流沟,  $i$  约等于  $i_0$  的  $3/4$  至  $1$ ; 对于常年流水的泥石流沟  $i$  约为  $i_0$  的  $1/2$  左右。

1. 谷坊坝的结构形式、各部名称和作用如图13—14。

这里用一座浆砌片石坝作为例子加以说明, 因为浆砌片石坝是使用最广泛的一种, 也是收效较好的一种, 它适合于拦挡任何类型的泥石流。

(1) 坝主体是阻拦泥沙的主体结构, 它的稳

定靠坝本身的重量来维持,但要求有良好的地基条件。

(2) 上下底栏是坝体伸入基础的两个齿墙,起加强坝体的抗滑作用。

(3) 泄水孔用来排泄泥库中稀泥浆或清水。

(4) 护坦是防止泥石流对坝脚的冲刷。

(5) 消力栏的作用是使坝下形成一消力池,以减弱从坝顶冲下来的泥石流及大石块的动能。

(6) 海漫是为了防止泥石流流出消力栏后继续发生冲刷。

(7) 导水墙是为保护两岸不受泥石流冲刷。

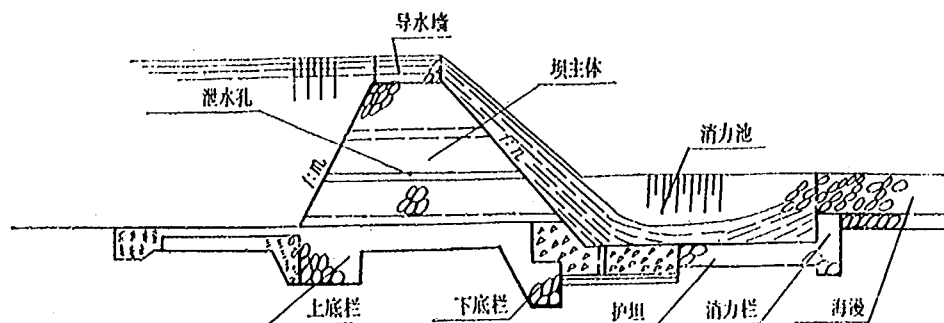


图13-14 谷坊坝结构图

## 2. 谷坊坝的建筑材料

泥石流地区往往交通不便,建筑谷坊坝可根据当地出产的建筑材料,选用石谷坊坝、混凝土谷坊坝、木石混合谷坊坝、土谷坊坝、石笼谷坊坝等。尤其是护坦、海漫这类建筑物用铁丝网笼比较合适,它强度大、整体性强、使用到一定时候就会被淤埋,是半永久性工程,比片石施工快、造价低。

## 3. 谷坊坝的坝高和坝距

坝高和坝距之间关系是当坝高时,断面大,坝的间距也大,坝的数目少。坝低时,断面小,间距小,坝数多。对此,要做技术经济比较来决定。但一般坝高以不超过5米为宜,在沟上游首当其冲的坝还要比下游更低一些。

坝高与坝距成下式关系(参阅图13-15)。

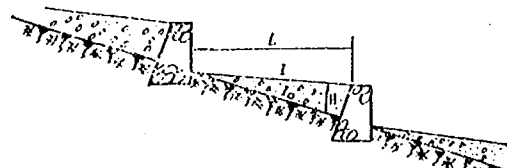


图13-15 谷坊坝的间距

$$L = \frac{H}{I_0 - I} \quad (13-26)$$

式中  $L$ ——坝与坝间距(m);

$H$ ——坝高(m);

$I_0$ ——原沟床坡度;

$I$ ——回淤坡度。

坝间距与坝数成下式关系

$$N = D/L \quad (13-27)$$

式中  $N$ ——坝的总数;

$D$ ——要设坝的全长范围,根据踏勘得出;

$L$ ——同上。

在一些泥石流重现期比较长、每年沉积量不多的泥石流沟,且不可能产生较大的下切和旁蚀现象时,可以考虑分批设坝分期加高等措施。

4. 谷坊坝的具体位置应在现场选定,必须适合当地地形,谷坊坝设置时,宜先做上游坝,后做下游坝。坝址应移向跌水上游沟底平缓处或在跌水下游平缓处,最后一座坝与路基之间的距离,应视河谷的特征及线路离开山坡脚的总距离而定。这一距离可以大致地规定等于坝的三倍长度。

## 5. 谷坊坝的断面设计

水力计算:设计谷坊坝,首先应做泥石流由溢流口过坝的水力计算,以确定整个谷坊坝的断面轮廓,消能池的尺寸,护坦、海漫的长度及加固类型等。

结构计算:坝的断面尺寸,按其受力情况检算确定。

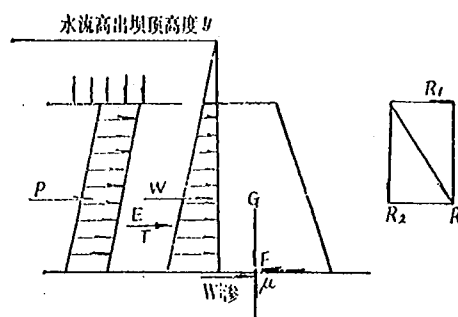


图13-16 谷坊坝所受荷载示意图

## (1) 坝的荷载组合及各种荷载的计算

### ① 坝的荷载组合

$P$ ——偶然堆积于坝上游的超荷载(t);

$E$ ——堆积物的土压力,应分别情况进行计算(t);

$T$ ——泥石流冲击力(t);

$W$ ——水压力,根据最高水位计算(t);

$w_{\text{渗}}$ ——坝基渗透压力(t);

$F$ ——基底摩阻力(t);

$\mu$ ——水的浮托力 (t) ;

$G$ ——坝体重量 (t) ;

$R_1$ ——水平方向的合力,  $R_1 = P + E + W - F_1$ ;

$R_2$ ——垂直方向的合力,  $R_2 = G - \mu$ 。

此外还应根据具体情况, 考虑坝承受渗透压力、泥石流对坝的冲击力, 及地震影响。

## ② 堆积物的土压力计算

当固体物质淤积高度与坝顶齐平时,

$$E = \frac{1}{2} \gamma_c \cdot H^2 \lg^2 \left( 45^\circ - \frac{\varphi}{2} \right) \quad (13-28)$$

式中  $\gamma_c$ ——泥石流容重 (t/m<sup>3</sup>) ;

$H$ ——坝高、或坝后淤积物的高度 (m) ;

$\varphi$ ——泥石流的内摩擦角。

如  $\varphi = 0$  时,  $E = \frac{1}{2} \gamma_c \cdot H^2$ ;

距坝顶深  $Z$  米处的土压力

$$E_z = \frac{1}{2} \gamma_c \cdot Z^2 \lg^2 \left( 45^\circ - \frac{\varphi}{2} \right) \quad (13-29)$$

如  $\varphi = 0$  时,  $E_z = \frac{1}{2} \gamma_c \cdot Z^2$

当泥石流溢过坝顶时

$$\begin{aligned} E &= \frac{1}{2} \gamma_c [(y + H + a)^2 - (y + a)^2] \\ &= \frac{1}{2} \gamma_c [H^2 + 2(y + a)H] \quad (t) \end{aligned} \quad (13-30)$$

式中  $H$ ——坝顶高度 (m) ;

$y$ ——水流高出坝顶的高度 (m) , 如取坝的单位长度进行计算时,  $y = q / V_{泥}$ ;

$q$ ——单位长度的泥石流流量 (m<sup>3</sup>/sec) ;

$V_{泥}$ ——泥石流的流速 (m/sec) ;

$a$ ——水流动能高度  $= V_{泥}^2 / 2g$  (m) ;

$g$ ——重力加速度  $= 9.81$  (m/sec<sup>2</sup>) 。

当泥石流深度较坝高虽低, 但因动能作用, 可能以波浪形态跃过坝顶时

$$\begin{aligned} E &= \frac{\gamma_c q^2}{g h} + \frac{\gamma_c h^2}{2} \\ &\quad - \frac{\gamma_c q \cos \theta}{g} \sqrt{\frac{q^2}{h^2} - 2g(H-h)} \end{aligned} \quad (13-31)$$

式中  $\gamma_c$ 、 $q$ 、 $g$ 、 $H$  意义同前;

$h$ ——泥石流的深度 (m) ;

$\theta$ ——坝上游边坡坡度角 (度) 。

## ③ 静水压力

$$W = \frac{1}{2} \gamma_1 H^2 / \cos \theta \quad (t) \quad (13-32)$$

## ④ 坝基渗透压力

$$M_{渗} = \frac{1}{2} \alpha \gamma_1 B h \quad (t) \quad (13-33)$$

式中  $\alpha$ ——基础接触面积系数取 0.8;

$\gamma_1$ ——水的容重为 1t/m<sup>3</sup>;

$B$ ——坝底宽 (m) ;

$h$ ——坝前淤积厚度 (m) 。

## ⑤ 冲击力

$$T = \frac{\gamma_c}{g} V_{泥}^2 \sin^2 \beta \quad (13-34)$$

式中  $\gamma_c$ 、 $g$ 、 $V_{泥}$  意义同前;

$T$ ——泥石流的冲击力 (t) ;

$\beta$ ——冲击方向与坝受力面所成角度。当  $\beta = 90^\circ$  时, 即冲击力与坝受力面垂直时,

$$T = \frac{\gamma_c}{g} V_{泥}^2$$

## (2) 稳定计算

将上述各荷载算出后, 即可求得荷载合力作用点位置, 并按挡土墙的要求检算其稳定性。

## (四) 拦截措施

### 1. 拦碴坝

拦碴坝通常是一沟一坝, 将泥石流全部拦入库中, 只许清水过坝, 对衰老期的泥石流沟, 在有利的地形条件下, 这种坝比较有效, 但目前使用尚不广泛。

### 2. 停淤场

当线路位在小型泥石流洪积扇的末端, 线路的下游距大河又较远, 沟床纵坡平缓, 无法将携带物输送到大河时, 可考虑在沟口与线路之间的回旋余地设置停淤场。在线路上游适当地点作拦截、分洪导流堤等, 将泥石流固体物质导入停淤场落淤, 余水由桥孔排泄。这种停淤措施只适用于泥石流储量有限的流域。

## (五) 防治泥石流工程设施的实践经验

### 1. 几种常用的拦碴排挡建筑物

#### (1) 石坊坝

图13—17是我国已采用的行之有效的浆砌片石谷坊坝, 其特点是构造简单, 稳定性较好。

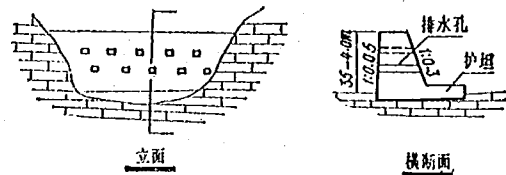


图13—17 浆砌片石谷坊坝

图13—18是采用过的台阶式浆砌块石谷坊坝。这种坝施工比较简单, 易减缓水势能, 效果很好。

图13—19是干砌片石谷坊坝, 在中南地区用的很多, 可节省费用。

#### (2) 铁丝石笼谷坊坝

图13—20, 此种坝适用于中小型泥石流沟谷。建造简易, 施工迅速, 造价比砌石低, 可就地取材, 使用沟中乱石, 整体性好, 不要求有基础, 是半永久性工程。在西南使用较多。此外, 也可以用竹笼代替铁丝笼以降低造价, 但使用期短, 整体性差。

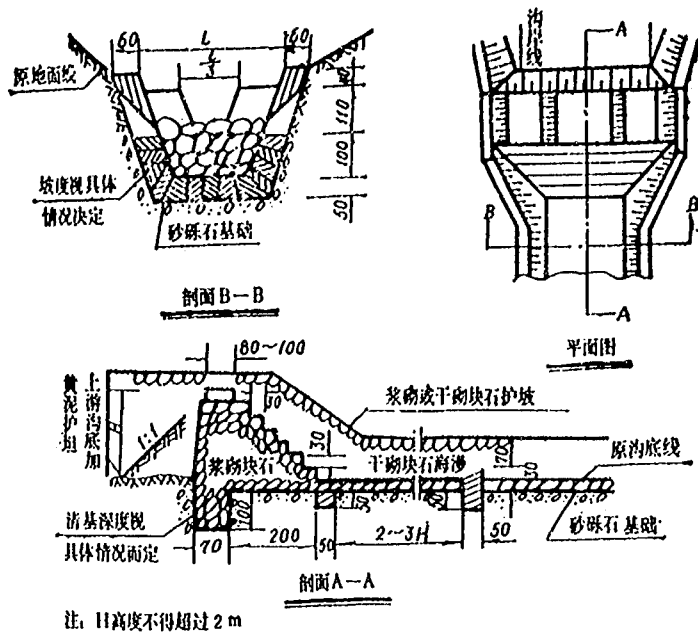


图13-18 台阶式浆砌块石谷坊坝 (尺寸以厘米计)

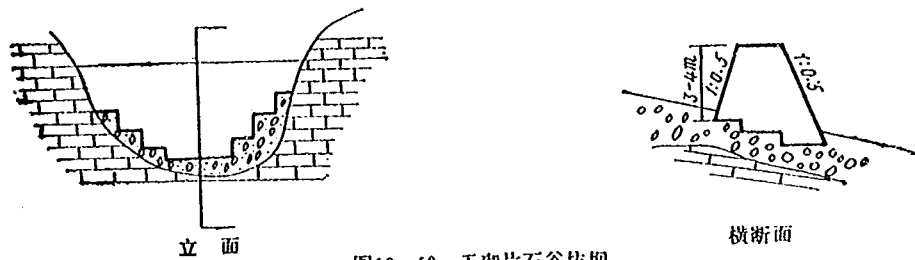


图13-19 干砌片石谷坊坝

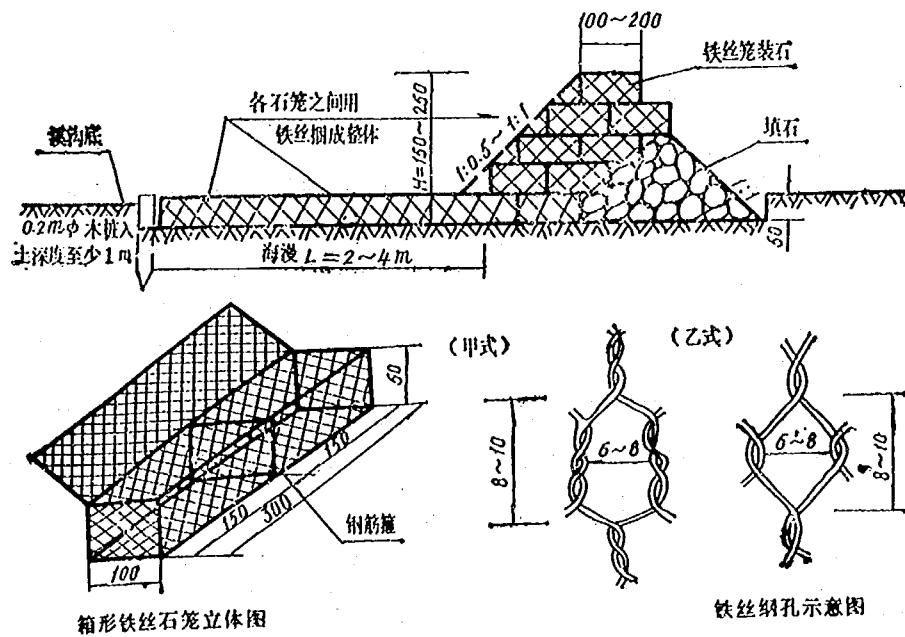


图13-20 铁丝石笼谷坊坝

注: 图中尺寸除注明者外均以厘米计。

### (3) 梢捆谷坊坝

适用于汇水面积不大, 流速较小, 水头差不大 (一般约1.5m), 沟底坡较平缓, 且为土质的情况及邻近产有梢料的地区。一般有栅栏坝和插柳坝等, 是一种比较临时性的谷坊坝, 图13—21是一个普通编篱谷坊坝。

