5.地震与冰雪型滑坡及堰塞湖

Avalaches and Damming Induced by Earthquake and Snowmelt



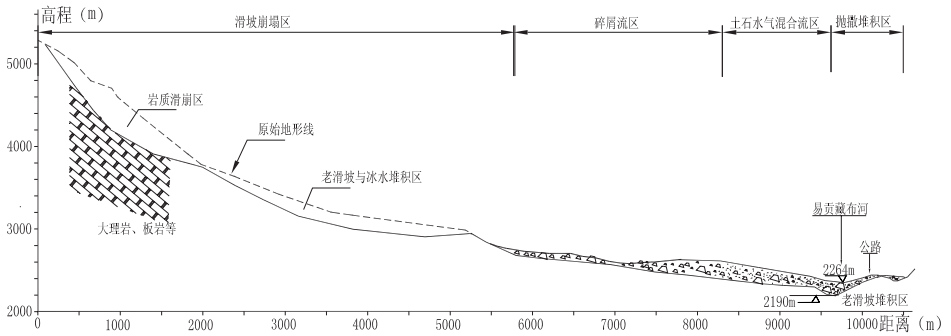
AVALACHES AND DAMMING INDUCED
BY EARTHQUAKE AND SNOWMELT
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西藏波密易贡高速巨型滑坡

The Gigantic Yigong Avalanche of the Bomi, Tibet



易贡滑坡远眺 (雪山为滑坡物源区)
Overview of the Yigong avalanche, Bomi, Tibet

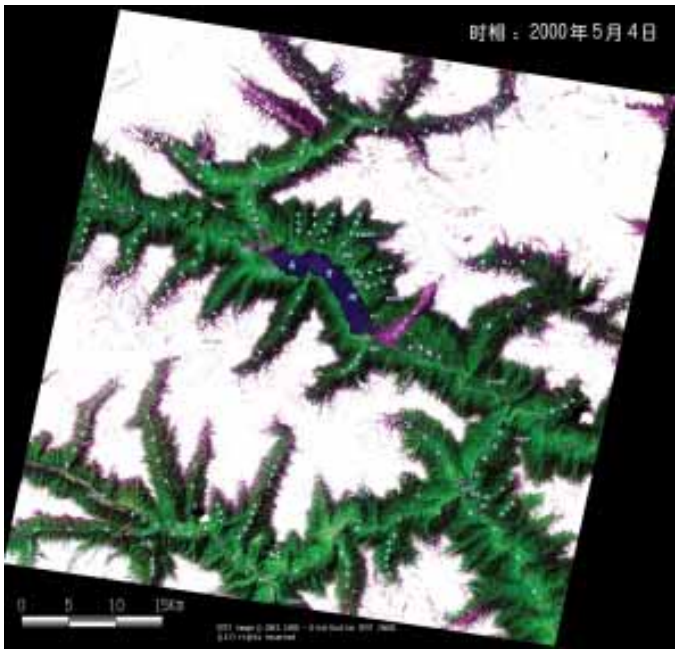


滑坡发生于2000年4月9日，从5500m左右的雪山上，沿陡倾岩层呈楔型高速下滑，历时约10分钟，滑程约8km，高差约3330m，截断了易贡藏布河（河床高程2190m），形成长约2500m、宽约2500m的滑坡堆积体。其面积约5km^2，最厚达100m，平均厚60m，体积约2.8亿～3.0亿m^3。滑坡形成堰塞湖，湖水水位持续上涨62天，最大水深62m，湖水面积50km^2，拦蓄水量约30亿m^3。

滑坡溃决后，几个小时之内下游河水水位陡涨四五十米，河水流量最大时达到12.4万m^3/s。下游局部河段相继发生了山体崩塌滑坡等衍生地质灾害，河道断面形状由“V”型改造为“U”型河槽。

The gigantic avalanche occurred on April 9, 2000, lasting 10 minutes and moved at a high velocity for 10 km. The 280-300 million m^3 avalanche began at an elevation of 5500 m and accumulated at an elevation of 3330 m. It has a length of 2500 m, a width of 2500 m and a thickness of 60-100 m.

A dammed lake of 3 billion m^3 and a depth of 62 m was formed. The water rose for 62 days after which the dam burst inducing enormous landslides and the flooding of the Great Gorge of the Yarlung Zangbo River, which rose rapidly by as much as 40-50 m. The avalanche transfomed the cross section of the Yarlung Zangbo valley from V to U shape, creating a maximum flow of 124 thousand m^3/s.



滑坡发生后 SPOT 遥感影像 (堵江形成堰塞湖)
Remote sensing image showing the Yigong avalanche,Tibet



滑坡溃坝后2000年6月14日SPOT遥感影像 (堰塞湖被泄干, 引发下游多处滑坡)
Remote sensing image showing the secondary slides and falls induced by dam bursting



滑坡从 5500 多米的高山上滑出, 滑床呈楔形
Avalanche started at an elevation of 5500 m. Wedge-shaped source zone



滑坡堆积于易贡藏布江中, 形成堰塞湖。茶场和数十个村庄被淹
Tea field and tens of villages were submerged after damming by the avalanche



滑坡坝体厚达 100m
Avalanche dam with a thickness of 100 m



滑坡体从5500多米的高山上坠落, 将冲沟原有的堆积物弹射铲出, 沟谷仅存少量后期屑流堆积

About 100 million m^3 of source material was suddenly launched down the valley, which lost almost all its pre-landslide deposits



滑坡堆积体上后期被折回和抛入高空的混合体覆盖, 形成土丘林

Mixed materials of the accumulation lobe-from bottom up; rocks and boulders, fine materials, and some materials that went to the opposite valley side, eventally flowing back to finally develop a “cone and pinnacle” soil structure on the surface



滑坡体包含大量风化和碰撞形成的土体, 极易形成土流
Accumulation of weathered and crushed rock, and soil that is prone to flow



100 年前的老滑坡体上树林上部被整齐截断
Trees on an ancient landslide over 100 years old were cut off by the fast-flow avalanche



老滑坡体上的巨树被拦腰斩断
Huge tree was cut by avalanche



滑坡体中的花岗岩块石
Granite blocks in the accumulation zone



滑坡体后期形成塌陷坑
Collapse in the water-bearing accumulation zone



滑坡体富含水汽, 后期形成气孔
Gas holes in the water-bearing accumulation zone



滑坡体富含水汽, 后期形成漩涡
Whirlpool is formed by internal erosion in the water-bearing accumulation zone



2000 年 6 月 10 日滑坡溃坝后残留的滑坡体远景
Overview of the accumulation after dam bursting on June 10, 2000



滑坡溃坝前下游 318 国道的通麦大桥
The Tongmai Bridge on the national highway 318 before dam bursting



滑坡溃坝后下游 318 国道通麦大桥被毁后的简易桥
The Tongmai Bridge destroyed after dam bursting. A temporary bridge was constructed



2000 年 6 月 10 日滑坡溃坝后易贡藏布河恢复正常
The Yigong Zangbo River returned to normal after dam bursting



2000 年 6 月 10 日滑坡溃坝后残留的滑坡体
Remaining materials after dam bursting showing the deposit thickness and structure



2000 年 6 月 10 日滑坡溃坝后残留的叠置巨石
Boulders after dam bursting



滑坡溃坝后残留的扎木弄沟滑坡堆积体
Avalanche track and residual lobe

(本版照片由程谦恭提供)

阿尼玛卿山现代冰川西缘冰崩碎屑流*

Glacial Debris Flow in Anemaqen, Qinghai Province



冰崩碎屑流形成滑坡坝
Overview of glacial debris flow and dammed river

冰崩碎屑流于2004年1月发生在阿尼玛卿山玛卿岗日现代冰川西缘、海拔约5900m的支沟。呈扇形，东西长3400m，南北宽1530m，面积2.4km^2，平均厚度10m，体积约2400万m^3，将支沟完全堵塞。主河道内形成宽约200m、顺河长1530m、高约30m、体积约560万m^{3}的堤坝，海拔4335m。堆积体由冰块和岩石碎屑物混合组成，其中冰块含量占70%～80%。冰块融化严重，形成大小不等的陷坑、融洞、暗沟、暗河、沉陷裂缝。坝体于2005年7月溃决。

It occurred near the modern Maqen Gangri glacier in Anemaqen, Qinghai Province in January of 2004. The fan-shaped debris flow started at elevation 5900 m. It stretched for a length of 3400 m, a width of 1530 m, a thickness of 10 m and a volume of 24 million m^3. The river was dammed with 5.6 million m^3 of material. The accumulation lobe is made of ice (70%-80%), rock and soil. Debris flow was triggered by snowmelt as the snow line had retreated 200m within 30 years. Collapses, caves, fractures and ground rivers were widely distributed in the accumulation lobe, and the dam bursted in July, 2005.