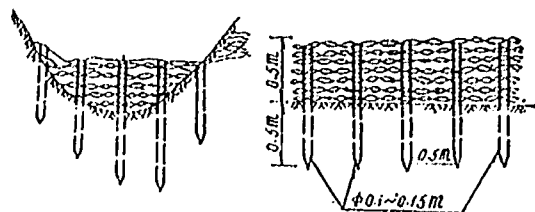


图13—21 编篱谷坊坝

### (4) 格栅坝

是用钢构件或钢筋混凝土构件装配而成的形似栅状的建筑物。它能将稀性泥石流、水石流携带的大石块经过格栅过滤停积下来形成天然的堆石坝, 从而缓冲了泥石流的动力作用。它可以节省建筑材料 (较实体坝节省约30~66%的材料), 施工速度快, 适用于交通不便的峡谷地区。

格栅形状有三角形桁架式, 交叉成菱形, 狭缝形等。图13—22为我国陕西华山北坡修建的狭缝式格栅坝。格栅孔隙的大小, 视固体物质大小而定。国外资料介绍, 孔隙直径要满足  $d = (1.3 \sim 1.4) D_{5\%}$  (式中  $D_{5\%}$  为机率, 等于5%的石块粒径)。狭缝形的孔径  $d \leq D_{5\%}$ 。

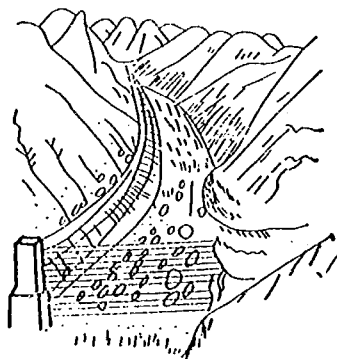


图13—22 格栅坝示意图

### 2. 排导、滞拦措施的综合使用

综合使用各种措施能达到更好的工程效果。如西北某线上成功地综合使用导流堤、滞淤坝和急流槽, 见图13—23。导流堤与山嘴相接, 在主沟中设滞淤坝, 坝一般高2~4米 (在石块较大的水石流中, 也有采用钢轨拦栅的)。滞淤坝下游则以急流槽通过铁路桥位。如导流堤与急流槽直接连接, 而无滞淤坝时, 要求导流堤收缩平顺, 尽可能降低壅水高度, 使壅水区有足够大的流速, 以减轻固体物质的淤阻, 如图13—24, 图中 $\alpha$ 角度的数字不大于 $10^\circ$ , 在渐变过程中, 沟底坡度一般不变。

### 3. 我国整治大泥石流的工程实例

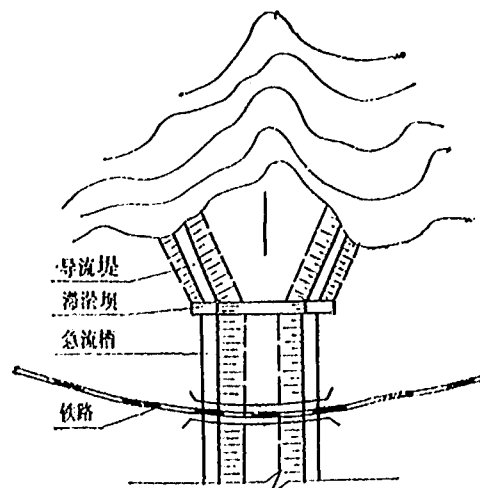


图13—23 排导、滞拦综合处理示意图

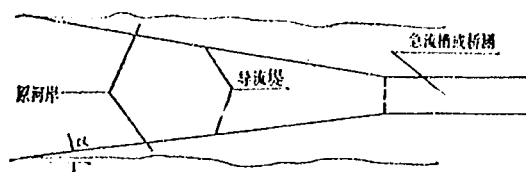


图13—24 导流堤与急流槽连接示意图

西南某线黑沙河泥石流沟, 规模宏大, 线路跨越泥石流沟宽3公里, 线路下游为广阔的水稻田和密集的村庄, 所以本工程点采用以治本为主和治标为辅的防治相结合的原则, 工程方面则与当地的农田水利建设远近期相结合, 因地制宜, 有主有次, 统筹兼顾地采取蓄、防、拦、排、清等多种综合措施, 收到了比较理想的效果。见图13—25。

(1) 在山口以上大力加强植树造林的水土保持工作, 并辅以必要的防、护、拦、蓄等工程。

① 在黑沙沟内设15个铁丝笼护面拦渣坝, 12个干砌片石沟坊, 500米长铁丝笼护岸, 截水沟239米以上, 工程分期完成。

② 麦地沟设两座拦渣坝。

③ 麻肚沟设一座拦渣坝。

(2) 在山口以下则以排为主, 拦、排、清结合, 一沟一桥, 小水集中, 大水分流, 并增设备险桥一座。

① 在洪积扇上作南北两条导流堤, 使中小洪水集中通过桥泄入大河。

② 在导流堤上游设60米长分流口, 特大洪水经分流口由赵家桥通过, 并在集中桥和赵家桥之间设设备险桥一座。

③ 为了使泥石流在腰带堤内漫流落淤, 降低腰带水位, 设鱼嘴坝一座, 腰带坝两座。

(3) 在上游清水区修筑水库 (此水库现已建成), 有效的控制了来水量, 也相应的控制了泥石流的发展趋势。

铁路工程设计技术手册

《路基》 第四篇

**特殊条件下路基**

铁道部第一设计院主编

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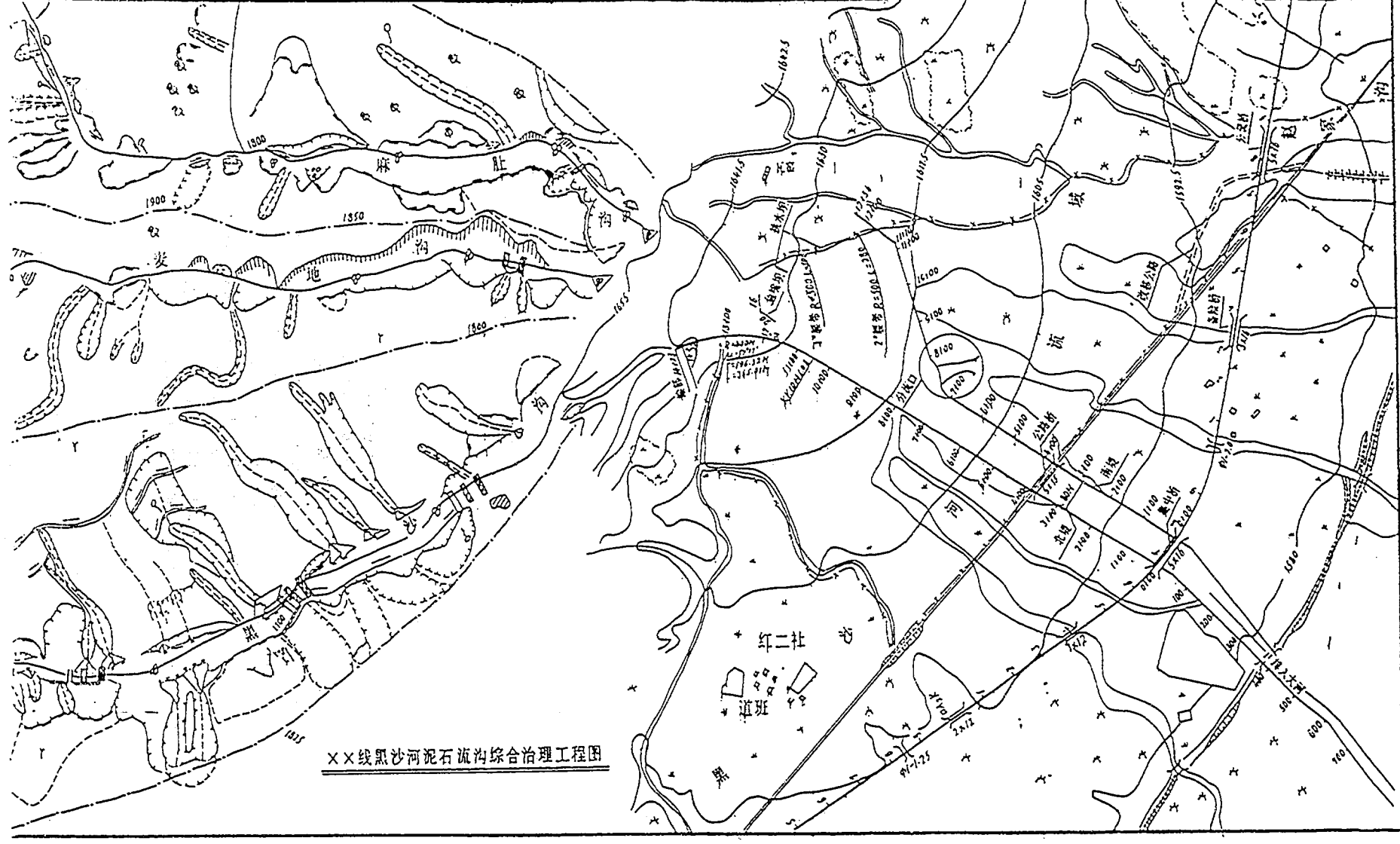
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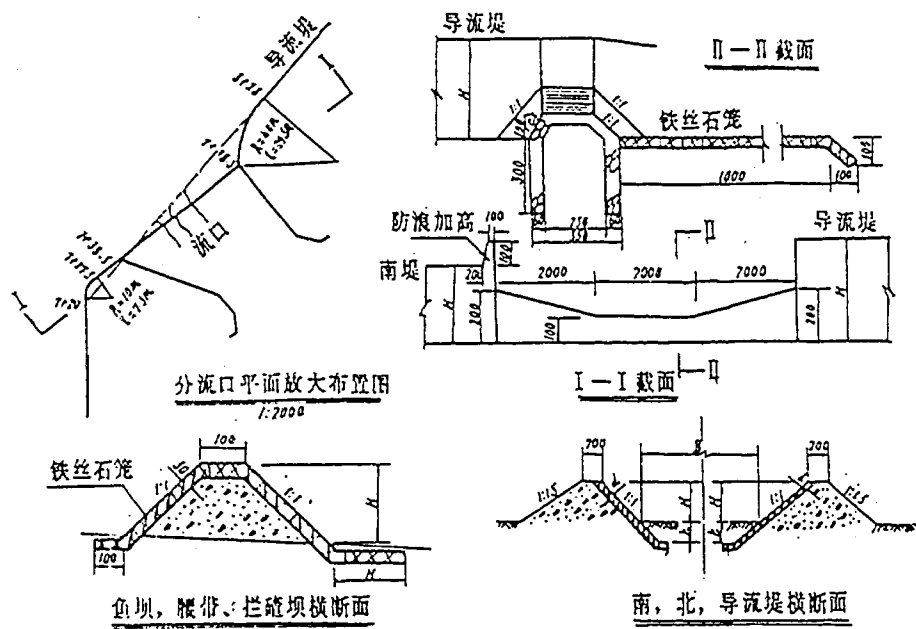
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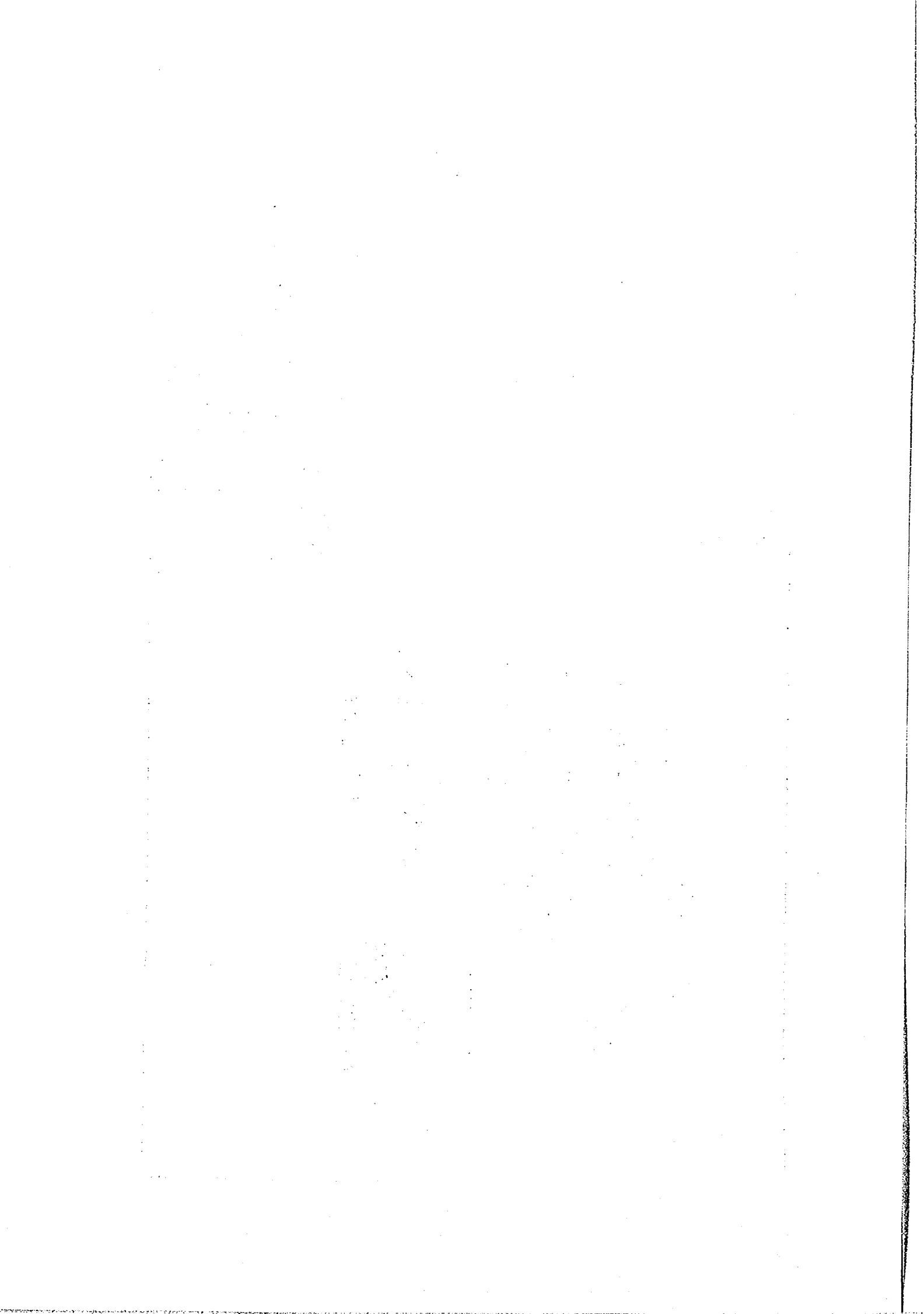
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# **The Designing Manual of Railway Roadbed in Debrisflow Area in China**

**Erosion Control Division  
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## **The Designing Manual of Railway Roadbed in Debris Flow Area in China**

**Takahisa MIZUYAMA**  
**Ping. Hue. Hu**

### **Synopsis**

This pamphlet is a translation of the section of Engineering Technical Manual For Railway Under Special Conditions published by The Railway Publishing House of China. The authors not only elucidate the basic characteristics of debris flow but also introduce a lot of countermeasures against it. Finally the principles of route planning for railway roadbed in debris flow area are given.

**Keywords:** debris flow area, planning principle, roadbed.

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## Paragraph 1. Introduction

## 1. Basic Concept

Debris flow is a kind of special fluid with great quantities of solid material of stones or debris, which is usually caused by rainstorm thaw or glacier melting in mountainous region where the geological characteristics and steep slopes favour the occurrence of debris flow.

The duration of a debris flow is usually very short but it has a powerful energy. Its front is a surging flow with a high density and volumetric weight as well as special structure and certain floatage. It is easy to be blocked up to deposit and also has a huge power to move again and carry more than 10 thousand or million cubic meter solid materials and as big as 10 tons or 100 tons of stones. A debris flow can destroy all the buildings, trees, traffic devices located on its way flowing, meanwhile it erodes river bed or deposited and stop up a river to form a temporary lake. In the place where it once stopped, a layer of solid materials will be left on the crops and buildings causing great losses in finance.

## 1.1. Division of Debris Flow Basin

A typical debris flow basin can be divided into three parts from upstream to downstream as shown on Fig. 13-1.

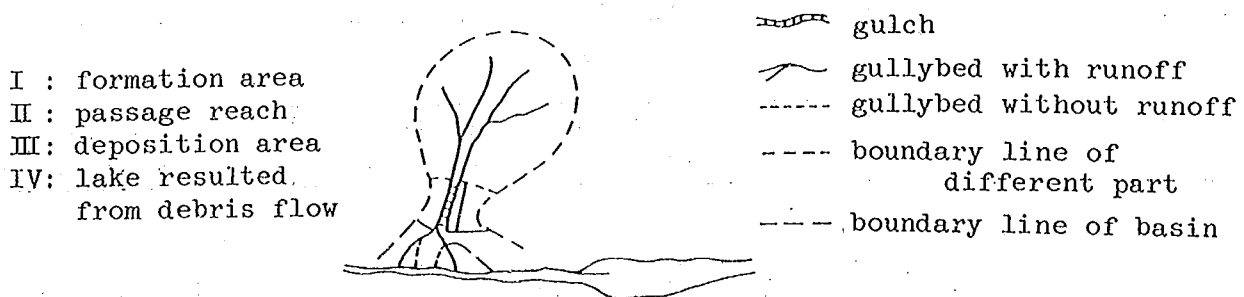


Fig. 13-1 A typical debris flow basin

## Formation area:

It is located in a depressed area in upstream of the basin surrounded by high mountains in a funnel-shaped from which a bound of water and solid materials are supplied. There are favourable conditions for occurrences of debris flow, such as slides, collapse status. Soil erosion and water loses is severe and hillslope is unstable. The size of formation area takes an important role in scale, property and calamitous degree of debris flow.

## Passage reach:

In the middle reach where has a canyon both the hillslope and longitudinal

gradient are steep. The gully bed is straight and usually has a visible flowing route.

Depositional area:

Depositional area locates at outlet of a debris flow gully where has a relative gentle slope and the solid materials from debris flows deposit there in a fan or cone-shaped. Various size of stones or rocks piled up together and form a flat land with a rough surface. It is easy to know the scale of a debris flow occurred and its calamitous degree by analysing this area.

The division shown above is only approximate, sometimes one of three parts may be absent. From geological history, three parts are changeable and might turn into each other. For example, prior deposited area probably turn into passage reach even formation area and form a series of alluvial fans.

## 1.2. Element Conditions of Occurrence for A Debris Flow

The occurrence of debris flow relates tight to the local natural conditions and human activities. The status of geograph and geology are internal causes while water supply is external cause for occurrence of debris flow. Their relationship can be shown on Fig. 13-2.

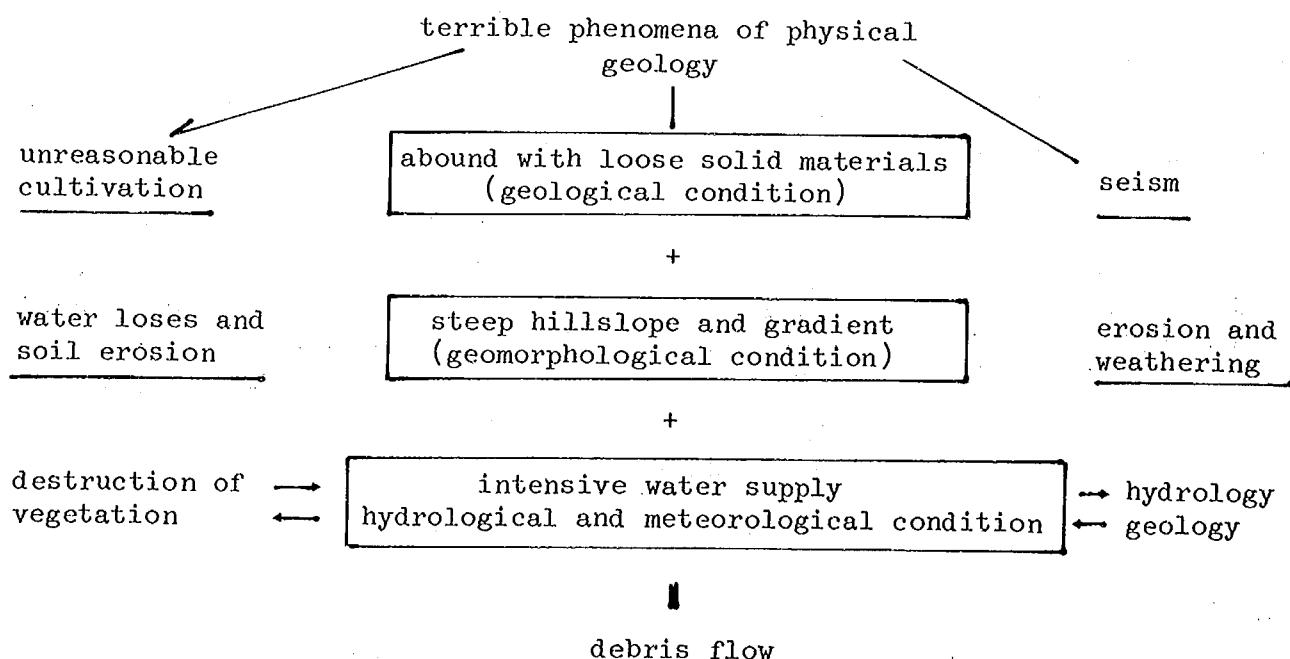


Fig. 13-2 Internal Relationship of Formation of Debris Flow

### 1.2.1. Geological Conditions

The geological features of debris flow gullies are intense, neotectonic activities and with complex structures and great quantity of faults and folds, frequent seismic activities which intensity are usually larger than 6° in degree.

Under these conditions the rocklayers are broken and the joint develops very well. Especially in the regions where there are soft rocklayers mixed with hard rocklayers, old rocklayers crop up, a large quantity of solid materials are provided to debris flow due to the tectonic activities by means of avalanche or collapse and so on.

#### 1.2.2. Geomorphological Conditions

High mountain, steep hill-slope and gradient are the basic landform features of debris flow which are favourable for concentrating and transporting water and solid materials.

A complete debris flow basin usually is in a depressed area where is surrounded by high mountains and has a outlet with a funnel or gourd shape. The hillslope is about  $30^{\circ}\sim 60^{\circ}$  in grade with a broken surface on which erosion and weathering are severe, vegetation is sparse. These are serious collapses in this area and the width of valley is very narrow with a V-shaped cross section. In the middle part, the gully has a U-shaped cross section, the hillslope on both sides of the gully have gradients of  $20^{\circ}\sim 40^{\circ}$  in grade. There are many water-drops and steep banks along the gully in the region with hard rock layer. The downstream is the site for deposition of debris flows that usually situates along a big river out of mountain with a fan-shaped or cone-shaped.

#### 1.2.3. Hydrology-meteorology Conditions

Generally speaking, rain pattern in debris flow area is rainstorm. The larger the precipitation and intensity of rainstorm, the larger the scale of debris flow will be. From the process of a debris flow formation, water acts two significant effects: Initially, sediments are saturated by water. In the most cases, the storage region of sediments is a convergent place of various sources of water so that solid materials are feasible to get enough water supply to become plastic state that is favourable for debris flow. Secondly, torrential water flow washes out the bottom or bank of gully to produce loose solid materials taking part in movement of debris flow moving downstream.

#### 1.2.4. The Affection of Human Activities

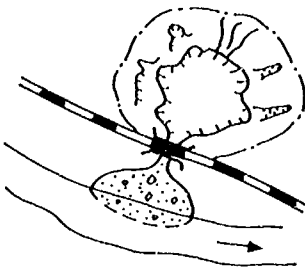
With the development mountainous area, the original structure is unreasonable destroyed, water loses and soil erosion provide debris flows with large quantity of solid materials or reactivates dead debris flow gully active. For instance, if waste residues from mine or construction site pile up unsuitably or a diversion channel is built in a loose slope, the occurrence and development of debris flow will be promoted.

### 1.3. Types and Features of Debris Flow

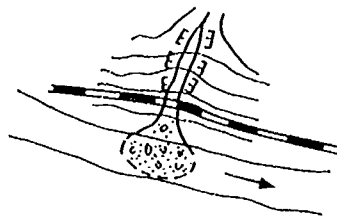
According to the causes, forms, properties, scales, movement, harmfulness and evolution stages, debris flows were divided into several groups as shown on Fig. 13-3, 13-4 and Tab. 13-1 for meeting the needs of countermeasures.

There are many factors that can influence the characteristics of debris flow. For example: variation of water amount and volume of solid material, percentage of fine sand in field will affect the properties of debris flow directly; change in the size of gullies will affect their properties, too. Even though in the same gully, the debris flow behave different properties in different time. For a given debris flow basin, properties and types of debris flow that may occur probably must be considered.

(a) Standard Type



(b) Valley Type



(c) Hillslope Type

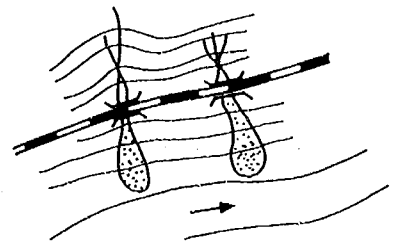
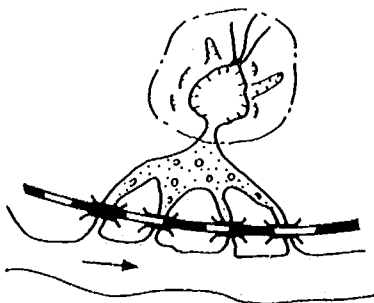
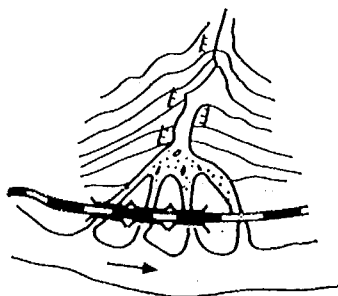


Fig. 13-3 Debris Flow in Mountainous Region

(a) Standard Type



(b) Valley Type



(c) Hillslope Type

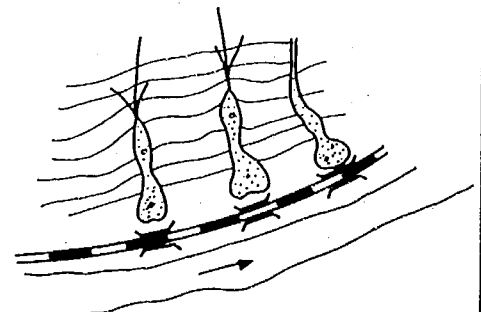


Fig. 13-4 Debris Flow in the Front of Mountains

# Classification Tables of Debris flow

(1) Kinds--Based on the Forms of Water Supply

Tab. 13-1-1

| kinds<br>features           | rainstorm              | thawing                   | glacier              |
|-----------------------------|------------------------|---------------------------|----------------------|
| forms of water<br>resources | runoff of<br>rainstorm | runoff of<br>melting snow | runoff of<br>glacier |

(2) Regions--Based on the geomorphological position of debris flow

Tab. 13-1-2

| regions<br>features          | mountainous regions                                                                                                                                                               | in the front of mountain                                                                                                                                                                    |
|------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| geomorphological<br>position | The alluvial fan locates in the foot of mountain and near the river. The edging of alluvial fan is cut by river formed a steep ridge. The alluvial fan can not develop perfectly. | The alluvial fan develops very well in a spread step-land of river in front region of mountain and is not influenced by cutting effect of river because edging of it is distant from river. |

(3) Shapes--Based on the features of basin slope

Tab. 13-1-3

| forms<br>features       | standard form                                                                                                                                                                                                                           | valley form                                                                                                                                                                                                                                                                                                 | hillslope                                                                                                                                                                                                       |
|-------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| properties<br>of shapes | formation area is of a calabash shape that is suitable for concentration of water. Passage reach is stable. Deposition area has a fan shape. Sediments are rhombic and deposit rapidly with a strong destructive power and large scale. | The basin usually is long and narrow. Formation area locates in up or middle reach and is eroded seriously. There is a visible flood-land in middle reach due to deposition along by gully. Passage reach is stable. Deposition area is fan-shape. Debris flow has a long period, strong destructive power. | The slope of gully equals the gradient of sideslope approximately. There's not a visible passage reach. Sediments with an rhombic shape deposit on the slope food directly and form a small scale alluvial fan. |

(4) Properties--There are classified into two groups based on their geological and hydrological properties

Tab. 13-1-4

| properties features     | viscous debris flow                                                                                                                                                                                                                                                                                                                                                                | dilute debris flow                                                                                                                                                                                                                                                                                                                                                                           |
|-------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| volume weight           | 1.5~2.1 (t/m <sup>3</sup> )                                                                                                                                                                                                                                                                                                                                                        | 1.2~1.6 (t/m <sup>3</sup> )                                                                                                                                                                                                                                                                                                                                                                  |
| concentration           | 1000~1400 (kg/m <sup>3</sup> )                                                                                                                                                                                                                                                                                                                                                     | 50~700 (kg/m <sup>3</sup> )                                                                                                                                                                                                                                                                                                                                                                  |
| viscosity               | >3 poise, that consists a lot of powder and clayforming a sticky                                                                                                                                                                                                                                                                                                                   | <3 poise that consists few powder and clay can not forming a sticky                                                                                                                                                                                                                                                                                                                          |
| natures of rock         | The layers of soil and rock in formation area are made of weathering products such as shale, mud-slate, phyllite, powder-sandstone, clay, sandy-clay and so on                                                                                                                                                                                                                     | The layers of soil and rock in formation area are made of quartzite basalt, sandstone, breccia, pebble and lumb of earth                                                                                                                                                                                                                                                                     |
| Hydrological properties | Water is not a medium for transporting solid materials. Solid and liquid move in one speed as a stratiform flow. In process of deposition, solid and liquid remain the same structure from upstream to downstream and do not separate immediately. Sediment with a poor permeability do not dry quickly in a few days. There is not a obvious phenomena of discharge seepage loss. | Water is a medium for transporting solid materials and water content is much more than that of solid materials. Solid and liquid move in different speed as a turbulent flow. After deposition, solid and liquid separate immediately. The grain sizes varies from large to small along the gully and have a strong permeability and loose structure. The discharge seepage loses seriously. |

(5) Scale--Based on the areas and storages

Tab. 13-1-5

| indexes scales | area of basin (km <sup>2</sup> ) | storage volume (*10000m <sup>3</sup> ) | designed discharge Qs (m <sup>3</sup> /s) | area of deposition (km <sup>2</sup> ) |
|----------------|----------------------------------|----------------------------------------|-------------------------------------------|---------------------------------------|
| large          | >10                              | >100                                   | >100                                      | >1.0                                  |
| middle         | 3~10                             | 30~100                                 | 40~120                                    | 0.2~1.0                               |
| small          | <3.0                             | <30                                    | <50                                       | <0.2                                  |

(6) Developing phases--Based on the natures of physical geological effects, degree of collapse and characteristics of water conservation measures.