冰崩碎屑流形成堰塞湖全景
Dammed lake caused by glacial debris

* 本滑坡照片由李长辉、刘红星提供



堆积物为富冰冻土。冰雪含量达 70%～80%
Ice-rich frozen accumulation lobe.The content of ice is 70%-80% of the total



堤坝上的冰裂缝, 库水极易渗漏
Ice cracks in the dam which is prone to seeping



由冰块和岩石碎屑物混合组成, 冰块含量占 70%～80%, 岩石碎屑物含量占 20%～30%
The lobe was made up of ice, rock and soil. The content of ice is 70%-80% of the total, the content of other materials is 20%-30%



冰裂缝长 60～80m, 宽 0.2～1.2m, 一般深 1～2m, 最深可达 3m
Ice cracks in the accumulation lobe with a length of 60-80 m, a width of 0.2-1.2 m and a depth of 3 m



滑坡坝溃决口
Dam breaking up



青龙沟堰塞湖的溃后残湖剩余 3000m³ 水体
Residual water (3000 m³) after dam bursting



溃坝洪痕及被洪水冲毁的桥梁引道
Mark created by dam bursting and bridge destroyed by flooding



监测组不顾安危强渡溃坝余洪前往坝区查险
Geologists carried out the site investigation regardless of personal danger

四川叠溪地震滑坡

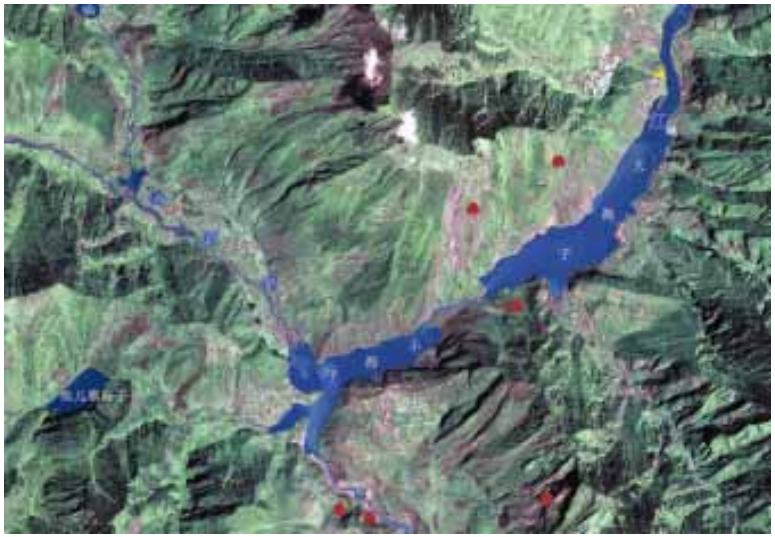
Diexi Earthquake-triggered Landslide, Sichuan Province



叠溪地震滑坡形成堰塞湖 (镜头朝北, 岷江上游)
Dammed lake due to 1933 Diexi earthquake

1933 年 8 月 25 日 15 时 50 分，四川茂县叠溪发生 7.5 级地震。诱发了一系列不同规模的崩塌、滑坡、碎屑流，致使岷江及其支流十几处被堵塞，造成了巨大灾害，至今还保存系列堰塞湖（当地称海子）。岷江干流上的大海子最大水深近 100m，蓄水容量 7000 多万 m^3。小海子最大水深 70m，蓄水容量 4500 多万 m^3。地震引发的山体崩塌使千年叠溪古镇毁于一旦，500 余人丧生。同年 10 月 9 日，处在大、小海子下游的叠溪海子堰塞坝溃决，使断流一个多月的岷江突发洪水，冲毁下游两岸农舍田地，造成约 2500 人丧生，洪水到达灌县时，仍高出正常水位 12m。

The Ms=7.5 earthquake occurred in Diexi Town, in the upper Minjiang River, Sichuan Province on Angust 25, 1933. Enormous rockfalls, landslides and debris flows were triggered and dammed tens of main and branch rivers. The remaining dammed lakes were named “ Haizi ” (lakes). Dahaizi was the largest one of the dammed lakes of the Minjiang River with a depth of 100m and a volume of 70 million m^3. Xiaohaizi was the second one, with a depth of 70 m and a volume of 45 million m^3. The earthquake created rockfall buried the 1000 years old town of Diexi, and killed 500 people. Forty five days later, on October 9, the Dahaizi and Xiaohaizi dams burst and caused flooding and temporary daming of the Minjiang River. The number of lives lost was about 2500.





叠溪地震引发山体崩滑, 滑坡堵江形成大海子 (镜头向南西, 岷江下游)。大海子堰塞坝由银屏崖和观音崖两山崩塌体构成, 坝高约 70m, 湖面长约 13km, 最宽处近 2km, 库容约 7000 万 m^3

The rockfall created by the 1933 earthquake (Ms=7.5) dammed the Minjiang River. The Dahaizi, 70 million m^3 in volume, was formed by a 70 m high landslide dam



叠溪地震引发山体滑坡堵江形成大海子 (镜头向北西, 岷江上游)

The 1933 Diexi earthquake (Ms=7.5) induced rockfalls that created landslide dams and formed two lakes



崩滑体后部山体 (镜头向西北)

The scarp of the rockfall



叠溪古滑坡前缘滑坡堵江形成小海子, 后期被人工疏通 (镜头向南东, 岷江下游)
In 1993, the front of 1933 landslide was reactivated and fell and dammed the Minjiang River; the resultant “Xiaohaizi” has been dredged now



叠溪古滑坡前缘滑坡堵塞岷江, 对岸发生山体崩塌 (镜头向西北, 岷江上游)
The ancient Diexi landslide and the reactivated front in 1993

小海子位于岷江干流与松平沟、鱼儿寨两支流的汇合处，堰塞坝位于校场滑坡前缘堵江体、演变至今为一高约 100m、长约 3km 的天然溢洪道，库容约 4500 万 m^3。

The Xiaohaizi (small lake) is at the confluence of the Minjiang River and other two branches. A natural spillway with a length of 3 km and a height of 100 m has developed on the down stream side of the landslide dam.



蚕陵山地震断层和拉裂槽, 表层发生崩塌
The Chalingshan seismic fault and tension crack. Rockfall on the surface



叠溪地区地质构造复杂, 岩体遭强烈挤压, 形成劈理密集带
In the region, the geologic tectonic condition is very complex and the rockmass is crushed and fractured



叠溪老县城及附近平台由巨厚堆积物构成。右岸龙池山古滑坡床保留完整
Landforms consist of huge thick avalache and river deposit. Opposite the ruined town, the landslide bed is clear.



湖相沉积发生柔皱及被新构造切割
Lake deposit are folded and fractured that indicates the new tectonic activity



多期湖相沉积及被新构造切割
Multiple lake deposit that indicates frequently damming by landslide



被滑坡摧毁后残留的叠溪古城门
Ruined casstle and gate of the ancient Diexi Town



叠溪地震滑坡堵塞岷江形成小海子堰塞湖, 西岸为古滑坡残体 (镜头朝北西, 岷江上游)
The Xiaohaizi lake dammed due to earthquake-induced landslide. The remnant on the west shore is residual landslide that was pushed up the opposite side



叠溪古滑坡前缘滑动堵塞岷江形成小海子堰塞湖, 西岸为古滑坡残体 (镜头朝南东, 岷江下游)
The ancient landslide front fell and dammed the Minjiang River where the Xiaohaizi (small lake) had been formed. Left side body is the remnant



校场至叠溪古滑坡平台上被湖相沉积黄土覆盖
The ancient landslide platform is covered with lake deposit loess

叠溪古城建在古滑坡堆积台阶上，历史记载地震前有房屋278所，居民500余人。地震引发后部山体崩滑，古城被埋于乱石之中，只有15人生还，造成古城毁灭性灾害。

Before 1933, the ancient Diexi Town was located on an ancient landslide terrace.The town was buried due to the 1933 earthquake-triggered rockfall, which killed 500 people, only 15 escaped.



团结村台地的湖相沉积泥岩, 上部为基座阶地覆盖
Silt layer showing lake deposit in the lake that was created by the landslide dam



团结村台地泥岩地震滑坡
Earthquake-triggered landslide made up of ancient lake deposit



叠溪下游的巨型滑坡, 前缘被岷江水淘刷, 稳定性差, 局部解体, 发生特大洪水时会形成堵江灾害 (镜头向南东)
View of large scale landslide in the lower Minjiang River, 50 km down stream from the Diexi lake, showing the river erosion and some sliding. During the wet season, reactivation of the landslide could create a flooding hazard

重庆黔江小南海地震滑坡

Xiaonanhai Earthquake-triggered Landslide in Qianjiang, Chongqing



小南海地震滑坡全貌
Overview of the Xiaonanhai (Smal South Sea) Earthquake-triggered landslide



小南海地震滑坡坝及堰塞湖
Xiaonanhai (Smal South Sea) Earthquake-triggered landslide dam and lake



小南海地震滑坡形成堰塞湖
Landslide dam due to 1856 Qianjiang earthquake (Ms=6¼)

滑坡简介

滑坡坝体长1170m，宽1500m，高50～70m，体积约2400万m^3，为1856年黔江6¼级地震(烈度Ⅷ度)诱发，原岩为志留系中统页岩及粉砂岩，分布三组方向分别为N40E、N30W、N70W的构造节理，岩体分离性好，结构松散。形成的堰塞湖——小南海，湖面长约5000m，最宽达900m，湖面面积约3km^2，水深约30m，最大蓄水量6700万m^3。现今已作为黔江城的供水水源。

A landslide dam with a length of 1170 m,a width of 1500 m and a height of 50-70 m was formed due to the1856 Qianjiang earthquake (Ms=6¼). The landslide, 24 million m^3 in volume is made of Silurian shale and sandstone, fractured with 3 groups of joints. The dammed lake is 5000 m long , 900 m wide and 30 m deep and has a volume of 67 million m^3; it has been used for water-supply to the town of Qianjiang County.



滑坡原岩被多组节理和劈理切割, 形成密集带
Dense jointing exposed on a face of the parent rock



滑坡母岩为志留系砂岩和页岩互层, 节理和劈理发育
Interbedded sandstone and shale in the parent material; the exposure exhibits well developed joints normal to the face



滑坡后部堆积体, 稳定性差, 后缘壁现今时有崩塌发生
Some fall and slides occur occasionally in the crown and at the accumulation lobe



滑坡体巨石峭立江中
Large block standing up in the lake



滑坡堆积于河道中, 形成堰塞湖
Lake dammed by accumulation lobe of interbedded sandstone and shale



地震滑坡被评为国家地质公园
The landslide and dammed lake have been selected as a National Geo-park



滑坡堆积体由片状砂岩和页岩构成
Landslide is made up of Silurian sandstone and shale



滑坡体巨石达数百立方米
The huge landslide block is over several hundred cubic metres



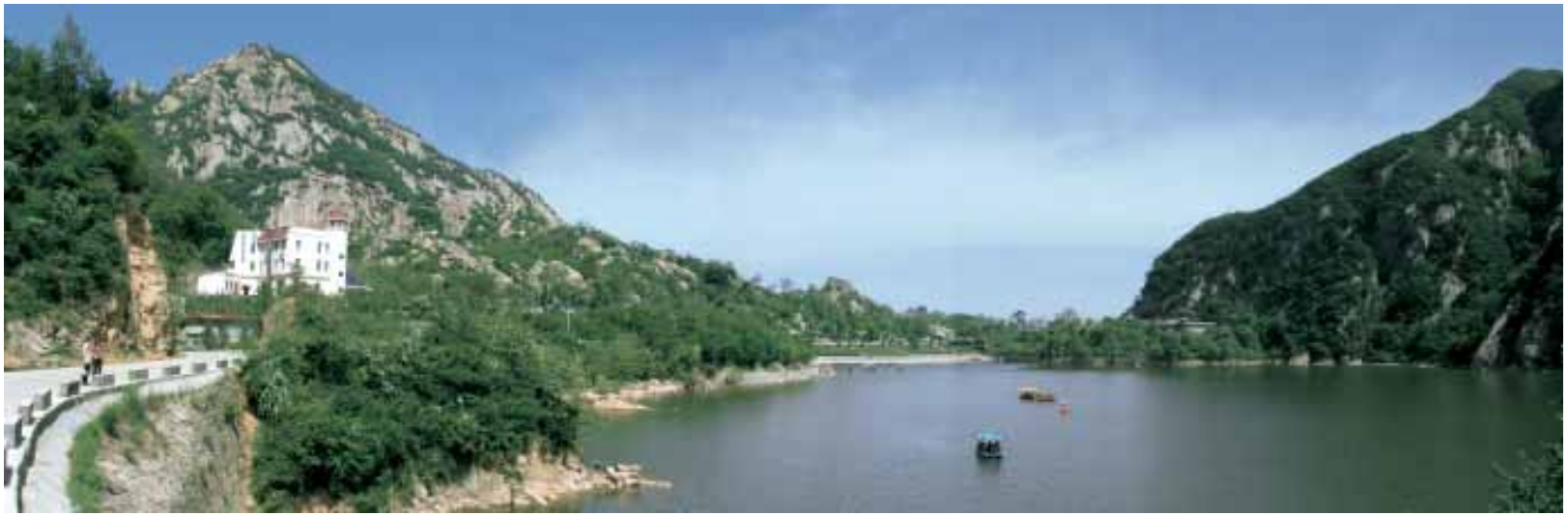
滑坡堆积体由板状岩体构成
Landslide is made up of slab material



滑坡堆积体稳定性良好
The vegetation and flowers cover the gentle morphology indicating inactivity

陕西西安翠华山崩塌及堰塞湖

Cuihuashan Rockfall and Dammed Lake of Xi'an, Shaanxi Province



翠华山崩塌长约 2500m，宽约 1000m，体积约 3.5 亿 m^3。原岩为印支期中粗粒二长花岗岩，发育 6 组构造节理，有共轭 X 型节理体系产出，将岩体切成菱形及棋盘格式形状，其中存在 3 组低角度顺坡节理，卸荷作用强烈，张开性好。地震是主要诱因。据史书记载，公元前 780 年(周幽王二年)，陕西关中地区发生大地震，有“ 三川(泾、渭、洛)皆震,三川竭、岐山崩 ”之现象的描述，推断由该次地震作用诱发翠华山山崩。崩塌具有多期性。

This rockfall has a length of 2500 m long, a width of 1000 m and a volume of 350 million m^3, and is made up of Mesozoic medium-coarse monzonitic granite. The rockmass is isolated into rhombic or checker-board patterns by six sets of joints. According to the historic record, in 780 B.C., a strong earthquake occurred in the Guanzhong zone of Shaanxi Province. It is inferred that rockfalls were triggered by this earthquake and more rockfalls have occurred repeatedly.



岩体中发育大型顺坡卸荷节理
Large exfoliation (sheeting) joints in the granite rockmass almost parallel to the slope surface



节理规模巨大, 展开性好, 将大型岩体切割分离
Rockmass is cut by large wide open joints. The extensive vegetation cover indicates a long period of inactivity



顺坡陡倾的节理密集带发育, 在坡脚岩体风化强烈
Dense exfoliation joints with dip-slope attitude, strongly weathered at the bottom



崩塌堆积块石巨大, 形成架空结构
Accumulation of large blocks forms talus deposit



巨石崩塌后解体
Large block from the rockfall has broken into several fragments



崩塌巨石最大长 100m, 宽 50m, 高 20m, 体积 1 万 m^3
The largest of the block is 100 m long, 50 m high and 20 m wide, and has a volume of 10 000 m^3



崩塌堆积形成堰塞湖
Dammed lake due to rockfall accumulation



崩塌体堆积概貌
General view of stable rockfall accumulation.The long inactivity is evidenced by dense vegetation

陕西华县莲花寺高速远程滑坡

High-speed, Long Run-out Lianhuasi Landslide, Huaxian County, Shaanxi Province



莲花寺滑坡后缘 2 级圈椅状地貌和后部滑坡残体 (新鲜面为现今采石场)
Remnant of the granite gneiss landslide. Two steps with chair-shaped morphology and residual accumulation of the Lianhuasi landslide (fresh face is a quarry)



后部滑坡残体花岗岩片麻岩成碎块状 (新鲜面为采石场) Remnants of broken granite gneiss in the landslide material (fresh face is a quarry)

发生于 1072 年 11 月 3 日, 即宋熙宁五年地震($5^{1}/_{2}$ 级)，后缘高程约 1200m，剪出口高程约 500m，滑床长约 2000m，估计体积 1.7 亿 m^3。原岩为太古代太华群花岗片麻岩，高速远程滑坡，滑动距离自剪出口到前沿达 3000m，堆积体高程约 400m。滑坡堆积物成碎块石，自 20 世纪 60 年代以来被开采为建筑砂石，破坏严重，现仅剩滑坡残体。

This landslide occurred on November 3, 1072, due to an Ms=$5^{1}/_{2}$ earthquake, and had an estimated volume of 170 million m^3. The landslide is made of Archeozoic granite gneiss. The crown is situated at an elevation of 1200 m and the toe at an elevation of 500 m. The material is 2000 m long and is divided into two stairs. The run-out length of the high speed landslide is over 3000 m that accumulated at an elevation of 400 m. Today some material remains because of quarrying since 1960's.



滑坡前部为花岗片麻岩碎块石, 上覆厚 2～4m 的坡积土
The accumulation lobe in the fragmented granite gneiss material covered by 2-4 m of colluvial loess



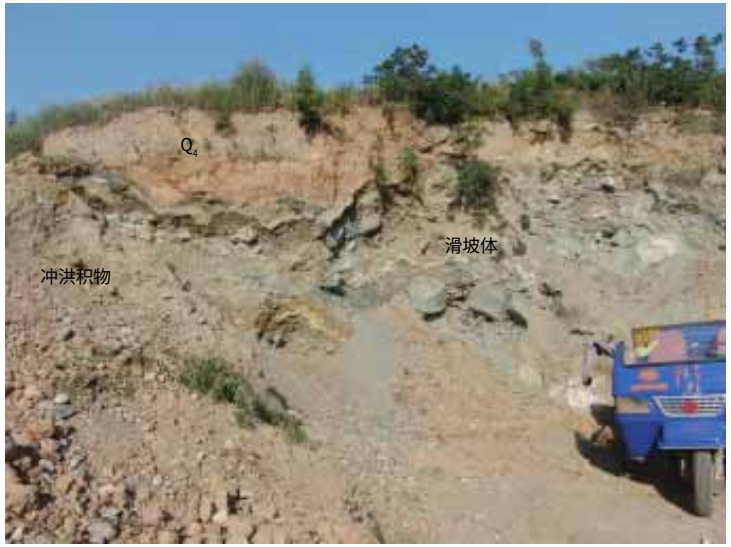
滑坡中部堆积体为呈碎块状的花岗片麻岩, 扰动强烈
Middle part of the landslide is made up of broken granite gneiss



滑坡中部堆积体为层状碎块花岗片麻岩
Detail of layered portion of landslide granite gneiss



滑坡中部堆积体为碎块状花岗片麻岩, 出现挠曲和糜棱化
Fragmented granite gneiss with flex and gruel in the middle of landslide accumulation lobe



滑坡超覆在第四系冲洪积物上, 滑坡堆积体出现柔皱, 上部为坡积物
Landslide with flexures overlying the colluvial deposit. The upper thin loess covered indicates a long period of inactivity



滑坡散落覆盖在冲洪积物上
Landslide debris scattered over the colluvial material (from previons downslope movement)



滑坡超覆在冲洪积物上
Landslide material overlying colluvial material

1920 年宁夏海原地震滑坡

Landslides by the Haiyuan Earthquake (Ms=8.5,1920) of Ningxia



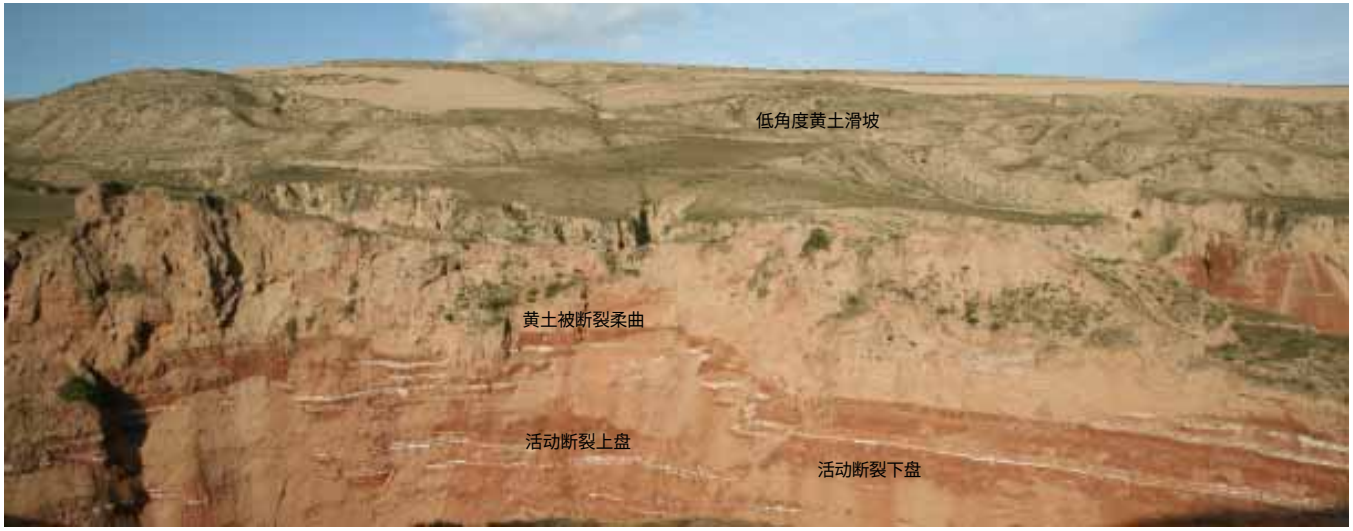
海原地震诱发的西吉苏堡乡滑坡及堰塞湖
The loess landslide and dammed lake of Supu Village, Xiji County triggered by Haiyuan Earthquake

1920 年 12 月 26 日，宁夏海原发生 8.5 级强震，20 多万人死亡。在海原、西吉、彭阳等地诱发了一系列黄土滑坡，最大体积达数千万立方米。滑坡普遍具有低角度、液化、远程、高速特征，由于受地震波作用，产生显著的波状地形。沿河流形成了一系列的堰塞湖，当地称为“震湖”。

The major earthquake (Ms=8.5) occurred at Haiyuan, Ningxia on December 26, 1920, over 200 thousand people died. It triggered lots of landslides in Haiyuan, Xiji, Pengyang and other counties. The landslides are made up of loess and the largest one has millions cubic metres of volume in max. The typical features were occurred, such as gentle angle of shear zone, liquefaction, long distance run-out, high velocity, and the wave topography. Lakes were created due to landslide damming.