Tab. 13-1-6

| phases<br>indexes                                                        | infancy                                                                               | activity                                                                                                                                        | descrepit<br>stage                                                                                                                   | relative<br>stability                                                                                               |
|--------------------------------------------------------------------------|---------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------|
| natures of<br>physical and<br>geological<br>effects                      | erosion of water<br>flow, gradual<br>evolution, wea-<br>thering effects               | developing well,<br>sediments pro-<br>vided by col-<br>lapse and<br>landslide                                                                   | gradually tends<br>to stability<br>and sediments<br>provided by<br>riverbed                                                          | relative<br>stable                                                                                                  |
| area of ac-<br>tive<br>collapse                                          | 1~8                                                                                   | >8                                                                                                                                              | 1~8                                                                                                                                  | <1.0                                                                                                                |
| modulus of<br>erosion                                                    | 1~8                                                                                   | >8                                                                                                                                              | 1~8                                                                                                                                  | <1.0                                                                                                                |
| coefficient<br>of collapse                                               | 0.5~0.9                                                                               | >0.9                                                                                                                                            | 0.5~0.9                                                                                                                              | <0.5                                                                                                                |
| degree of<br>harm                                                        | ordinary                                                                              | the most<br>serious                                                                                                                             | serious                                                                                                                              | harmless                                                                                                            |
| natures of<br>deposition                                                 | deposition rate<br>increases<br>gradually                                             | deposition rate<br>reached the<br>largest value                                                                                                 | deposition rate<br>decreases<br>gradually                                                                                            | cutting                                                                                                             |
| status of<br>vegetation<br>and con-<br>servation<br>of soil and<br>water | broken vegeta-<br>tion and will be<br>worsen further                                  | vegetation is<br>destroyed<br>seriously                                                                                                         | vegetation is<br>been renewed<br>and conserva-<br>tion of soil<br>and water is<br>getting well                                       | vegetation is<br>recovered very<br>well                                                                             |
| features of<br>landform                                                  | Alluvial fan has<br>formed and is<br>developing with<br>a rapid deposi-<br>tion rate. | deposits quick-<br>ly and alluvial<br>fan is thick<br>and large;<br>there is no ob-<br>vious channel<br>but strong ac-<br>tivity of<br>collapse | erodes gradual-<br>ly and a rela-<br>tive stable<br>channel formed;<br>deposition rate<br>is slow and<br>there are<br>plants growing | Riverbed is cut<br>deeply; allu-<br>vial fan is<br>cultivated and<br>colour of<br>debris and<br>earth is<br>changed |

(7) Intensity of debris flow--Based on the discharge, deposition thickness, percentage of water to soil (volumetric) clay content.

Tab. 13-1-7

| index intensity | deposition thickness (cm/Yr) | designed discharge $Q$ ( $m^3/sec$ ) | percentage of water to soil or the ratio of clay grains to soil weight and its evolution phase                                                            |
|-----------------|------------------------------|--------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------|
| intense         | $>5.0$                       | $>120$                               | 1. active phase with strong erosion.<br>2. solid content $>60\%$ , $\gamma_c > 1.63$ , clay grains $>20\%$                                                |
| medium          | $2 \sim 5$                   | $40 \sim 120$                        | 1. Debris flow is in transition phase from active to decrepit.<br>2. solid content $30 - 60\%$ , $\gamma_c = 1.4 \sim 1.8$<br>3. clay grains $1.5 - 20\%$ |
| feeble          | $<2.0$                       | $<50$                                | 1. Debris flow is in transition phase from decrepit to stable.<br>2. solid content $10 - 30\%$ , $\gamma_c = 1.1 \sim 1.4$<br>3. clay grains $1.5 - 20\%$ |

## 2. The Harmfulness of Debris Flow to Roadbed Projects

### 2.1. Erosion

2.1.1. When a route crossing over and alluvial fan, the roadbed on bridgehead is often bursted due to the invalidation of diversion projects and a shorter bridge span. See Fig. 13-5.

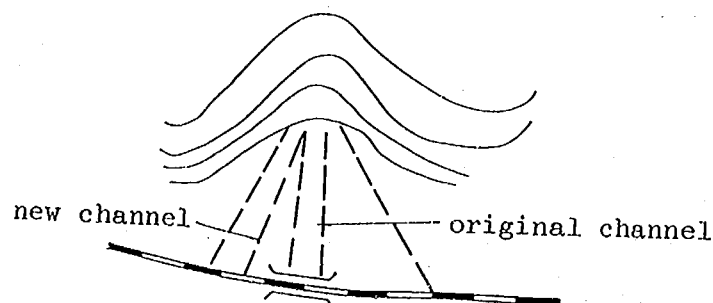
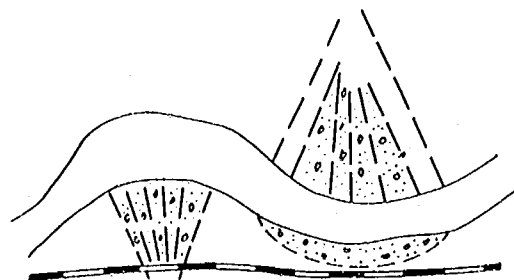


Fig. 13-5 A Sketch Map that Roadbed Is Washed Out by a New Channel

2.1.2. When the discharge of water flow in main river is too small to transport sediments from debris flow and debris flows develop very well on both sides of the river, alluvial fans along the river bank will take up the place of main river and enforce to change its flowing direction frequently. When a debris flow occurs on opposite bank, the main river will wash out roadbed as shown in Fig. 3-6.



## 2.2. Silt

2.2.1. When a route crossing over alluvial fan by a bridge while the discharge of debris is too large to pass through the bridge opening, roadbed on the bridgehead will be silted up or buried.

2.2.2. If the debris flows on both sides of main river develop very well and discharge of main river is too small to transport all the solid materials then the riverbed level will rise quickly. With the development of alluvial fans, the river will become wide and shallow, all the alluvial fans will join together forming a huge group of alluvial fans to threaten or destroy roadbeds by the river.

## 2.3. Erosion Alternating with Silting

Erosion always alternates with silting even though in the same process of a debris flow or a flood.

## 3. Investigation for Designing Roadbed in Debris Flow Areas

### 3.1. Comprehensive Investigation

To investigate a debris flow basin from hydrological and geological aspects in order to get first-hand data as a basis of planning, we should pay sufficient attention to know historical debris flows or floods, precipitation, cutting, erosion, movement of solid material and their distribution. The disastrous status and practical experiences in the struggles against debris flows in history also should be known as detailed as possible.

### 3.2. Survey and Drawing of Debris Flows Areas

We must have a good grasp of whole processes of debris flows as basis of designing constructs by survey and drawing.

#### 3.2.1. The Survey and Drawing in Individual Part of a Debris Flow Basin Formation Area:

To investigate and estimate the thickness, range and amount of loose solid materials that are possible to provide debris flow and to determine the probability of project to strengthen stability of hillslope and to adjust surface water on the area.

#### Passage Reach:

To ascertain the length, gradient and engineering geological conditions of the reach where the projects are to be built.

Deposition Area:

The follows should be known:

The morphological features of alluvion;

The developing features of alluvion fan, present status of erosion or silting and the variation of main course of river;

The procedure, composition, distribution, moving direction, thickness, volumetric weight and the maximum probable volume of a debris flow;

The distance between river and alluvial fan as well as the transitional patterns from outlet to main course.

### 3.2.2. The Analysis of Developing Trend of Debris Flows

By investigating the level, discharge and velocity of debris flows, we can judge and analyse their properties, scale, erosion or silting tendency and range in future so as to determine the position and height of projects and to compute their intensities.

## Paragraph 2 The Principles of Planning

### 1. Route Planning

A route in debris flow area can cross over the gully by different projects such as roadbed, bridge, tunnel (or opening tunnel) depending on the position in which the route will be built. Contracted to others, roadbed is more easy to be destroyed therefore when it crossing over a debris flow area, bridge or and tunnel should be used other than roadbed.

#### 1.1. Crossing of Debris Flow Gully

When crossing over a debris flow gully, it is the best to build a long-span bridge or tunnel in passage reach so as to prevent roadbed from damages. If it is inevitable to cross over the rear part of alluvial fan by a long-span bridge or a series of bridges, even by open tunnels in the middle part of alluvial fan, the safety of roadbed on both sides of bridges or tunnels must be considered carefully.

At an alluvial fan that is being in active stage, an access for roadbed should be built by filling other than cutting. The available years of the railway and the rising rate of the alluvial fan also should be noticed.

#### 1.2. Route Planning in the Regions with Narrow Valleys

Because of narrow landform, alluvial fans are tightly closed to main course of the river one by one and can not develop well, in addition, deposition rate and ability of debris flow are much stronger than that in front of mountain, consequently route planning is restricted by native landform. If a roadbed is closed to rear part of an alluvial fan, roadbed could not decrease the depositing rate of debris flow, in contract, it will be washed up by main course of the river. The principles of route planning in this area are: To raise the elevation of route by setting bridges in top part of alluvial fan or tunnels in formation area of debris flow.

In a reach where the main channel of debris flow is variable or in flood land that is affected by debris flow severely on both sides, the bridges should be built instead of embankment or changing the original river to artificial channel. In a narrow reach, a roadbed do not take up the sectional area of water flow.

#### 1.3. Route Planning in Debris Flow Regions Along with a Wide Valley

When a route is along a wide river where there are debris flows gullies on its both sides, we can take the step-land alluvial fans as roadbed and chose meandering regions that will not be affected by debris flows or floods

to build roadbed but the altitude of roadbed should be higher than total height that riverbed may reach within available years of the route.

1.4. When a route crossing over or parallels with the projects, the follows should be noticed:

1.4.1. A railway and a highway parallelly cross over debris gullies, the distance between them should be longer enough otherwise the sediments will deposit quickly (especially in the region with a gentle slope) because the highway bridge in downstream will resist water flow or the highway bridge in upstream will be destroyed by debris flow and then threaten the safety of railway roadbed.

1.4.2. When a irrigation channel passing through debris flow region, water flow penetrates and promotes development of debris flow and affect railway in downstream so we should pay attention to this kind of problems.

## 2. Determination of Altitude of Road Shoulder

Designing altitude of road shoulder relates with safety, stability, costs and available period as well as large scale constructions near the road. In a debris flow area, among the factors that influence altitude of road shoulder, there are two important ones: depositing rate and height of debris flow which should be determined after surveying and adopting several calculation methods compared each other.

### 2.1. Calculation of Deposition

The research on deposition deals with deposition time (past, present and future), position (in which part it locates), rate (developing trend of debris flows), characteristics of river (width, gradient, range of deposition). After comparing several methods, a conclusion which is as feasible as possible will be picked out.

#### 2.1.1. Calculation of Average Yearly Depth of Deposition

(1) Surveying Method:

$$H_{pj} = \Sigma h / n \quad (13-1)$$

Where  $H_{pj}$ ---average yearly depth of deposition (M.)  
 $\Sigma h$ ---total depth of deposition within given years (M.)  
 $n$ ---number of given years (investigation) (Yr.)

## (2) Analysing Method Basing on the Causes of occurrence

$$H_{pj} = H/N \quad (13-2)$$

where  $N$ --designed number of the years (Yr.)

$H$ --total depth within  $N$  years (M.)

$$H = (W - N\omega)/A ;$$

$W$ --total volume of solid materials of whole catchment which is probably provided to debris flow within designed years ( $M^3$ )

$\omega$ --estimated volume of solid materials which can be transported by water flow every year ( $M^3$ )

$A$ --area of deposition range (considering variance of alluvial fan) ( $M^2$ )

$h_{pj}$ --average yearly depth of deposition (M)

## (3) Statistical Method

After having a seriat depth values of deposition in ( $n$ ) years, average yearly depth can be calculated by using statistical method.

$$h_{pj} = \frac{\sum_{i=1}^n h_i}{n} \quad (13-3)$$

then an average depth with a frequency of  $p\%$  will be:

$$h_p = h_{pj}(\Phi_p C_V + 1) = K_p h_{pj} \quad (13-4)$$

where  $C_V$ --coefficient of variation  $C_V = \frac{1}{h_{pj}} \sqrt{\frac{\sum (h_i - h_{pj})^2}{n-1}}$

$\Phi_p$ --discrete coefficient with a frequency  $P$

$$\Phi_p = (k_p - 1)/C_V$$

$K_p$ --the ratio of deposition value with a frequency  $P$  to average value

## 2.1.2. Calculation of Accumulation Height ( $H_N$ ) Within Designed Years $N$

### (1) annual average value method

$$H_N = KN h_{pj} \quad (13-5)$$

where  $H_N$ --Accululative value within  $N$  years (M.)

$N$ --number of designed years (Yr.)

$h_{pj}$ --annual average value of deposition (M.)

$K$ --a coefficient of depositing trend determined by analysing development of debris flow, local human activities, projects and their positions comprehensively. The variable range is

0.4--1.2

## (2) Limited Value Method

Based on the investigation on a stabilized deposition slope, length, erosion reference plane and drainage level, the probable maximum deposition depth can be evaluated.

### 2.2. Calculating Altitude of Road Shoulder

#### 2.2.1. A Road Along by river in Debris Flow Area

$$H_p = H_N + h_p + 0.5 \quad (1.3-6)$$

where  $H_p$ --altitude of road shoulder within desired years  
 $H_p$ --altitude of road shoulder within designed years (M.)  
 $H_N$ --total deposition depth within designed years (M.)  
 $h_p$ --debris flow height under a designed years (M.)  
0.5--safety value  
or  $H_p = n\bar{h} + h_p + 0.5$   
where  $\bar{h}$ --average yearly deposition depth (M.)  
 $n$ --reappearance period

2.2.2. When a route crosses over debris flow gully, determination of altitude of the road shoulder depends on the altitude of the bridge.

$$H_p = H_N + h_p + C \quad (1.3-7)$$

where  $C$ --Height of front in debris flow or big stone drifting upon the flow plus a coefficient of safety. Since the value  $C$  varies with different gullies, a detailed investigation should be executed before determining it.