海原地震诱发的海原黑木乡滑坡
The loess landslide of Heimu Village triggered by Haiyuan Earthquake



活动断裂切割第三系和黄土, 海原地震时诱发浅层低角度黄土滑坡 (兴仁盆地)
Tertiary mudstone and Q_3 loess were displaced by active fault. A gentle loess landslide was triggered due to Haiyuan Earthquake at the Xingren Basin, Ningxia



海原地震诱发浅层黄土－第三系滑坡, 下部地层石膏发育 (西吉九彩村公路)
The Loess-Mudstone landslide was triggered by Haiyuan Earthquake. The underneath is the gypsum-rich layer



海原地震诱发的西吉苏堡乡党家岔村滑坡群及堰塞湖 (当地称为 “ 震湖 ”)
The couple of loess landslide and dammed lake of Dangjiacha Village, Xiji County triggered by Haiyuan Earthquake



滑坡后缘及中脊　Crown of two loess landslides and ridge



滑坡 A 地貌　Topography of loess landslide A



滑坡群及混合堆积区
Couple of two loess landslides and mix accumulation



滑坡 A 侧缘落水洞　Laterial and karst cave of loess landslide A



西吉苏堡乡党家岔村滑坡 A 侧缘陡壁
The steep laterial of loess landslide A of Dangjiacha Village, Xiji



西吉苏堡乡党家岔村滑坡B侧缘陡壁
The steep laterial of loess landslide B of Dangjiacha Village, Xiji



党家岔村滑坡坝及堰塞湖 (当地称为 “ 震湖 ”)
The couple of loess landslide and dammed lake of Dangjiacha Village, Xiji

四川泸定摩岗岭地震滑坡

Mogangling Earthquake-Triggered Landslide, Luding, Sichuan Province



摩岗岭滑坡全貌。左岸保留的滑坡残体显示大渡河被堵塞

Overview of Mogangling earthquake-triggered landslide. The landslide residual at the left shore indicates the Daduhe River was dammed

滑坡位于四川泸定下游约35km的德威乡，现修建过江彩虹桥。由1786年6月1日四川省康定南发生的$7^1/_2$级地震诱发，并堵塞大渡河，断流10日后河道溃决，洪水位到乐山仍高达数丈（十几米），淹没民众约10万人。

滑坡体长约1200m，宽1600m，最大厚度约250m，体积约1.8亿m^3。由于溃坝及后期大渡河流的改造，滑坡体已不完整，残留体积约5700万m^3。滑坡地处活动强烈的“Y”字型构造中心，母岩为元古界钾长花岗岩，被多组构造切割，岩体较为破碎。

Mogangling landslide was triggered and dammed the Daduhe River due to the Ms=$7^1/_2$ earthquake occurred in the south of Kangding on June 1, 1786. Ten days late, on June 10, the landslide dam burst and caused flooding. The number of lives flooded was about 100 thousand.

The landslide with a length of 1200 m, a width of 1600 m and a max height of 250 m is made up of Proterozoic granite fractured with dense joints. The landslide had 180 million m^3 in volume before dam bursting, the remnant has 57 million m^3 in volume due to dam bursting and erosion.



滑坡位于大渡河右岸。下游地势开阔
Mogangling Landslide is at the right shore. The river valley is opening that is easy to flood disaster



大渡河左岸因堵江溃决后保留的滑坡残体
The residual at the left shore indicates that the Daduhe River was dammed by the landslide



滑坡母岩为被构造强烈切割的花岗岩体, 较为破碎
The parent rockmass is granite fractured by dense joints

6.水库滑坡

Landslides Induced
by Reservoir Filling



LANDSLIDES INDUCED BY RESERVOIR FILLING

LANDSLIDES INDUCED
BY RESERVOIR FILLING

LANDSLIDES INDUCED

LANDSLIDES INDUCED BY RESERVOIR FILLING

BY RESERVOIR FILLING

长江三峡之瞿塘峡高陡斜坡

Steep Slope in Qutang Gorge, Three Gorges



三峡起点——瞿塘峡夔门

The entrance to Qutang Gorge, marks the start of Three Gorges, in thick limestone with large karst caves



瞿塘峡斜坡岩体被节理切割
Steep slope in limestone, densely jointed from top to the river level. Potential rockfall hazard to ship, especially during reservoir water level fluctuation



瞿塘峡斜坡岩体被节理切割
Unloading fractures in the steep rockmass of Qutang Gorge, Yangtze River



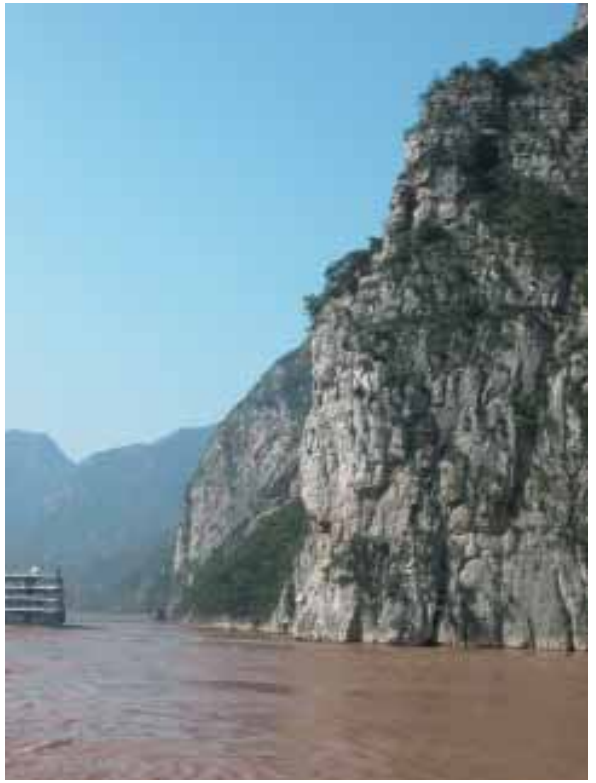
瞿塘峡斜坡岩体溶洞发育
Dense unloading joints and karst caves in steep slope of Qutang Gorge, Yangtze River

长江三峡之巫峡高陡斜坡

Steep Slope in Wu Gorge, Three Gorges



巫峡单斜层状岩体结构
Inclined bedding rockmass structure in Wu Gorge, Three Gorges



岩体被多组节理切割
Steep limestone slope with major joints

岩体被多组节理切割, 形成卸荷松动带, 岩溶发育
Dense unloading (stress-relief) joints and karst caves in steep slope





岩体被多组节理切割, 形成危岩体
Fractured rockmass with several unloading joints. Potential rockfall hazard to shipping



岩溶沿层面发育，形成层状溶洞
Bedding karst caves along layers



岩溶在厚层岩体中发育，形成溶洞
Karst cave in thick limestone



岩溶沿裂隙发育，形成溶隙和构造溶洞
Crevices and tectonic karst caves in limestone



岩体中溶洞发育
Karst caves in limestone rockmass

三峡工程湖北库区巴东新城黄土坡滑坡全貌

Huangtupo Landslide, Badong Town, Hubei Province



2001 年新城黄土坡滑坡全貌（防护前）
Overview of the Huangtupo landslide in 2001 (before prevention)

(本照片由江鸿彬提供)

该滑坡发生在三叠系巴东组第二段、第三段以泥岩、泥质粉砂岩、泥灰岩为主的易滑地层中。经过多期活动、主要由古滑坡体和崩滑堆积体组成的地质灾害群体，其前缘没于江水下高程50～70m处，后缘高程约600m，体积约 6934.1 万 m^3。

Gigantic ancient landslide with a volume of 69 million m^3 at the southern shore of the Yangtze River. The landslide accumulation has been used for relocation of the town of Badong. The crown is situated at 600m and the toe at about 50-70 m. The parent rock is purple-red Triassic mudstone and limestone which is prone to sliding.

三峡工程湖北巴东新城黄土坡滑坡防护工程

Prevention Engineering Work Huangtupo Landslide, Badong Town, Hubei Province



2003 年新城黄土坡滑坡全貌（防护后）
Overview of the Huangtupo landslide in 2003, Badong, Hubei (after prevention)

(本照片由江鸿彬提供)

2002 年 9 月，国家投资 1.3 亿元，首先实施了削坡整形、锚杆格构砌石护坡、护坡桩工程、三道沟填筑工程、地表排水及监测等工程。通过对崩滑堆积体前部水位变动带的防护，限制库岸再造向岸坡内发展，保护库岸稳定，并辅以滑坡区排水措施，提高坡体的整体稳定性。经治理后，沿江岸坡稳定，经受住了蓄水的考验，未产生塌岸等岸坡变形现象。

The Huangtupo landslide has been stabilized since September, 2002; the stablization measures, at a cost of 130 million RMB yuan, include slope excavation (unloading), lattice girder of reinforced concrete with anchoring, retaining piles, surface drainage, backfilling, and monitoring. The stablization measures have been effective in preventing slope deformation and river bank erosion. Stability of the slope has been enhanced.



黄土坡滑坡中后部及房屋拉裂
Cracks have developed in a house located in the middle and rear of the landslide



黄土坡滑坡前缘三道沟挡墙拉裂
Cracking developed in a retaining wall in the front of the landslide



黄土坡滑坡前缘头道沟口岩层膝折压裂
Block-flexural toppling and knee-shaped cracks of the rockmass in the front of the landslide



黄土坡滑坡中部岩层弯曲折断
Flexing and cracking of the rockmass in the middle of the landslide



采用钢筋砼格构滑坡防治
Latlice girder of reinforced concrete with anchoring



巴东黄土坡二道沟滑坡防治工程
Prevention works



钢筋砼格构钢筋笼编制现场
Steel reinforcements being placed



滑坡格构防治工程
Completed concrete lattice girder



巴东黄土坡滑坡防治工程 (蓄水 139m 水位)
Prevention engineering works on the Huangtupo landslide
(water level 139m altitude in 2003 after filling)



巴东黄土坡二道沟滑坡和沿江库岸防护工程
Prevention engineering works on the shore of Erdaogou
(area of the second trench), Huangtupo



巴东黄土坡二道沟滑坡防治工程
Prevention engineering works on the shore of Erdaogou
(area of the second trench), Huangtupo

三峡工程湖北库区秭归千将坪滑坡

Qianjiangping Landslide, Zigui County, Hubei Province

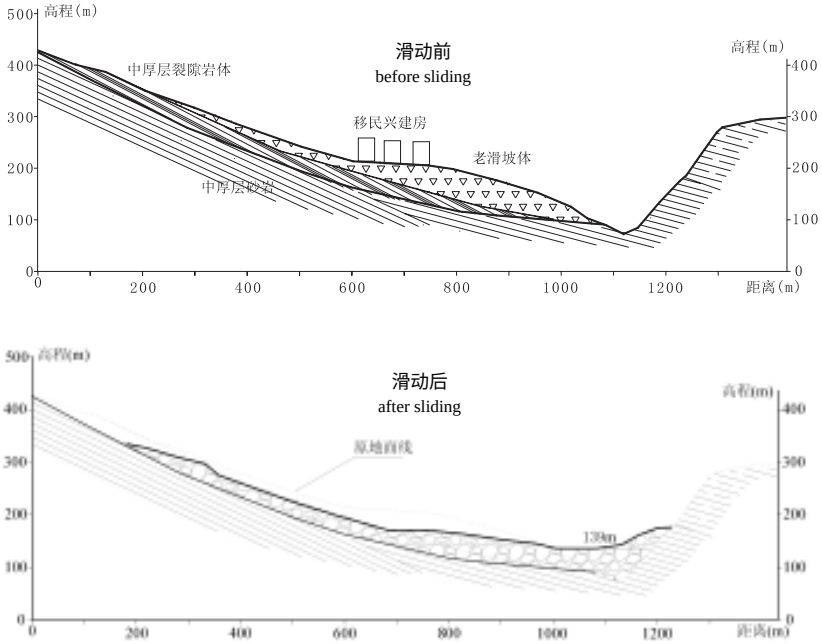


滑坡发生于2003年7月13日，地处长江三峡支流青干河左岸，与沙镇溪镇隔河对峙，距三峡工程坝址约56km。出露三叠系沙镇溪组碎屑岩，岩层稳定延伸，倾向南东，倾角较缓，滑坡所在岸坡为顺向坡。平面形态呈舌状，长1200m，宽1000m，均厚约20m，面积约1.2km^2，体积约2400万m^3。滑坡体顶高450m，剪出口高程102m，前缘没入青干河。产生的涌浪高达30m。堵江形成堰塞湖，形成堆石坝高程达149～178m。14人死，10人失踪，1100多座房屋被毁。

The landslide occurred on July 13, 2003, one month after the rising of the reservoir from elevation 70 m to elevation 135 m. The slip surface is within dipping beds in the left shore of Qingganhe River, a tributary of the Yantze River. The landslide is located 56 km upstream of the Three Gorges Dam Site. The landslide is made up of Triassic, gently dipping, clastic rock. The landslide is tongue-shaped, with 1200 m long, 1000 m wide, 20 m thick, and has a volume of 24 million m^3. The crown is at an elevation of 450 m and the toe at 102 m (submerged under the reservoir). A dammed lake was formed, and the surge during breaching was over 30 m high, and killed 24 people and destroyed 1100 houses.



千将坪滑坡发生于顺向坡, 附近分布多处老滑坡
The Qianjiangping landslide occurred in dipping beds, where there are several ancient landslides



千将坪滑坡剖面示意图
Skelton section of the Qianjiangping landslide



滑坡滑床上顺坡大型擦痕
Large sliding scars on the bedding layer



滑坡下游约 1km 的青干河大桥
The Qinganhe River Bridge is 1km from the Qianjiangping landslide



滑坡滑床上顺坡大型擦痕
Large-scale sliding scars on bedding planes



滑坡中后部堆积体的破碎块石
Accumulation in the middle and rear of landslide



滑坡堆积体原岩结构解体
Ridge and trench of the accumulation



滑坡中前部堆积体及堰塞湖
Ridge and dammed lake



滑坡体原岩层状结构保存较好
Landslide is made up of stratified sandstone



滑坡前缘堵江, 部分滑体冲入对岸, 形成高达 5m 的堆积体
Landslide dammed the river with 5 m of accumulation above the water-table, some material was pushed up opposite shore

三峡工程湖北兴山峡口滑坡治理工程

Stabilization of Xiakou Landslide, Xingshan, Hubei Province



兴山峡口滑坡防治工程全貌
Overview of stabilization for the Xiakou landslide, Xingshan

滑坡位于湖北兴山峡口镇香溪右岸，前缘高程 160m，后缘 330m，滑体面积 70 万 m^2，体积 105 万 m^3。自 1990 年开始，滑坡造成其前缘房屋、堡坎和公路拉裂变形，限制了新城镇的布局，用地面积减少，将峡口镇分割为东西两半，并对城镇和通过其上的秭兴公路构成了严重威胁。因此，采用了整体清除，并用挡墙形成多级台阶加固滑坡残体，为就地后靠的移民提供建筑场地的整治方案。

The Xiakou landslide is situated on the right shore of the Xiangxi River, a branch of the Yangtze River, 1.05 million m^3 in volume. The crown is at 330 m elevation and the toe at 160 m (below the 175 m normal water level of the Three Gorges reservoir). Since 1990, the landslide had obviously been sliding that caused fractures of roads and houses in Xiakou Village. The measure of removing most of the landslide was conducted, and multiple retaining walls have been constructed to provide platforms for relocation.



实施防治工程后滑坡体被作为移民后靠场地
The stabilized landslide is used as the site for relocation



三峡水库蓄水后峡口新镇成为支流香溪河的明珠
Xiakou Village is a bright pearl in the Xiangxi River, a branch of the Yangtze River



峡口滑坡次级滑面擦痕非常明显
Secondary sliding plane of the Xiakou landslide with clear new scars



利用多级挡墙形成建筑平台
Multiple retaining walls providing platforms to relocation

三峡库区马槽岭滑坡防治工程

Stabilization of Macaoling Landslide，Three Gorges



三峡支流香溪河口右岸——香溪镇和马槽岭滑坡全貌(蓄水前, 2002 年 7 月)
Overview of Xiangxi Village and the Macaoling landslide (before reservoir filling, 2002-07)



昔日香溪旧镇大部被淹没水下，后部为马槽岭滑坡（蓄水后，2003 年 6 月)
The old Xiangxi Village was submerged. Overview of Macaoling landslide (after reservoir filling, 2003-06)

滑坡位于湖北秭归长江左岸、香溪河入江处，前缘高程 88m，后缘高程 220m，均厚 25m，总体积 195 万 m^3。三峡水库蓄水后，马槽岭滑坡大部分将位于库水位 175m 以下，极有可能整体滑入水库。采用了锚拉桩技术进行两级支挡。

The Macaoling landslide, with a volume of 1.95 million m^3, is situated on the left shore of the Yangtze River at the confluence with the Xiangxi River. The crown is at 220 m elevation and the toe at 88 m.Most of the landslide has been submerged after reservoir filling. Two rows of pile have been driven.



采用预应力锚拉桩治理马槽岭滑坡
The Macaoling landslide was stabilized using retaining piles with pre-stressed anchoring



马槽岭滑坡防治工程预应力锚索 (37m 长)
A 37-m-long cable to be prestressed and used as an anchor



治理后的马槽岭滑坡锚拉桩
Completed stabilization works on the Macaoling landslide, Zigui, Hubei



马槽岭滑坡防治工程
Prevention engineering work on the Macaoling landslide



秭归归州镇新址原为滑坡发育区,下部为冲沟
The new Guizhou Village, Zigui County, is situated on the stabilized landslide near a gully



秭归归州镇街景,蕴含了诗人屈原故里的灵气
A street scene in the new Zigui Village brings forth the poetic spirit of Quyuan's hometown



秭归归州新镇建筑风貌
Scenery of houses in the new Guizhou Village, Zigui County



归州镇利用开挖弃渣回填冲沟, 形成建筑平地, 同时, 对上部滑坡压脚, 提高稳定性
A platform is created with waste rock fill for a relocation site, and the toe is loaded to increase stabilization

贵州鲁布革电站水库滑坡

Landslide at Lubuge Reservior, Xingyi, Guizhou Province



鲁布革电站贵州库区移民新村坐落在古滑坡体上
Relocation village, on the ancient landslide at Lubuge Reservior, Guizhou Province



鲁布革电站库水下降促使古滑坡体前缘下滑
The front of the ancient landslide is being reactivated due to water level decline at Lubuge Reservior, endangering the new houses

7.矿山滑坡与崩塌

Landslides and Rockfalls Induced by Mining



LANDSLIDES AND ROCKFALLS INDUCED BY MINING

LANDSLIDES AND ROCKFALLS INDUCED BY MINING
LANDSLIDES AND ROCKFALLS INDUCED BY MINING

长江三峡链子崖危岩体及防治工程

Prevention Works for the Potential Lianziya Rockfall at Three Gorges, Yangtze River



链子崖危岩体紧邻长江右岸 (镜头向西)
Overview of the potential Lianziya rockfall, situated on the right shore of Three Gorges, Yangtze River (Looking west)