It is very important to choose appropriate altitude of road shoulder in debris flow area. We have had several failed lessons on the constructions of railway therefore we must pay sufficient attention to it.

Based on the experiences and lessons we have had in the struggle against debris flows over a long-term, the designing principles for roadbed should be:

3.1. The roadbed along by river in debris flow area should be protected perfectly by sound projects or diversion devices. For the river where debris flow gullies concentrates on its both sides, the principles of protection project should be: to ensure that water flow on its own direction other than changing it. When dams are required to be built, provided the flow is not squeezed and the dams are strong enough then the dams could resist the impact of debris flow from any direction; with the ascent of the riverbed gradually, the dams can be rised, too. In this way, the basement of roadbed will be

getting deeper and deeper. When spur-dikes are not favourable to variable water condition, some parts of spur-dikes are easy to be destroyed or to be inavailable by concentrated flood due to ascent of riverbed rapidly. If original river is changed, it is difficult to restrain the main course in the artificial channel, thus the channel will be silted up rapidly and the flow will go back its original channel again.

3.2. When an roadbed is far from river, a culvert should be built under it in case that water level difference between its both sides is too large due to deposition on the side by mountain.

3.3. When there is soaking water in roadbed, it should be designed according to a filterable embankment. The erosion and deposition of debris flow on both sides of the embankment must be considered simultaneously. If there is a great disparity between the water levels on both sides of the roadbed due to different deposition rates or there will be a dead pound in the side by mountain due to ascent of riverbed, the roadbed should be designed in a pattern of earth-filled dam.

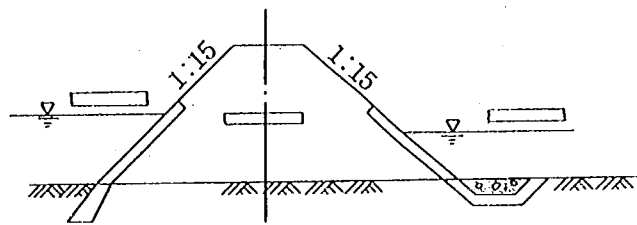


Fig. 13-7 A Map of Protection Slope of Embankment

3.4. At the end of a bridge, pear-shaped slope protection or road maintenance should be built connected to the cone-body of the bridge in order to avoid collapse of both ends of bridge and also to make it possible to let train pass through during the period when the broken bridge is being repaired.

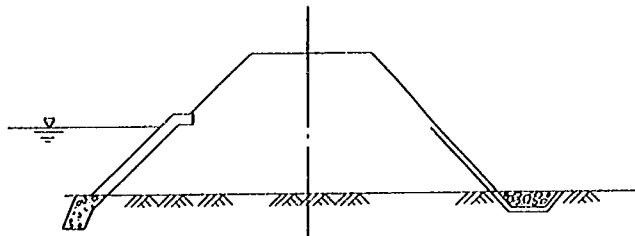


Fig. 13-8 A Map of Strengthening Slope Protection by a Pear-shaped Embankment

(It should be built in a length of 10-15 meters and in a width of 4 meters wide turning into normal width of roadbed gradually)

3.5. The local filterable soil should be used as stuff materials for embankment. If there is no filterable soil, the viscous soil also can be used. Among them it will be the best to use clay as stuff materials.

3.6. Picking up soil for embankment must avoid digging too deep or in the direction along by river; Picking up stone materials from riverbed must avoid fining the grade of sediments, otherwise it will promote erosion effect and affect the safety of basement of construction.

3.7. Most sideslopes in debris flow area are unstable and rock layers are broken resulting from weathering therefore the cutting must be protected with slurry pavement. When a cutting crossing over a small debris gully, the best way is to build a aqueduct to transport debris flow instead of new conduit on the top of cutting.

3.8. The area of cross-section of drainage dike should be enlarged properly and do not change its original flowing direction.

3.9. In debris flow region, bridges should be used as far as possible but conduit. The bridge must have enough span and height as well as protective projects both on the upstream and downstream in case that sediments from debris flow deposit under the bridge or on the main channel and threaten the safety of roadbed.

3.10. The opened channel or tunnel also should be longer enough to prevent damages from debris flow rushing into and destroying roadbed both sides.

### Paragraph 3 Hydrographical Calculation of Debris Flow

#### 1. Calculation of Velocity

##### 1.1. Formula for Dilute Debris Flow

##### 1.1.1. The Present Formula in Southwest of China

$$V_c = \frac{M_c}{a} \cdot R_c^{2/3} \cdot I^{1/2} \quad (13-8)$$

where  $V_c$ --average sectional velocity (m./sec)

$R_c$ --hydraulic mean depth (m.)

$a$ --coefficient of resistance,  $a=[\psi \cdot \gamma_H + 1]^{1/2}$

$\psi$ --correction coefficient of debris flow

$$\psi = (\gamma_c - 1) / (\gamma_H - \gamma_c) \quad (13-9)$$

$M_c$ --roughness coefficient of the gully bed (see Tab. 13-2);

$\gamma_c$ --volumetric weight of debris flow, 1.0-2.3 (T/M<sup>3</sup>)

$\gamma_H$ --special gravity of solid material from debris flow, which is usually 2.4-2.7 (T/M<sup>3</sup>).

For simplifying the calculation, the values of  $a$ ,  $\psi$

can be obtained directly from the Tab. 13-3 after

having had values of  $\gamma_c$ ,  $\gamma_H$ .

$I$ --gradient of the gully or water surface level

##### 1.1.2. The Present Formulae in Northwest of China

$$V_c = \frac{M_0}{a} \cdot R_c^{2/3} \cdot I^{3/5} \quad (13-9)$$

where  $M_0$ --when the roughness with the features of debris flow have not be considered, The First Institute of Railway Ministry recommended to use  $M_0=15.5$  based on the results of statistics;

1.1.3. For the turbulent debris flow in mountain or semi-mountainous regions, some foreign researcher in abroad suggested to use the formula as follow based on the kinetic energy balance under a constant velocity.

$$V_c = \frac{M_0}{a} \cdot R_c^{2/3} \cdot I^{1/4} \quad (13-10)$$

where  $M_0$ --roughness coefficient of gully bed in mountainous region ( $M_0=6.5$ ).

Table 13-2 Roughness Coefficients of Gully Bed

|   | characteristics of the gully                                                                                                                                                                                               | $M_0$         |         | gradien          |
|---|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------|---------|------------------|
|   |                                                                                                                                                                                                                            | extreme       | average |                  |
| 1 | There are many unmovable rhomboid stones piled up on the gully bed and the channel is obstructed by trees. There are no aquatic plants. The gully bed leads fall away downstream in a step-shaped with a great roughness.  | 3.9<br>~ 4.9  | 4.5     | 0.375<br>~ 0.174 |
| 2 | There are various size of stones on the gully blocked by trees and vegetations. The river-bed is not flat and leads fall away towards downstream in a step-shaped.                                                         | 4.5<br>~ 7.9  | 5.5     | 0.199<br>~ 0.067 |
| 3 | Debris flows are not so active but they will encounter a great resistance when flowing. The gullybed is consist of gravels and pebbles obstructed by bushes severely.                                                      | 5.4<br>~ 7.0  | 8.8     | 0.220<br>~ 0.112 |
| 4 | In the middle or downstream, the gullybed is made of smooth rocks and there exist some water falls along by the gully. At the expansive reach the branches and sediments deposits temporarily and no aquatic plants there. | 7.7<br>~ 10   | 12.9    | 0.090<br>~ 0.022 |
| 5 | A gullybed located in mountain or semi-mountain area is made of some small movable gravels and pebbles. The flowing channel with a gentle slope is hardly to be blocked and there are grasses and bushes beside it.        | 9.8<br>~ 17.5 | 12.9    | 0.090<br>~ 0.022 |

## 1.2. Calculation Formulae of Viscouse Debris Flows

## 1.2.1. The Empirical Formula in Guxiang Gully in Tibet

$$V_0 = \frac{1}{n} R_c^{3/4} \cdot I^{1/2},$$

(13-11)

where  $K_1$ --ratio of average velocity ( $V_{pj}$ ) to intermediate velocity ( $V_0$ )  
of debris flow surface

$$K_1 = V_{pj}/V_0 = 0.6$$

$K_2$ --distribution coefficient of velocity in vertical direction,

$$K_2 = 0.77$$

$V_0$ --intermediant velocity of the surface (m/s)

$$V_0 = 1/n \times R_c^{3/4} \times I^{1/2}$$

$n$ --roughness coefficient = 0.45

$R_c$ --hydraulic radius of debris flow (m)

$I$ --surface gradient of debris flow (‰)

$V_c$ --velocity of debris flow (m/s)

the construct list of values of  $\gamma_c$  and  $\alpha$

Table 13-3 The Contrast List of Values of  $\gamma_c$  and  $\alpha$

| $\gamma_H$ | $\gamma_c$<br>$\psi \cdot \alpha$ | 1.0 | 1.1   | 1.2   | 1.3   | 1.4   | 1.5   | 1.6   | 1.7   | 1.8   | 1.9  | 2.0  | 2.1  | 2.2  | 2.3  |
|------------|-----------------------------------|-----|-------|-------|-------|-------|-------|-------|-------|-------|------|------|------|------|------|
|            |                                   | 0   | 1.0   | 1.0   | 1.0   | 1.0   | 1.0   | 1.0   | 1.0   | 1.0   | 1.0  | 1.0  | 1.0  | 1.0  | 1.0  |
| 2.4        | $\psi$                            | 0   | 0.077 | 0.167 | 0.272 | 0.400 | 0.556 | 0.750 | 1.00  | 1.33  | 1.80 | 2.50 | 3.67 | 6.00 | 13.0 |
|            | $\alpha$                          | 1.0 | 1.09  | 1.18  | 1.29  | 1.40  | 1.53  | 1.67  | 1.84  | 2.05  | 2.31 | 2.64 | 3.31 | 3.92 | 5.68 |
| 2.5        | $\psi$                            | 0   | 0.071 | 0.154 | 0.250 | 0.364 | 0.500 | 0.667 | 0.875 | 1.14  | 1.50 | 2.00 | 2.75 | 4.00 | 6.50 |
|            | $\alpha$                          | 1.0 | 1.08  | 1.18  | 1.28  | 1.38  | 1.50  | 1.63  | 1.79  | 1.96  | 2.18 | 2.45 | 2.81 | 3.32 | 4.15 |
| 2.6        | $\psi$                            | 0   | 0.067 | 0.143 | 0.231 | 0.333 | 0.454 | 0.600 | 0.778 | 1.00  | 1.28 | 1.67 | 2.20 | 3.00 | 4.33 |
|            | $\alpha$                          | 1.0 | 1.08  | 1.17  | 1.26  | 1.37  | 1.48  | 1.60  | 1.74  | 1.90  | 2.08 | 2.31 | 2.55 | 2.96 | 3.50 |
| 2.7        | $\psi$                            | 0   | 0.063 | 0.133 | 0.214 | 0.308 | 0.416 | 0.545 | 0.700 | 0.890 | 1.12 | 1.43 | 1.83 | 2.40 | 3.25 |
|            | $\alpha$                          | 1.0 | 1.08  | 1.17  | 1.26  | 1.35  | 1.46  | 1.57  | 1.70  | 1.84  | 2.01 | 2.21 | 2.44 | 2.74 | 3.13 |

### 1.2.2. Experimental formula of Флейшман С. М.,

$$V_c = V_B(1 - a) \quad (13-12)$$

where  $a = 0.09 \sqrt{n_c - n_0} + b(\gamma_c - 1)$

$$b = \text{tg}(3n_c)^\circ$$

$$V_c = V_B[1 - 0.09 \sqrt{n_c - n_0} + \text{tg}(3n_c)^\circ \cdot (\gamma_c - 1)]$$

$V_c$ --velocity of debris flow

$V_B$ --velocity of water flow which can be obtained from the formula (13-10)

$n_c$ --estimated effective viscosity (poise), from practical value of the

Table 13-4

$n_0$ --the minimum viscosity of a viscose debris flow=3 (poise)

$\gamma_c$ --volumetric weight of debris flow (t/m<sup>3</sup>)

Table 13-4 The Contrast List of Consistency and Effective Viscosity of Debris Flow

| property of soil on sideslope | light sandy clay | clay and heavy clay | powder and sandy clay | powder and sandy clay | clay         |
|-------------------------------|------------------|---------------------|-----------------------|-----------------------|--------------|
| consistency                   | thick slurry     | dilute mud          | thick slurry          | dilute mud            | thick slurry |
| effective viscosity           | 3 ~ 8            | 3 ~ 8               | 9 ~ 12                | 12 ~ 25               | 10 ~ 20      |

### 1.2.3. Mo's Formula

$$V_c = K_c \sqrt{gh(i - i_0)} \quad (13-13)$$

where  $V_c$ --velocity of debris flow

$K_c$ --the maximum losing parameter of energy under a given discharge, which relates to relative roughness ( $e$ ) of solid materials in debris flow.

$$K_c = \frac{2}{\sqrt{3 \cdot e}} \sqrt{\frac{(1 - e)^2}{1 - \frac{e}{2}}}$$

$e$ --the ratio of mean diameter of sediments to depth of debris flow

$$e = D_u / h$$

$g$ --acceleration of gravity

$i$ --longitudinal gradient of the gully

$i_0$ --the minimum gradient while a debris flow starting to move it is about 0.05-0.06

When the formulae mentioned above are to be used, what is the best to do is to calculate velocities by using all of them and then to chose the most satisfactory results.

## 2. Calculation of Discharge of Debris Flow

### 2.1. Investigative Method of Morphology

$$Q_c = W_c * V_c \quad (13-14)$$

where  $Q_c$ --discharge of debris flow (M<sup>3</sup>/s)  
 $W_c$ --cross-sectional area of debris flow calculated from the highest level of flood based on the investigation. (m<sup>2</sup>)  
 $V_c$ --velocity determined by the formula according to the type of debris flow

### 2.2. Ration Method

According to the proportion of water and solid materials, a probable flood discharge with a designed standard plussing the volume of solid material will be the discharge of debris flow.

$$Q_c = Q_B(1 + P) \quad (13-15)$$

where  $P$ --correction coefficient of debris flow considering the natural moisture content of the earth

$$P = \frac{\frac{\gamma_c - 1}{\gamma_H(1 + W)} - \gamma_c}{\frac{W\gamma_H}{W\gamma_H + 1} + 1}$$

$W$ --natural moisture content of soil

$Q_B$ --discharge of water flow (m<sup>3</sup>/s)

This formula is available for estimating discharge of debris flow in the northwest in China.

### 2.3. Correction Method by Discharge of Flood and Precipitation

#### 2.3.1 Empirical Formula in Dongchuan District

$$Q_c = Q_B(1 + \phi)D_u \quad (13-16)$$

where  $D_u$ --choking coefficient to debris flow

It has been verified by using 40 data within 7 years in Dongchuan district, the values of  $D_u$  vary from 1.0 to 3.0 and are directly proportional to the duration of choke and are inversely proportional

to the scale of debris flow

$$D_u = 0.87t^{0.24} \quad D_u = 5.8/Q^{0.21}$$

When determining the choking coefficient, we must take a consideration of the various facts comprehensively and concretely. The values of choking coefficient can also be obtained from the following table while  $D_u$  varies within 1.0-3.0.

where  $\phi$ --correction coefficient of sediment  $= \frac{\gamma_C - 1}{\gamma_H - \gamma_C}$ ,

$\gamma_C$ --volumetric weight of slurry obtained from the test

$Q_C, Q_B$ --have the same meanings as above

List of observed choking coefficients

| choke degree | the most serious | serious   | general   | feeble    |
|--------------|------------------|-----------|-----------|-----------|
| $D_u$        | 2.6 ~ 3.0        | 2.0 ~ 2.5 | 1.5 ~ 1.9 | 1.0 ~ 1.4 |

#### 2.3.2. Stocks's Formula (1960)

$$Q_C = Q_B \frac{(1 + \phi)^{7/6}}{(\phi \gamma_H + 1)^{1/4}} \cdot D_u \quad (13-17)$$

#### 2.3.3. Hao's Formula

$$Q_C = Q_B \cdot a \cdot D_u = Q_B \left[ \frac{P}{\gamma_H(100 - P)} + 1 \right] \cdot D_u \quad (13-18)$$

where  $P$ --the percentage of solid materials in weight

#### 2.3.4. La's Formula

$$Q_C = Q_B \cdot e^{0.3 \left( \frac{\gamma_H}{\gamma_B} - 1 \right)} \cdot D_u \quad (13-19)$$

where  $e$ --napierian logarithm  $e=2.718$

$\gamma_B$ --specific gravity of water

Among the formulae mentioned above, formulae 2,3,4 from foreign countries have been used in 25 gullies located in Dongchuan, Xichang and Xining. The result from the Stocks's is closed to that of Dongchuan and conform to reality. The results from La's formula are always larger than observed values but results of Hao's vary from -14.4% to 23.2% compared with actual situation. At present, research and knowledge on inherent laws of debris flow have not been fulfilled,

we have not a perfect method to calculate velocity and discharge of debris flow. When these formulae being used, the investigation and survey must be carried out carefully and then chose the formula and coefficient correctly to get a satisfactory result by comparing various calculation methods.

### 3. Calculation of Erosion Rate and Storage of Collapse Soil

#### 3.1. Erosion Rate of Soil

See Table 13-5 (large scale collapses are excluded).

Table 13-5 Erosion Rate of Soil

| erosion degree | erosion rate (m/Yr.) |
|----------------|----------------------|
| feeble         | 0.02 ~ 0.05          |
| medium         | 0.06 ~ 0.15          |
| serious        | 0.16 ~ 0.30          |

#### 3.2. Calculation of Storage

$$W = V \times F \quad (13-20)$$

where  $W$ --total supply in a year ( $m^3$ )  
 $V$ --erosion rate ( $m/Yr.$ )  
 $F$ --collapse area ( $m^2$ )

If erosion rate is changeable, the storage should be calculated by weighed average.

#### 3.3. Analysis and Collation of the Data

Based on the results from investigation, the drawing and tables concerned should be finished (geology and hydrology) as the basis of adopting counter-measures.

## Paragraph 4 Countermeasures of Debris Flows

The occurrence and development of debris flow are affected by various causes, among them, one of the most important reasons is that natural vegetation were destroyed. Generally speaking, the developing process from the beginning stage, active stage to extinction of debris flow will take up decades or more than hundred years. Because scales of debris flows are usually large, the construction against debris flow must be large enough too. If we want to recover vegetation, it will take a long time up to get a visible efficiency. So we should adopt a comprehensive measure to control debris flow. For example, we can recover vegetation to decrease the frequency of occurrence of debris flow and meanwhile protective works should be built so as to strengthen the constructions against damage power of debris flow.

### 1. Countermeasures of Preventing From Occurrence of Debris Flow

#### 1.1. Conservation Measures of Soil and Water

##### 1.1.1. Forestation

To restrict access to hillslopes to facilitate forestation both at hill-slope and watershed as well as at terraced fields, ravines, alluvion. In this way not only the forests will be prevented but turfs will have a chance to grow well. The tree roots and turfs are of an ability to prevent cultivated land from erosion and mitigate affection of weathering force exerting on rock layers beneath soil layer. Since it will take up a long time to grow up for trees and turfs, at the beginning stage of construction, appropriate projects should be built as well as recovering forest in case that constructions are destroyed by debris flow in the coming few years.

##### 1.1.2. Sorts of Plants

Based on the results of investigation, the plants with deep roots, exuberant foliage and drought-enduring should be chosen. In order to protect turfs, it is necessary to intercrop bushes and arbors. The sorts of arbors used in most cases are: elm, silk tree, oriental oak, Yunnan pine, birch-leaf pear and so on; the sorts of bushes are: false indigo, shrub lespedza and so on.

### 1.2. Technological Measures of Farming and Animal Husbandry

The projects in fields are: catch puddle, intercept ditch, etc. the forms of cultivation are: crop rotation, intercropping, interplanting, mixplanting, cross plough, ridge plough, suspending plough, horizontal protective furrow etc. Measures in animal husbandry are: putting pastureland to rational use,

restricting access to hillslope to facilitate grasses and so on.

### 1.3. Engineering Measures of Conservation of Soil and Water

1.3.1. For the purpose of harnessing water flow of surface and underground to dry soil and stabilize hillslope, we can set up following works: slope water catchditch, storage channel, fish-scale and so on.

1.3.2. The projects to stabilize hillslope involve protecting head of ditch, slope flood diversion, check stones adjusting flood-peak and sediment desposition. If debris flow results from landslide or snow avalanche at most cases, appropriate supporting structures must be adopted.

## 2. Constructions of Transportation, Guidance, Obstruction and Blocking for Debris Flow

A debris flow out of outlet should be tackled first in a comprehensive method by using projects mentioned above. Among them, the major method is guidance.

### 2.1. Drainage Dike of Debris Flow

A drainage dike is a popular construction to drain debris flow, that designing method is different from a common construction for water flow even for flood. Considering the features and sorts of debris flows, an illustration is given individually as follow.

#### 2.1.1. A Plane Arrangement of Drainage Dike

A debris flow, especially a viscous one, has a strong ultra-high ability in bend of gully as well as an ability of climb up. It can dash against original bank and flow in a new straight way. It is also easy to be blocked and stopped. There are usually two cases for a viscous debris flow as follow when it rushes through a bend of gully.

(1) When the velocity of a debris flow on concave bank is faster than that on convex bank, the concave bank will be eroded and sediments will deposit on opposite bank as shown on Fig. 13-9.

(2) When front part of debris flow is resisted by concave bank, the rear part is unable to surpass it and its flowing direction will have to change. The sediments deposit on concave bank while the convex bank will be eroded as shown on Fig. 13-10.

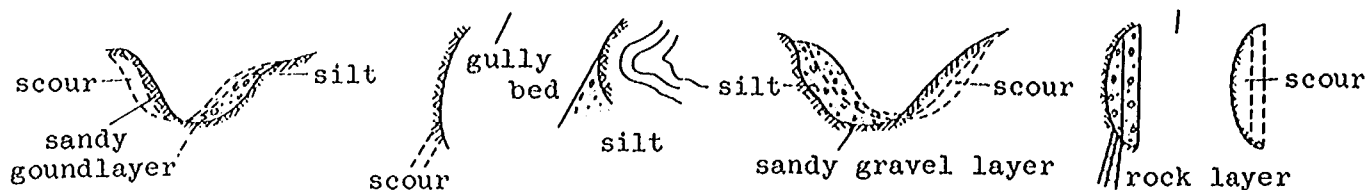


Fig. 13-9, 10 Movement Situation of Viscous Debris Flow in Bend

In order to prevent drainage dikes from erosion, deposition, over flow or rupture it they should be built in curve by a reason of topograph. Their radium of curve should be 8 ~10 times the width of drainage dike bottom for non-viscous debris flows and 20 times for viscous ones.

The outlet of drainage dike should connect with a river in an acute angle of less than 45 in order to ensure that river can transport all the sediments from drainage dikes.

2.1.2. At the confluence part with river, elevation of drainage dike should higher than that of water level with the same frequency, at least, it should be higher than that of flood level with a frequency 0.05. Otherwise sediments will deposit in drainage dike due to withstanding effect of river. When a drainage dike connects with a bridge opening, its cross-sectional area should be coincident with that of opening so that the cone of the bridge and drainage dike will become a entirety. Under the opening of bridge, the sectional area of drainage dike must avoid contracting or expanding abruptly in case that sediments deposit under bridge or drainage dike bottom is eroded.

### 2.1.3. Longitudinal Gradient of Drainage Dike

For determining a gradient of drainage dike reasonably, the best method is to observe natural gully or artificial channel and then find a suitable value. The following table is recommended by Lanzhou Institute of Glaciology and Cryopedology, Chinese Academy of Sciences.

Table 13-6 The Values of Gradients for Artificial Drainage Dike

|             | volumetric weight(ton./m <sup>3</sup> ) | composition      | the minimum gradient(%) |
|-------------|-----------------------------------------|------------------|-------------------------|
| non-viscous | 1.3 ~ 1.4                               | mud, debris flow | 2.5, 3.5                |
|             | 1.4 ~ 1.5                               | mud, debris flow | 3.0, 4.0                |
|             | 1.5 ~ 1.6                               | mud, debris flow | 3.5, 4.5                |
| viscous     | 1.6 ~ 1.8                               | debris flow      | 5 ~ 7                   |
|             | 1.8 ~ 2.2                               | debris flow      | 8 ~ 15                  |

When designing gradient based on the investigated results, we should pay attention to following items.

(1) A designed gradient should accord with the gradient of alluvial fan and keep a value from upper to downstream. If it is unavoidable to change the gradient of drainage dike due to restriction of landform, it must be changed gradually and gently.

(2) If a gradient of alluvial fan is too flat to meet the need of designed value, we can construct a check dam to stop debris flow or supply it with water in order to transport sediments under a small gradient.

(3) As a gradient of alluvial fan is larger than that of designed value, a significant problem is how to prevent the works from erosion. This kind of problem usually can be solved by deepening the foundation of protective embankment or thickening protective bottom as well as constructing ribbed panel structure to prevent drainage dike from erosion. The designed gradient recommended in Table 13-6 are only suitable to some limited situations, when the variation of erosion and deposition is not serious enough to threaten safety to drainage dike. Since even though in the same basin, various kinds of debris flows are probable to abrupt and their discharges, flowing pattern and volumetric weight are always changeable, when designing a gradient of drainage dike we must take a consideration of all the situations mentioned above.

#### 2.1.4. Setting Depth of Drainage Dike Basement

Debris flow is not only of a rapid deposition property but also of a strong erosion function. A debris flow can erode gully bed one or three meters, some times even six meters. When designing a setting depth of protection slope basement, erosion affection must be considered, especially on concave bank. There are many elements that influence erosion. In most cases, we use the data of investigation and observation as the basis of calculation. Here we suggest following formula as a reference for calculating the setting depth of non-viscous debris flow.

$$h_p = \frac{0.19q}{\sqrt{d_{pi} \left(\frac{H}{d_{pi}}\right)^{1/6}}} \quad (13-21)$$

where  $h_p$ --erosion depth after a debris flow (m)  
 $q$ --discharge in unit width ( $m^3/s$ )  
 $d_{pi}$ --mean diameter of sediments (m)  
 $H$ --original depth (m)

In concave bank, next formula was recommended by Lanzhou Institute of Glaciology and Cryopedology.

$$h_p = \frac{0.17q}{\sqrt{d_{pi}} \left(\frac{H}{d_{pi}}\right)^{1/6}} \quad (13-22)$$

#### 2.1.5. Excessed Height in Drainage Dike

A debris flow moves down with a great inertia due to its high volumetric weight so the excessed height on outside is much higher than that of a common water flow. The excessed height should be obtained from investigation and visition, also the formula as below can be used

$$\Delta h = \frac{2.3V_c^2}{g} \cdot \lg \frac{R_s}{R_i} \quad (13-23)$$

where  $\Delta h$ --excessed height in outside of a bed (m)

$V_c$ --velocity of a debris flow (m/sec.)

$g$ --acceleration of gravity (m/sec<sup>2</sup>)

$R_s, R_i$ --radius of curvature of concave ( $R_s$ ) and convex ( $R_i$ ) (m)

#### 2.1.6. The Section Shapes of Drainage Dikes

The four shapes of drainage dikes as shown on Fig. 13-11.

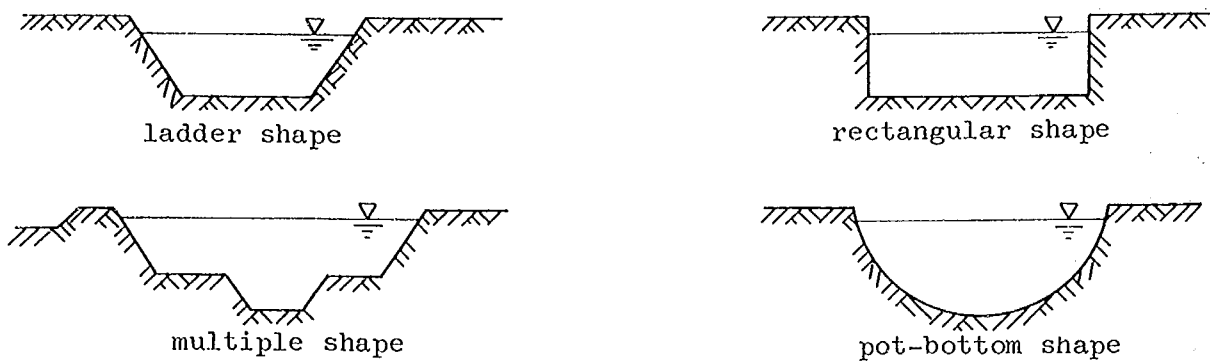


Fig. 13-11 Cross Sectional Shapes of Drainage Dikes

Choosing the shapes of drainage dikes should base on the landform of location where debris flow will pass through, the requirement of projects and the structure of drainage dike itself. The trapezoidal shape (ladder shape) and rectangular shape usually are used when a drainage dike is not to be built along by original gully bed and the discharge of debris flow is not so large. While multiple shape and pot-bottom shape are used when the project is to be built along by original gully bed and discharges large enough.

#### 2.1.7. The Cross-Sectional Size of Drainage Dike

After having had a designed discharge ( $Q_c$ ), gradient ( $i$ ), volumetric weight of debris flow and specific gravity of sediments, the depth ( $h_c$ ) can be found

out according to cross sectional shape and width ( $B$ ). All the parameters of drainage dike should confirmed to following formula.

$$Q_c = W_c * V_c \quad (13-23)$$

where  $Q_c$ --designed discharge yo of l ( $m^3/sec.$ )

$W_c$ --sectional area ( $m^2$ )

$V$ --velocity of debris flow ( $m/sec.$ )

The optimum combination of width ( $B$ ) and depth is that a designed value equals to the value of  $B/h_c$  of natural stable gully bed approximately, at least the designed value of  $B/h_c$  should be less than 5 ~ 7.