链子崖危岩体正面 (镜头向南)
The potential Lianziya rockfall of Three Gorges. The upper part is an ancient landslide (Looking south)



危岩体 T_0～T_6 号缝危岩体区
Prominent zone of tension fractures (T_0-T_6) in the potential Lianziya rockfall



危岩体 T_9 号缝危岩体区
The T_9 fracture of the potential rockfall



危岩体与左岸的新滩滑坡对峙
Opposite the potential rockfall is the Xintan landslide that was successfully predicted in 1986



链子崖前缘“五万方”危岩体
Toppling and sliding in the front of the potential Lianziya rockfall

链子崖危岩体位于湖北省秭归县新滩镇长江南岸，兵书宝剑峡出口处，下距三峡坝址27km，是长江三峡库区稳定性最差的大型崩塌滑坡体，历史上曾断航82年之久，对长江航道和三峡大坝工程施工构成了严重威胁。1992年实施治理，目的是改善危岩体的稳定状况，防止崩塌体入江造成危害。采用了预应力锚固、承重阻滑键、地面排水和防冲拦石坝等综合防治工程。三峡水库蓄水后，监测表明防治效果良好。

The potential Lianziya rockfall is situated on the south shore of the Yangtze River, Zigui, Hubei Province, 27 km upstream from the dam site of the Three Gorges Project. Historically, rockfalls had dammed the river for 82 years, and recently posed hazards to shipping and the construction of the Three Gorges Project. The rock mass has been stabilized since 1992 with comprehensive measures, including pre-stressed anchor cables in the front, reinforced concrete beam at the bottom, drainage on the surface and a retaining wall to prevent falls from running out to the river directly.



“五万方”危岩体下部发育 R_{203} 软层
A soft layer (R_{203}) occurs at the bottom of the potential rockfall



“五万方”危岩体被多组裂缝切割
Rockmass is cut by several joints



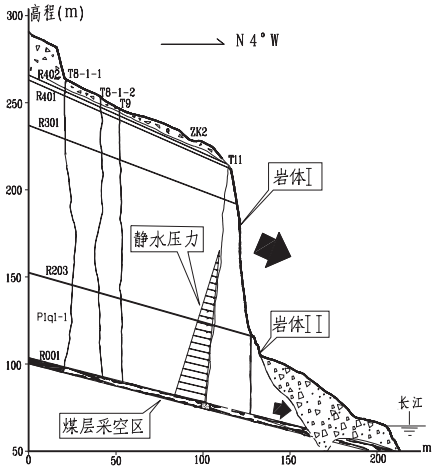
R_{203} 软层厚数十厘米
The R_{203} soft layer is tens of centmetres thick

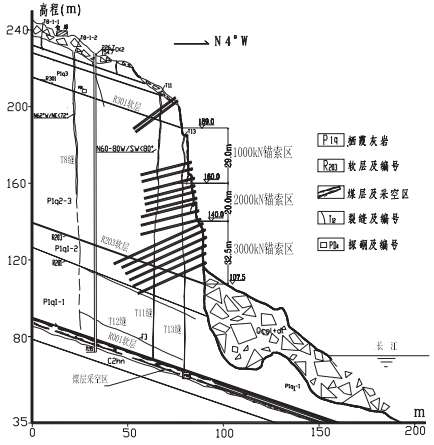


“五万方”危岩体预应力锚固工程施工现场
Eighty-meter high scaffolding for pre-stressed anchoring work

危岩体地质力学模型和预应力锚索布置图

Geotechnical section of the layout with pre-stressed anchoring work







“五万方”危岩体预应力锚固工程
Completed pre-stressed anchoring of the rockmass



预应力锚索入孔安装
Installation of steel tendon in borehole



锚固工程脚手架安装
Scaffolding for anchoring work



危岩体下部采煤硐口
Entrance of the mine opening at the bottom of the rockmass



安装“ 3D ”位错计监测采空区裂缝变形
“ 3D ”displacement instrument to monitor fracture movement



采空区钢筋砼承重阻滑键工程
Engineering work in the mine under the rockmass to provide support



危岩体下部采空区
Worked-out section of coal mining under the rockmass

辽宁阜新海州露天煤矿边坡

Engineered Slope in the Haizhou Open-pit, Fuxin, Liaoning Province



辽宁阜新海州露天煤矿边坡
The Haizhou engineered open-pit slope, Fuxin, Liaoning Province



辽宁阜新海州露天煤矿边坡失稳
Large slope failure in the open-pit

海州露天矿位于阜新煤田北部，煤层为上侏罗系陆相地堑沉积生成的。于 1953 年 7 月 1 日正式投入生产，设计年产量 300 万 t。露天矿采场面积 7km²，东西长 4.0km，南北宽 2.0 km，开采深度 350 m。当时为亚洲最大、世界闻名的大型露天煤矿。随着煤炭资源的枯竭，于 2005 年闭坑。

This open-pit is located in the northern coal field of Fuxin City, Liaoning Province. The mining started on July 1, 1953 and ended in 2005, creating one of the largest open-pits in Asia, with a length of 4000 m (EW), and a width of 2000 m (SN). The coal layer is in a Jurassic graben and the slope has been developed in sandstone and shale.



露天煤矿边坡失稳滑动
Slope sliding due to coal self-ignition



露天煤矿边坡煤层自燃
Self-ignition of coal layer



露天煤矿边坡失稳导致地表房屋拉裂下沉
Ground and houses sunk due to slope sliding



露天煤矿边坡失稳导致围墙拉裂下沉
Wall sunk due to slope sliding

辽宁抚顺西露天煤矿边坡

Engineered Slope of the West Open-pit, Fushun, Liaoning Province



抚顺西露天煤矿边坡
Overview of large mine slope with berms at the west open-pit of Fushun, Liaoning Province

位于辽宁抚顺西南部。煤田发育于浑河深大断裂带，为一套老第三系内陆沼泽相沉积地层。露天开采始于1914年，并集中在主向斜的南翼。经过近百年的开挖，已形成东西长6.6km，南北宽2.0km，深约400m的大坑，矿坑面积约10.87km^2，容积约17亿m^3。随着煤炭的开采，西露天矿坑滑坡、岩体位移和地面变形等地质灾害时常发生。首次滑坡发生在1927年，迄今为止已发生较大的滑坡90余次，破坏区面积63.5万m^2，滑落岩体总量2081.7万m^3，最大的一次滑坡体体积43.1万m^3。目前该矿坑北帮仍存在滑坡变形区120万m^2，其中危险区面积达64万m^2。

This open-pit is located to the southwest of Fushun City in inland-swamp Tertiary materials. The coal mining started in 1914, mainly in the southern flank of a cyncline. The resulting open-pit is 6600 m (EW) long, 2000 m (SN) wide, and 400 m deep, the largest in Asia. Landsliding, subsidence and fracturing have often occurred during coal mining. The northern flank of the syncline presents a threat of landsliding with an area of 640 000 m^2 and a hazard to several thousand lives.



抚顺西露天煤矿边坡　The west engineered open-pit slope, Fushun, Liaoning Province



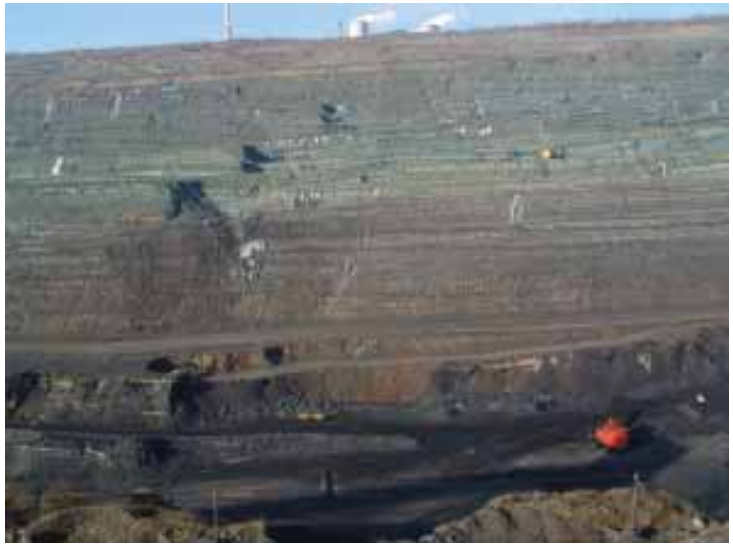
抚顺西露天煤矿坑底及两帮边坡 (地质构造为倒转向斜, 左为逆向坡, 右为顺向坡)
The bottom and the two engineered slopes of the west open-pit (the geology structure is an overturned sycline, the left slope is overturned and the right slope is normal)



抚顺西露天煤矿北边坡下部煤层
Coal layer under the northern side of the open-pit



抚顺西露天煤矿北边坡下部煤层
Good quality coal layer



抚顺西露天煤矿北边坡为逆向坡
The overturned bedding of the north slope



抚顺西露天煤矿南边坡为顺向坡
The dipping bedding of the south slope



抚顺西露天煤矿南边坡为顺向坡
Dipping beds on the southern face of the open-pit



南帮边坡下部的老矿坑
Old mining works in the southern side of the open-pit



北帮边坡上部出现浅层滑坡
Shallow landslide on the north slope



北帮边坡地面出现拉裂下滑
Crown cracks of shallow landslide on the north slope



煤矿采空导致上部房屋沉降, 被淹, 在冬季被冰冻
Houses are submerged and frozen in winter due to subsidence



抚顺西露天煤矿南边坡顺层滑动
Landslide along dipping beds on the nouthern slope of the open-pit



北帮边坡地面建筑物出现拉裂破坏
Road is fractured and sunk due to slope sliding



建筑物出现雁列破坏
Fractures in echelon pattern

贵州开阳磷矿矿山崩塌

Rockfalls in Kaiyang Phosphate Mine, Guiyang, Guizhou Province



开阳磷矿采矿引发的山体崩塌
The rockfalls due to phosphate mining in Kaiyang County

贵州开阳县素有“中国磷都”之称。著名的开阳磷矿分布在洋水背斜两翼，为我国少有的超大型沉积磷矿。受采矿影响，在洋水河流域，崩塌呈带状分布，沿垂直裂隙带形成规模较大的崩塌带，并转化为泥石流。崩塌带发生在震旦系灯影组白云岩中。灯影组白云岩为磷矿层顶板，为厚层硬质岩类；磷矿层及底板均为软质岩类，组成了软岩在下、硬岩在上的结构。

Kaiyang County is named as the capital of phosphorus ore. The phosphate presents in two sides of the Yangshui anticline, the large scale ore deposit in China. Phosphate-mining induced rockfalls occurred on the two sides of the Yangshui valley and became debris flow that accumulated at the bottom of the valley. The rockfalls are made up of massively bedded, jointed dolomite rockmass, of Sinian age, which overlie the soft phosphate layer.



下部采矿形成数千米长的拉裂缝, 对面为采矿诱发的崩塌
A crack, several kilometers long and rockfalls due to mining at the bottom, on the opposite side



磷矿上部灰岩岩体被多组节理切割，扰动后发生崩塌
The parent rockmass is fractured by multiple joints and rockfall has occurred due to phosphate mining



磷矿上部灰岩岩体稳定性差
Unstable rockmass; the morphology indicates previous karst micro-forms



磷矿上部灰岩岩体被多组节理切割，岩溶发育形成石林
Densely jointed limestone and karst forest overlies the phosphate mine



磷矿上部灰岩岩体被多组节理切割
Densely jointed limestone overlies the phosphate mine

重庆武隆鸡冠岭崩塌治理工程

The Rockfall and Prevention in Jiguanling, Wulong, Chongqing



崩塌堵塞乌江, 后缘危岩体仍存在巨大威胁 (1993)
The 1993 Rockfall dammed the Wujiang River, Wulong, Chongqing; a hazard was still posed by the remaining rockmass



崩塌体堆积于斜坡上对航道构成巨大威胁
Rock debris accumulation also endangered navigation



危岩体爆破工程 (1993)
The remaining rockmass was removed by blasting (1993)



山体崩塌残体, 航道已通畅 (2006)
The residual rockfall debris; navigation is now safe (2006)



云南元阳老金山采矿区滑坡 (1996 年 6 月 3 日, 死亡 372 人, 受伤 146 人, 直接经济损失 1.6 亿元)
The June 3, 1996 Laojinshan landslide, Yuanyang, Yunnan Province, was caused by gold mining; it killed 372 people, injuried 146, and created economic losses of 160 million RMB yuan



乌江河谷沿背斜采上山煤，对山体稳定构成危害
Coal mining in the anticlinal strata along the Wujiang River valley



乌江河谷沿岸开采煤炭，对斜坡稳定构成危害
Coal mining in the stratified strata along the Wujiang River valley has caused large rockfalls

8.城市建筑和道路滑坡

Landslides Induced by Urban Development and Highway



LANDSLIDES INDUCED BY
URBAN DEVELOPMENT AND HIGHWAY
LANDSLIDES INDUCED BY
URBAN DEVELOPMENT AND HIGHWAY
LANDSLIDES INDUCED BY URBAN DEVELOPMENT AND HIGHWAY

三峡工程库区巫山移民新址滑坡灾害防治

Landslide and Stablization Works in the Relocated Wushan Town, Three Gorges Reservoir



巫山移民新城库岸滑坡防治工程 (水位 139m, 2005 年 5 月)

Landslide stablization works and shore embankment in the relocated Wushan Town, Chongqing (139m elevation of water level, May, 2005)



巫山新城库岸邓家屋场滑坡防治工程 (水位 135m, 2003 年 8 月)
The Dengjiawuchang landslide prevention works (water level elevation in 2003 is 135 m)



巫山新城库岸滑坡剪出口
The toe of slip surface of the Dengjiawuchang landslide



巫山新城库岸邓家屋场滑坡 (水位 70m, 2002 年 1 月)
The Dengjiawuchang landslide on shore (water level elevation in 2002 is 70 m), Wushan, Chongqing



岩溶塌陷胶结形成溶塌角砾岩
Karst collapse breccia cemented with travertine



巫山溶塌角砾岩边坡
Engineered slope in karst collapse breccia



巫山新城库岸邓家屋场滑坡滑带
Sliding zone of the Dengjiawuchang landslide



溶塌角砾岩被钙质胶结
Karst collapse breccia cemented with travertine



巫山新城岩溶残积物构成软弱条带
Weak zone is made up of karst residuum



巫山新城溶蚀残积物转化为滑带，形成挤压片理
The residuum in the shear zone has developed schistosity



巫山溶塌角砾岩边坡开挖后基岩稳定性良好
Engineered slope was completed, limestone rockmass shows to be stable after karst collapse breccia was removed



巫山溶塌角砾岩边坡
Engineered slope in karst collapse breccia



巫山新城边坡失稳危及建筑物安全
Landslide damaged the new houses in the relocated Wushan Town



采取应急措施加固房屋地基
The emergency measures were taken to control landsliding



边坡失稳危及坡下建筑物安全
Engineered slope failure endanged the new houses



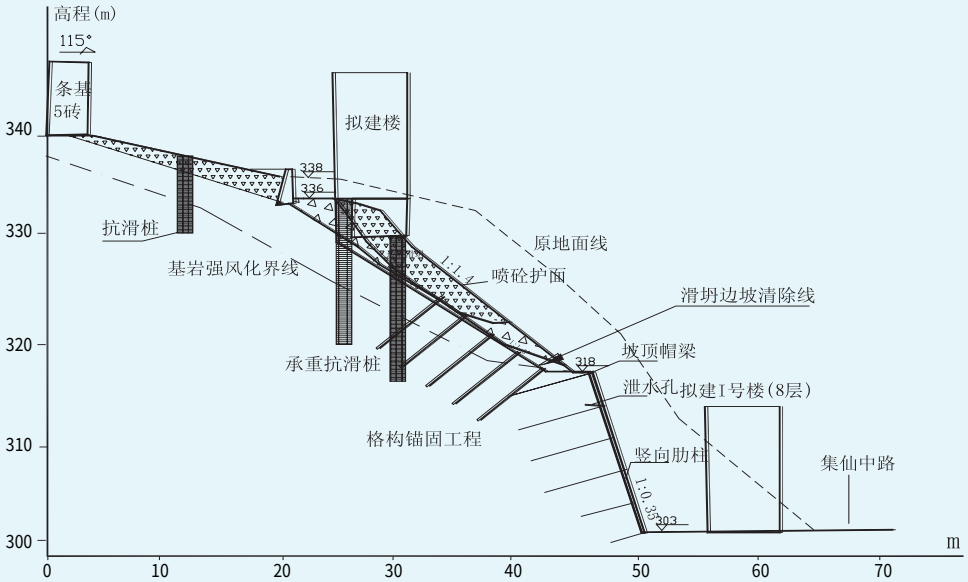
采用桩和锚固工程加固边坡
The retaining piles and anchoring are constructed to control landsliding



巫山集仙路边坡加固工程
Prevention works on the slope failure in the relocated Wushan Town, Chongqing



加固后的巫山林业局边坡作为建筑场地，在边坡的下部、中部和后部均修建起高楼
The stablized slope has been used as the site for dense building construction, Wushan, Chongqing



基于治理的边坡利用方案图
Diagram of the slope stablization project

重庆武隆县城“5 · 1”滑坡

The “5 · 1” Rockfall in Wulong Town, Chongqing



武隆县城“5 · 1”滑坡远景
Overview of the “5 · 1” rockfall in Wulong Town, Chongqing

滑坡发生于2001年5月1日，致使一幢9层楼房被摧毁掩埋，79人死亡、7人受伤。滑坡体体积约1.6万m^3，岩性为三叠系上统须家河组砂岩，夹泥岩互层，属缓倾角的切向坡，为层状碎裂岩体，形成大小不等的分离块体，其最大体积达10m^3。

滑坡所处地段自1989年以来，遭受两次开挖切脚。第一次是1989年兴建319国道，沿乌江河谷开挖斜坡，形成高约20m倾角达60°～80°的陡倾边坡，未加支护；第二次是1997年被规划为建设用地，形成了宽160m、深15.5m、高46.6m的槽形场地。业主意识到了后缘边坡稳定性差，局部采取了浆砌块石挡墙支挡措施，但未能有效地发挥作用。从挡墙结构上看，未设置合理的防水反滤层和排水孔等。

This rockfall took place on May 1, 2001 and caused 79 deaths, and the destruction of a 9-storey building. The rockfall occurred in jointed Triassic sandstone and mudstone strata that dipped gently into the slope. The slope had been cut twice since 1989; first the slope was cut for road construction; second, a cut 46.6 m high, with a length of 160 m along the slope, and a width of 15.5 m into the slope, was created for housing development. The inadequate slope stablization work performed at this site did not prevent the disaster.



滑坡原岩为层状碎、裂岩体，缓倾山内。边坡支护不合理
Parent rock is a fractured stratified rockmass dipping into the stope.
Rock-cut stablization measures were inadequate



边坡开挖后，岩体损伤，形成多处卸荷张裂带
Stress-relief cracks and rockmass damage due to slope cutting



滑坡掩埋了 9 层高楼, 79 人死亡
The rockfall, with volume of 16 000 m^3, destroyed the 9-storey building and killed 79 people



有关部门组织现场抢险救灾
Rescuring group at the rockfall site where 79 people were buried



紧急调用挖掘机和翻斗车现场清理滑坡体
Removing the accumulation to search for victims



滑坡体巨石达数十立方米，被埋人员无一生还
The rockslide had a volume of several tens of cubic metres and no one of 79 occupants survived



抢险人员现场分解巨石
Huge block is being broken down into several fragments



滑坡体被清除，边坡被加固，不再存在滑坡隐患
No danger exists after removing the rockfall material and stabilizing the slope



残留数千立方米滑坡体和边坡被综合加固
Remaining material of the rockfall with a volume of several thousands m^3 has been controlled and slope has been stabilized



利用钢筋砼和预应力锚索加固后的边坡
The slope has been stabilized with lattice girder and anchoring



加固后的边坡下部被作为建设场地
The bottom of the slope has been used for building after the slope was stabilized



利用钢筋砼肋柱和预应力锚杆加固边坡
Reinforced concrete retaining columns and prestressed anchoring were used to stablize the slope

四川丹巴县城滑坡

Landslide in Danba Town, Sichuan Province



丹巴县城坐落在滑坡前缘平台上
Danba Town is situated on the ancient landslide

滑坡位于大渡河上游右岸丹巴县城后侧，为古滑坡，纵长约 270m，宽约 200m，平均厚 30m，最大厚度约 40m，前后缘高差近 200m，总体积 150 万～230 万 m^3。

The landslide, 270 m long, 200 m wide and 30 m thick, is part of an ancient landslide, on the right shore of the Dajinghe River, in the upper reach of the Daduhe River. The landslide has a volume of 1.5-2.3 million m^3 and the height difference from the crown to toe is 200 m.