#### 2.1.8. The Depth of Drainage Dike

For a stainght channel:  $h = h_c + h_1$  (13-24)

For a bend of gully  $h = h_c + h_1 + \Delta h$  (13-25)

where  $h$ --depth of drainage dike (m)

$h_c$ --designed depth of debris flow (m)

$h_1$ --protection height, 0.2 ~ 0.5 (m)

$\Delta h$ --excessed height in the bend (m)

Besides using formula, a revising discharge method is also a way to determine depth of drainage dike. For example, if a frequency of designed discharge is 0.01, considering the significance of engineering project, a presumed discharge with a frequency of 0.05 or 0.0033 can be used to modify the desined depth of drainage dike.

#### 2.1.9. Shapes and Sizes of Drainage Dike

Both sides of a drainage dike usually are made in three kinds of shapes, protection slope, retaining wall and embankment. Protection slope and retaining wall are adopted when a drainage dike has to be built by excavation while embankment is used when fill is necessary. The stable protection slope and rational cross sectional size depend on indexes of physical dynamics of earth. Because there a lot of sediments and gravels in fluid, a debris flow is of a stronger tractive force and erosion ability than common water flow or flood, the protection slope and embankment made of earth must be strengthened by paving their bottoms. But if the bottom is too wide, the pavement will cost a lot, following method can be used to prevent basement of drainage dike from erosion. To deepen depth of paving basement and to construct ribbed panel structures in order to remain a certain gradient and to keep a entirety of drainage dike.

The bottom of ribbed panel should link up with the side walls of drainage dike and the elevations of the top of ribbed and gully bed should be the same. The interval between ribbed panels usually is 8 ~ 15 meters or determined by the

formula as follow:

where  $L$ --interval (m)  
 $i$ --longitudinal gradient of drainage dike  
 $H$ -- whole height of ribbed panel (m)  
 $\Delta H$ --safety value 0.3~0.5, see Fig. A-A section on Fig. 13-12. (m)

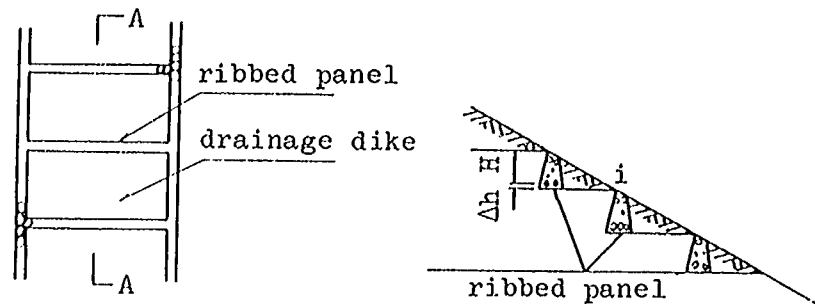


Fig. 13-12 Drainage Dike

The thickness of ribbed panel is 0.5-0.6 meter, only when  $i > 5\%$ , the ribbed panel is necessary.

#### 2.1.10. Other Measures for Transporting Debris Flow

The following structures are adopted when drainage dikes cross over a railway.

##### (1) Aqueduct for Debris Flow

For a small scale gully where solid sediments and discharge of debris flow are limited, an aqueduct can be considered if the topographical condition is favourable to transporting debris flow. The discharge that an aqueduct can transport is less than  $30 \text{ m}^3/\text{sec}$ . There are two patterns of structures, open and covered. Aqueduct is always steeper with 8~15 in grade.

##### (2) Rapid stream channel

This kind of construction forces a debris flow to move rapidly by contracting cross sectional area and increasing gradient in case that debris flow deposits or block up at bridge opening. In order to prevent rapid stream channel from erosion, it should be paved smoothly and have dados at connection parts. The shape of its cross section usually are trapezoid, rectangle, multiple shape, triangle and so on. Among them, the multiple shape and triangle shape are favourable to transportation of debris flow. A rapid stream channel should have a proper width and uniform gradient for draining water flow. The minimum gradient will be determined based on the non-depositing gradient of natural debris flow gully as shown as on Fig. 13-13. On this figure, the curves of  $V = f(Q)$  of natural gully and rapid stream channel should be drawn down and we

must ensure that the velocity of rapid stream channel is larger than that of natural non-deposition gully. A rapid stream channel should be built as straight as possible. If it is inevitable, the outside must higher due to effect of rushed height and rising phenomenon.

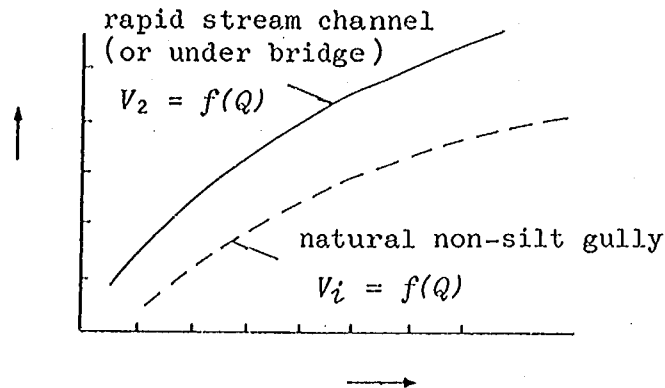


Fig. 13-13 Curve of  $V = f(Q)$

### (3) Facilities of transporting sediments by supplying water

If it is possible, we can use the water from neighbouring gully to dilute debris flow in drainage dike, aqueduct or rapid stream channel and enable debris flow move well to prevent from blocking up.

### 2.2. Diversion DiKE

Diversion dike usually locates in alluvial fan or the place where the roadbed or railway project are threatened by debris flow in order to ensure the safety or roadbed or constructions by draining solid materials. Its height is a sum of deposition thickness within available years and depth of debris flow. When a diversion dike is influenced by deposition, the height can be added by stages in the coming years.

We can use the following formula to calculate the top elevation of a diversion dike.

$$H_p = h_p + \Delta X + C \quad (13-26)$$

where  $H_p$ --top elevation of diversion dike (m)

$h_p$ --deposition thickness within designed year plus designed level (m)

$\Delta X$ --height of congested water (m)

$C$ --safety value, 0.5 in upstream; 0.25 in downstream

In a curve or in a place where debris flow is probably blocked up, the rushed height and excessed height must be added. The rushed height can be get from the results of investigation or from following formula:

where  $\Delta H$  -- raised height

(m)

$V_0$  -- velocity of debris flow

(m/sec)

$\alpha$  -- angle between gully bed and flowing direction

Setting basement depth of diversion dike is similar to that of drainage dike mentioned above and its cross sectional size can be calculated according to the dynamics indexes of earth.

### 2.3. Detention Measures

Detention project means to construct a series of lower dams called check dam through which debris flow will overflow. It has three functions:

- (1) to stop and store sediments for reducing the scale of debris flow
  - (2) to fix sideslope and gully bed to preventing them from erosion and collapse
  - (3) to ease off gradient in order to reduce the velocity of debris flow.
- Generally, in a small scale gully where there is not water flow in ordinary time,  $i = i_0 \times 3/4$  or  $i = i_0$ ; but for a gully where water flows all the year,  $i = i_0 \times 1/2$ . The back-deposition gradient ( $i$ ) is usually less than that of original gully bed.

2.3.1. There is a typical check dam on Fig. 13-14, which is the most popular one with a good efficiency and is suited to any kind of debris flow.

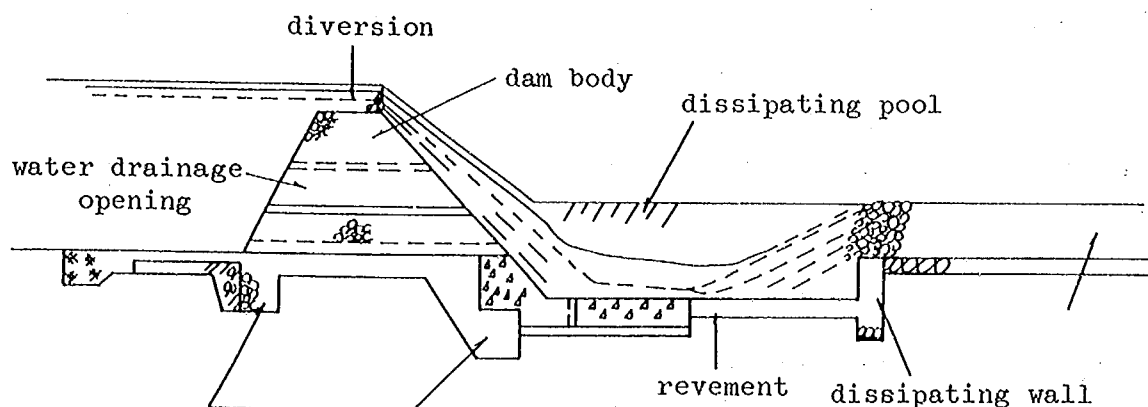


Fig. 13-14 A Typical Check Dam

- (1) Dam body is a major structure to obstruct sediments and its stability depends on the weight itself so the foundational condition must be sound enough.
- (2) There are two tooth-like wall penetrated into the basement to prevent dam body from slip.
- (3) The fluid of water or slurry flow through the drainage opening

- (4) Revement bed prevents the foot of dam from scour
- (5) Dissipating wall can mitigate the kinetic energy of debris flow or big stones by making a pool under the dam.
- (6) Construction named Haiman will prevent the bottom of dam from scour after a debris flow passed the dissipating wall.
- (7) Diversion wall protect the banks of gully.

### 2.3.2. Structural Materials for Check Dams

In debris flow area, there always exists some problem in communications. What is the best to do is to choose local materials to build stone check dam, concrete check dam, stone and timber dam, earth dams, stone gabion check dams and so on. When setting up a revetment bed or a project named Haiman, the stone gabion is the most appropriate one. It is semi-permanent project with a good entirety and stability because it will be submerged soon after finished. Furthermore the construction of it takes up much shorter time and costs less than a common chip stone dam.

### 2.3.3. Height of Dam and Intervals between Dams

The larger the height of dam, the shorter the interval between dams and vice versa. So that the values of them depends on the economic and technological conditions. In most cases, the height of a check dam is lower than 5 meters and the height of the dam in upstream should lower than that in downstream. The relationship between them is shown on Fig. 13-15.

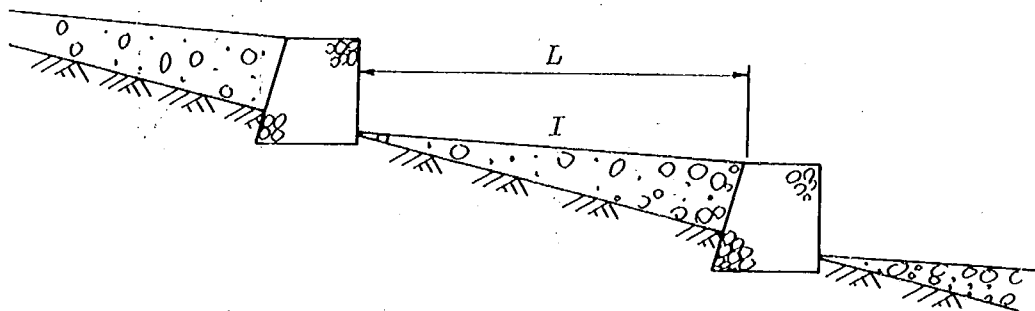


Fig. 13-15 Intervals of Check Dams

$$L = \frac{H}{I_0 - I}$$

where  $L$ --interval between dams (m)

$H$ --height of a check dam (m)

$I_0$ --gradient of original gully bed

$I$ --back-deposition gradient

The relationship between interval and amount of check dams is given in the formula as below.

$$N = D/L$$

where  $N$ --total numbers of dams

$D$ --total length of the gully where dams are to be built (m)

$L$ --interval between dams (m)

In the gullies where the reappearance period of debris flows is rather longer and the deposits are few every year, the check dams can be considered to be set up and to be raised by stages in the coming years.

2.3.4. Choosing the position of check dam must conform to local landform so we should do in site and in the order from upstream to downstream. The check dam should locates near waterfall where gradient is relative gentle. The distance between last dam and roadbed should be designed based on the features of gully and on the whole length from mountain foot to roadbed. It usually is three times the length of the dam.

#### 2.3.5. Design of Cross Section of Check Dam

First of all, hydraulic calculation of spillway when a debris flow passing through should be done for determining the sizes and patterns of components of dam. The structural calculation depends on the stress distribution on every part of the dam.

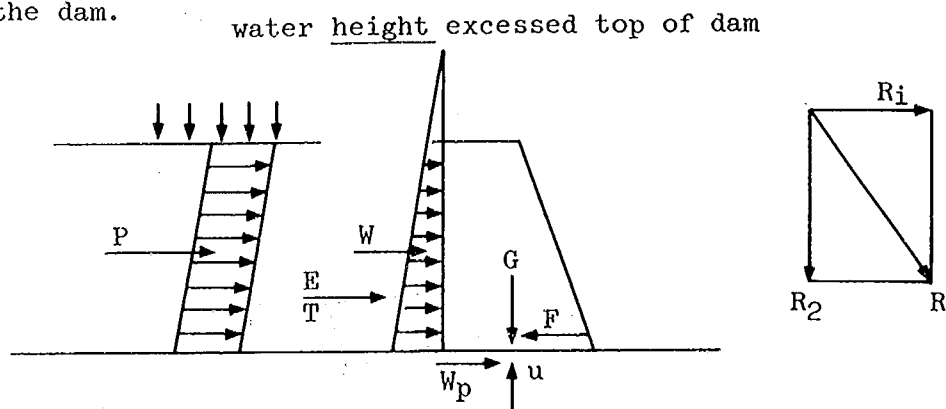


Fig. 13-16 Load Distribution of a Check Dam

#### (1) Load Distribution Their Calculation

##### ① Load distribution of dam

$P$ --excessed load deposited on the dam accidentally

$E$ --pressure of earth

$T$ --impact force of debris flow

$W$ --water pressure under the highest level

$w_p$ --permeation pressure on basement  $w$

$F$ --friction on the bottom of basement

$u$ --buoyancy of water

$G$ --weight of dam body

$R_1$ --join force in horizontal direction,

$$R_1 = P + E + W - F ;$$

$R_2$ --join force in vertical direction,

$$R_2 = G - u .$$

In addition the influence of earthquake, permeation pressure on dam, and impact force of debris flow exerted on dam should be considered.

## ② Earth pressure of deposits

When elevations of deposits and top of dam are the same, earth pressure  $E$  can be represented in next formula

$$E = \frac{1}{2} \gamma_c \cdot H^2 \tan^2 \left( 45^\circ - \frac{\phi}{2} \right) \quad (13-28)$$

where  $\gamma_c$ --volumetric weight

$H$ --height of dam or deposits

$\phi$ --internal friction angle, if  $\phi = 0$ ,  $E = \frac{1}{2} \gamma_c \cdot H^2$

The pressure of earth at  $Z$  point

$$E_2 = \frac{1}{2} \gamma_c \cdot Z^2 \tan^2 \left( 45^\circ - \frac{\phi}{2} \right) \quad (13-29)$$

if  $\phi = 0$ ,  $E_2 = \frac{1}{2} \gamma_c \cdot Z^2$

When a debris flow reaches the top of dam

$$E = \frac{1}{2} \gamma_c [(y + H + a)^2 - (y + a)^2] = \frac{1}{2} \gamma_c [H^2 + 2(y + a)H] \quad (t) \quad (13-30)$$

where  $H$ --height of dam

$y$ --excessing height over dam top, if using a unit length in

calculation  $y = q/V_c$

$q$ --discharge in unit width

$V_c$ --velocity of debris flow

$g$ --acceleration of gravity

$a$ --kinetic height of water flow,  $a = V_c^2/2g$

When the height of debris flow is lower than that of dam, it is able to flow over the top of dam due to effect of kinetic energy. Then

$$E = \frac{\gamma_c q^2}{gh} + \frac{\gamma_c h^2}{2} - \frac{\gamma_c q \cos \theta}{g} \sqrt{\frac{q^2}{h^2} - 2g(H-h)} \quad (13-31)$$

where  $h$ --depth of debris flow

$\theta$ --angle of sideslope in upstream of dam

## ③ Static pressure of water

$$W = \frac{1}{2} \gamma_1 H^2 / \cos \theta \quad (t) \quad (13-32)$$

④ Permeation pressure on the basement

$$M = \frac{1}{2} \alpha \gamma_1 B h (t) \quad (13-33)$$

where  $\alpha$ --area coefficient of touching basement,  $\alpha=0.8$

$\gamma_1$ --volumetric weight of water

$B$ --bottom width of dam

$h$ --deposition depth at the front of dam

⑤ Impact force of debris flow

$$T = \frac{\gamma_c}{g} v^2 \sin^2 \beta \quad (13-34)$$

where  $T$ --impact force of debris flow

$\beta$ --angle between the force direction and the plane on which the force exerts

When  $\beta = 90^\circ$ , then  $T = \frac{\gamma_c}{g} v^2$

(2) Calculation of stability

After getting all the loads mentioned above, working apex of join force can be calculated and stability of dam will be tested according to the requirement of retaining wall.

4. Interception Measures

4.1. Retaining Dam

Retaining dam is made in each gully, which can retain the vasy majority of sediments from debris flow and drain the water flow. Under a favourable condition, this kind of dam is efficiency for decrepit debris flow gullies, unfortunately, it has not been applied widely.

4.2. Parking Works

When a route cross over rear part of an alluvial fan and it is far from river which can transport sediments, a parking work should be built in the place between outlet of debris flow gully and route. Diversion dike and obstructive dam lead debris flow into parking works depositing there and they can also let water flows out through bridge opening. The parking works is only used in the basin where the amount of storage of sediments is limited.

5. Practical Experiences in Engineering Works Against Debris Flows

5.1. Several Common Dams

(1) Clip stone dam

The dam on Fig. 13-17 is a check dam made of slurry chip stones that has a simple structure and a good stability.

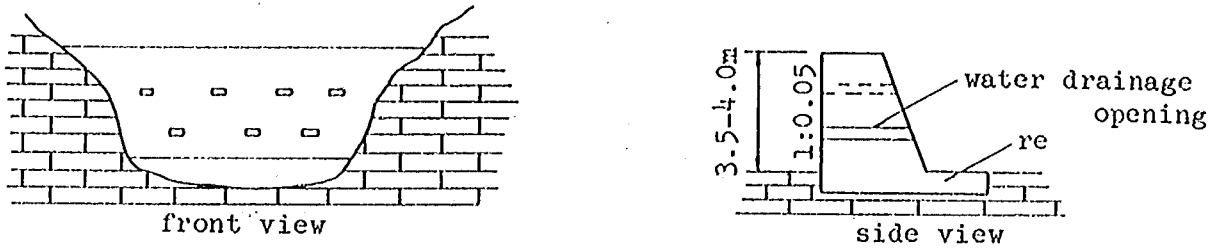


Fig. 13-17 Slurry Clip Stone Dam

The dam on Fig. 13-18 is a slurry lump stone dam that is easy to be built and is of a good efficiency to reduce potential energy of debris flow.

A step-shape dam on Fig. 13-19 is made of chip stone that has been widely used in middle souther of China.

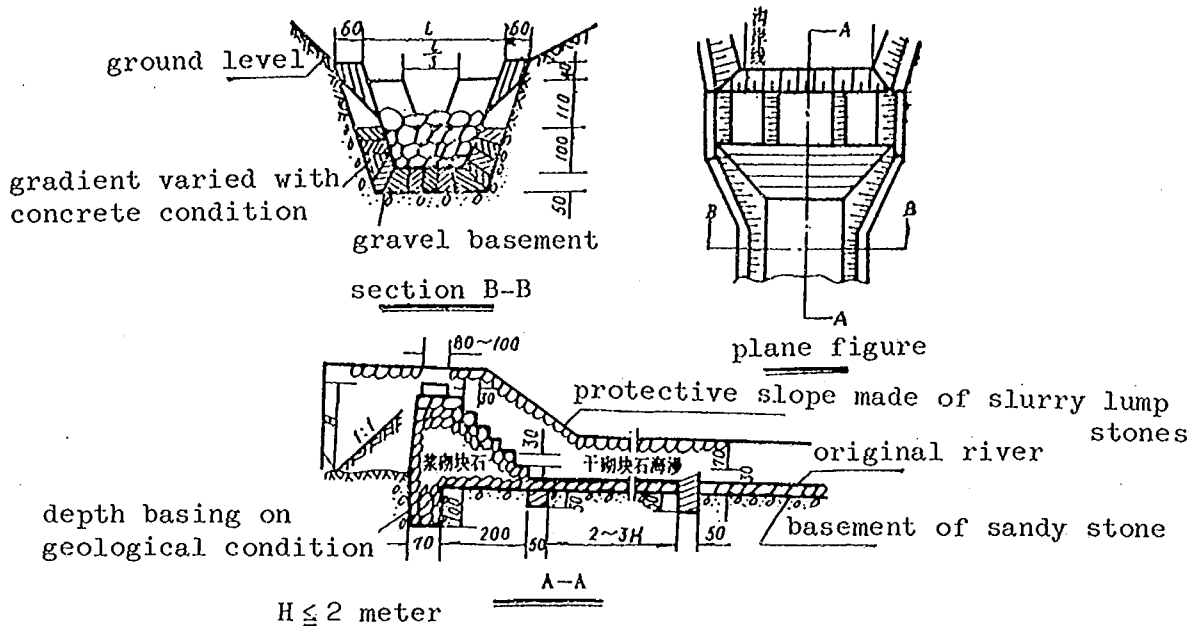


Fig. 13-18 Step-shaped Dam Made of Slurry Lump Stones

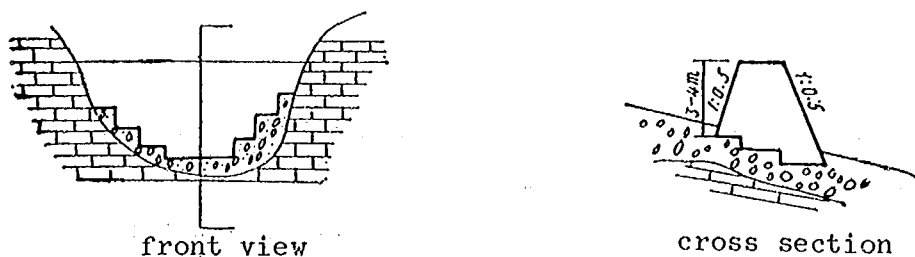


Fig. 13-19 Chip Stone Dam

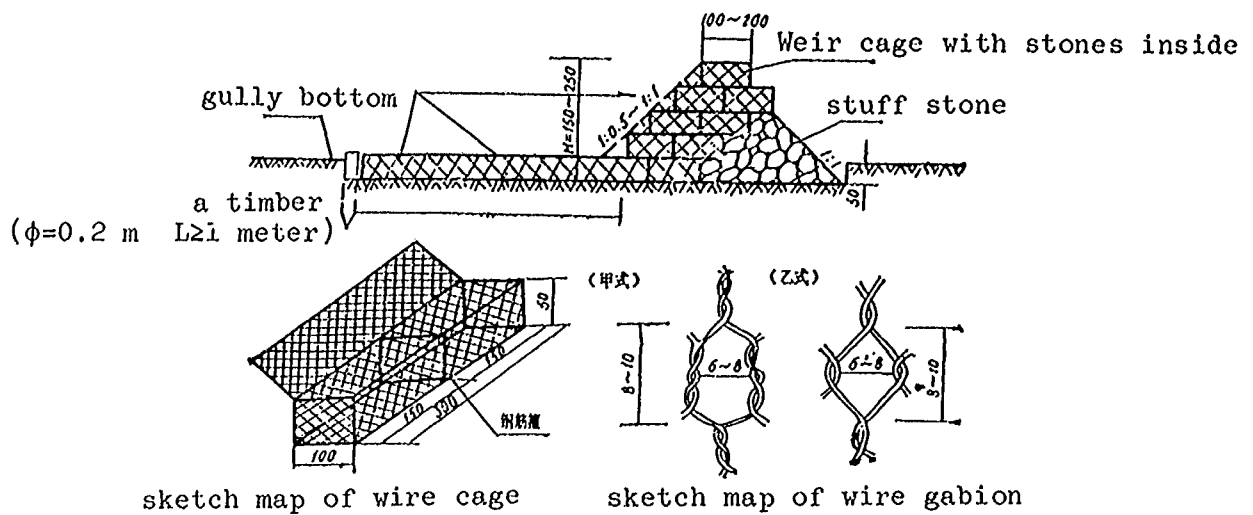


Fig. 13-20 Stone Gabion Dam

(2) The check dam made of gabions with stones inside

This kind of dam is applicable to small or middle scale debris flow gullies. It is of many advantages in construction, expenses time limit for a project and so on, consequently it is widely used in southwest area of China. If we want to decrease the costs further, we can use bamboo cage instead of iron wire's but the available period will be shorter and it does not have a good entirety.

(3) Check dam of plant branches

This kind of dam is most suitable for a small basin with soil gullybed and a gentle slope where velocity of debris flow is generally slow, head difference of water is less than 1.5 meter. It is a temporary dam and are usually two patterns: raling and willow twig. Fig. 13-21 shows a common woven wicker check dam.

(4) Chequered dam

A frame made of steel bars or concrete can obstruct and storage sediments and forming a natural dam. It also mitigate the influence of impact force of debris flow and reduce 30%~40% of constructive materials than a solid dam. It is suitable for mountainous region where communications condution is very poor.

Chequeral dams have following shapes: triangular frame, cross-rhombic

shape, and narrow-crack dam. Fig. 13-22 shows a dam that was built in north slope of Mt. Huashan in Shaanxi province of China. The chequered apertures depend on the sizes of sediments. Some foriegn scientists suggested that the aperture of frame should be satisfied to the formula of  $d=(1.3 \sim 1.4)D_{5\%}$  (where  $D_{5\%}$  means that the grain diameter taking up 5% of whole weight is  $D$  or larger than  $D$ ). The aperture of a narrow crack dam is equal or less than  $D_{5\%}$ .

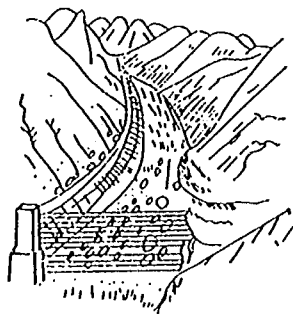


Fig. 13-22 A Sketch Map of Chequered Dam

## 5.2. Comprehensive Utilization of Drainage and Obstruction Measures

A comprehensive utilization of various countermeasures will obtain much more efficient results as shown as Fig. 13-23. A dicersion dike connects with outlet of mountain. An obstructive dam with a height of 2-4 meters was made at main gully (a steel rail dam also can be used in a dilute debris flow gully with large stones). Following obstructive dam, a rapid stream channel was built to let debris flow pass through railway bridge. If a diversion dike connects with a rapid stream channel directly without a obstructive dam, the diversion dike must be gentle in order to reduce height of water congestion well. We must ensure that debris flow has a fast enough speed to prevent it from erosion in congestion area. The angle of  $\alpha$  on Fig. 13-24 should be less than  $10^\circ$  in grade and the gradient of gully bed should remain the same value.

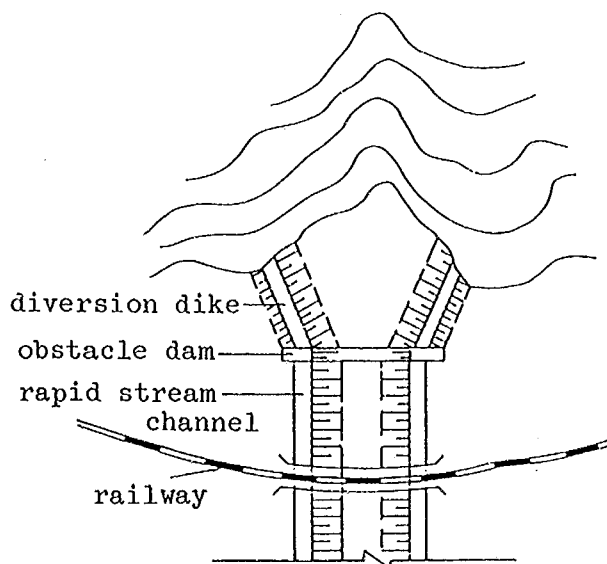


Fig. 13-23

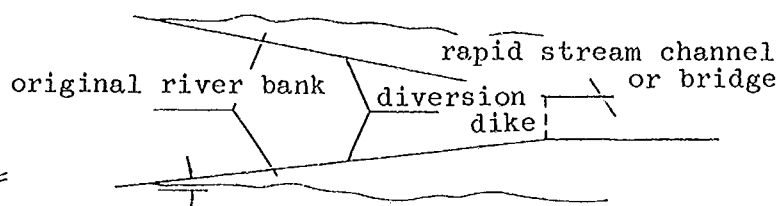


Fig. 13-24

### 5.3. A Practical Example of Realignment of Large Scale Debris Flow Gully in China

The gully named Heisha locates in southwest of China. The span of railway is three kilometers and on its downstream, there are many villages and croplands. By adopting a comprehensive treatment, a very good result had been obtained as shown as Fig. 13-25.

- (1) At upreach, water and soil were conserved to facilitate forestation and cultivation of grasses as well as some necessary projects.
  - ① There are 15 obstructive dams which surface are protected by gabions; 12 litter check dams made of chip stones, 500 meter long prevention slope and a pitch water channel with a length of 239 meters in this gully.
  - ② There are two obstructive dams in a branch gully named Maidi.
  - ③ There is a obstructive dam in a branch gully named Madu.
- (2) The main purpose of projects in area of outlet of mountain is to transport debris flow. The bridges are built for each little branch gullies.
  - ① Two diversion dikes are built at north and south parts of alluvial fan to make flood or small scale debris flow empty into river through bridge openings.
  - ② At up part of diversion dike, a separation levee is built to enable a extreme flood pass through the bridge named Zhaojia. A alterative bridge also is built between the bridges of Jinzhong and Zhaojia.
  - ③ In order to reduce water level and make debris flow deposit at belt zone of the basin, a fish-shape dam and two belt dams are set up there.
- (3) There is a reservoir at the upreach to control input of runoff and development tendency of debris flow.

The Designing Manual of Railway  
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in which the planning principles and methods of  
railway roadbed in debris flow area are given.

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