原岩为志留系石榴石二云片岩和黑云母斜长变粒岩夹少量大理岩。岩层倾角普遍较大，倾向 35°，倾角 35°～45°，遭受强烈挤压，裂隙发育，石榴石二云片岩较软，表层有不同程度的风化。二云片岩富含云母矿物，易沿层面滑脱，加剧岩石风化。

The parent rock is garnet two-mica schist with a steep dip angle of 35°- 45°. The rockmass is densely jointed with mica-rich filling in which slippage occurrs.



丹巴县城及沿江 Quick Bird 遥感影像
Quick Bird remote sensing image of Danba Town

·四川丹巴县城滑坡·



由于近年城镇建设加快，切坡建房形成 6～28m 的高陡边坡，未加有效支护
Because of rapid housing development, a steep benched cut was excavated without efficient reinforcement



滑坡后缘出现弧形贯通裂缝
The curved crack in the crown of the landslide

滑坡自 2002 年 8 月发现有较明显的变形，从 2005 年 2 月初出现加速变形迹象，呈现出整体下滑的特征，后缘出现弧形贯通张裂缝，整体下错超过 1.0m，最大达 1.5m。及时采用应急加固措施，避免了整体滑动，确保了县城安全。

In August, 2002, signs of deformation were discovered; accelerated deformation began in February, 2005 with a crack in the crown slipping as much as 1.0-1.5 m, indicating that the entire mass was sliding. Emergency measures to prevent large-scale sliding included overload in the toe, anchoring in the front and the middle, etc.



滑坡后缘裂缝下错 1.0m 以上，整体滑动可能加大
Crack in the crown dislocated vertically as much as 1.0 m, indicating a great possibility of large scale landsliding



滑坡后缘拉张裂缝宽达 0.5m, 贯通良好
A crack with a width of 0.5 m in the crown



滑坡后缘被牵引滑动
Secondary landslide in the rear



滑坡前缘挡墙压裂鼓胀
Retaining wall bulged due to landslide thrust



滑坡前缘房屋挤压变形
The house was crushed and the cement floor had to be cut down



滑坡前缘建筑物脱层架空
A house in front of the landslide was damaged



滑坡前缘保坎叠置
Steps were displaced one by one due to landslide thrust



滑坡前缘挡墙抗推强度差
Retaining wall destroyed by the landslide



滑坡前缘房屋钢筋砼柱错断
Steel concrete column of the house was sheared by the landslide

(本版照片由徐志文、许强、李廷祥提供)



紧急调用武警部队在滑坡前缘堆载沙袋压脚
Civil defense personnel urgently moved to stack sandbags in front of the landslide



滑坡后缘岩体被牵引变形，危及下部县城安全
Fragmented rockmass of the landslide endangered Danba Town



堆放 7000m^3 沙袋，有效地减缓了滑坡变形滑动
Sandbags with a volume of 7000 m^3 were urgently stacked in front of the landslide that efficiently reduce sliding



清除滑坡后缘危岩，确保县城安全
Removing the dangerous rock to ensure the safety of Danba Town



滑坡应急抢险预应力锚固工程施工
Pre-stressed anchors were urgently applied



在滑坡前缘紧急堆置沙袋压脚，上部进行锚索加固
Pre-stressed anchors were constructed above the sandbag stack



预应力锚索入孔搬运
Moving anchor cable into borehole



安装完成的预应力锚索及格构梁
Anchor and concrete lattice girder for stabilization of landslide



锚索入孔，即将张拉锁定
Placing the cable in the borehole for pre-stressing



锚固工程外锚墩打筑
Casting the concrete bulkhead for the pre-stressed cable



用钢筋砼格构梁连接锚索，增加结构刚度
The anchor cables were connected with reinforced concrete beam



预应力锚固工程外锚墩浇筑
Casting concrete bulkhead of the anchor cable in place



应急抢险结束后的滑坡：施加了244束1000kN级预应力锚索，前缘压脚支挡7000m³
The emergency measures consist of 244 anchor cables with 1000 kN capacity and 7000 m³ of sandbags stacked at the toe of the landslide



独具藏族特色的丹巴县城一角
The Tibetan scenery of Danba Town near the Daduhe River

四川康定城白土坎滑坡

Baitukan Landslide, Kangding, Sichuan Province



康定城区白土坎滑坡全貌
Overview of the Baitukan landslide in Kangding, Sichuan Province



白土坎滑坡滑带
The slip zone of the Baitukan landslide, Kangding, Sichuan Province



白土坎滑坡前缘被瓦斯沟河水冲刷掏空
The Baitukan landslide toe eroded by the river



白土坎滑坡防治工程
Remedial work on the Baitukan landslide



康定城街景
Scenery of Kangding City

青海黄南州隆务镇黄土滑坡

Loess Landslide at Longwu, Huangnan, Qinghai Province



青海黄南州隆务镇后山黄土滑坡
Loess landslide at Longwu Town, Huangnan, Qinghai Province



隆务镇后山黄土滑坡后缘出现滑动
New sliding on the main scarp of the loess landslide, Huangnan, Qinghai Province



青海黄南州隆务镇后山黄土滑坡危及下部居民
The landslide endangers the town of Huangnan, Qinghai Province



青海黄南州隆务镇后山黄土滑坡前部
The front of the loess landslide, Huangnan, Qinghai Province



青海黄南州隆务镇后山黄土滑坡
The loess landslide at Longwu Town, Huangnan, Qinghai Province



青海黄南州隆务镇后山马兰黄土
Malan loess (Q_3) at the back of the town that is the parent material of the landslide

云南德钦县城滑坡和泥石流

Landslide and Debris at Deqing, Yunnan Province



云南德钦县城被滑坡和泥石流围困
Landslide debris surrounds, Deqing Town, Yunnan Province



云南德钦县城东后山古滑坡
Ancient landslide at the back of Deqing Town



云南德钦县城后部雪山物理风化强烈，形成泥石流物源
Strongly weathered rockmass provides materials for debris slide



云南德钦县城西泥石流治理工程
Drainage trench for debris flow, Deqing, Yunnan Province



云南德钦县城后山泥石流物源非常丰富
Abundant materials for debris flow in a back hill of Deqing Town, Yunnan Province



云南德钦县城建房开挖滑坡堆积体边坡
Slope cuts for housing in the landslide material, Deqing Town, Yunan Province



云南德钦县城玄武岩非常破碎，稳定性差
Unstable slope made of intensely fractured basalt



数方土体下滑毁坏房屋，造成 2 人死亡
A damaged house and 2 deaths resulted from a mass sliding of several cubic metres

北京黑龙潭景区山体崩塌

Rockfall in the Scenic Heilongtan District, Miyun, Beijing



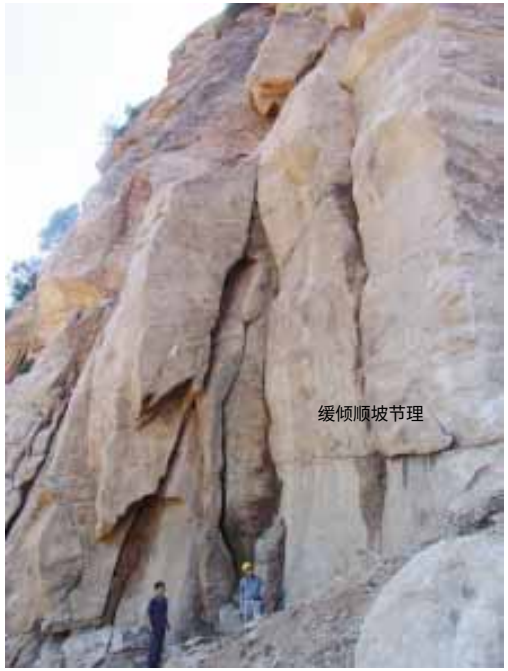
山体为前寒武系花岗岩，被多组节理切割
The slope is made of densely jointed Pre-Cambrian granite gneiss

2005 年 8 月 15 日，北京密云黑龙潭景区柏平段 31km 处发生山体崩塌，形成长 100m、宽 60m、高 25m、体积约 1.5 万 m^3 的堆积体。岩性为片麻状花岗岩。崩塌是因岩体垂直节理发育，边坡陡峻，突降暴雨所致。暴雨历时80分钟，最大降雨量达到220mm。

The 100 m-long, 60 m-wide, 25 m-high, and 1500 m^3-volume rockfall suddenly severed the transportation and was triggered by a 200 mm / 80 minutes rainfall event.



岩体中发育一组与公路直交的节理
Rockmass crossed by vertical joints normal to the slope face and stress relief joints almost parallel to slope surface



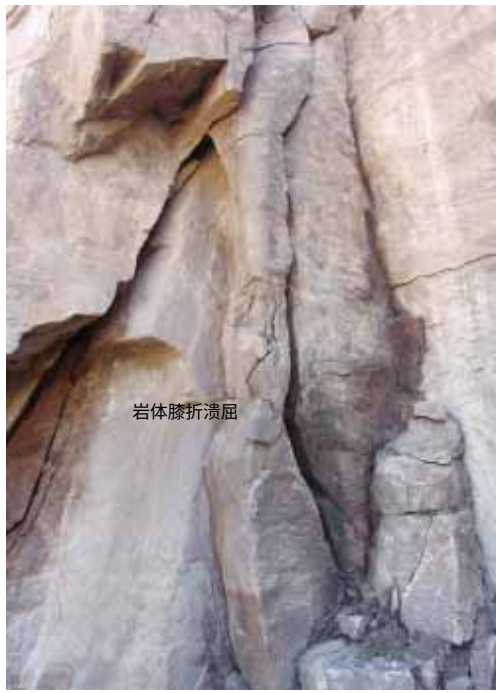
岩体中分布缓倾顺坡节理, 构成下部分离面
Stress-relief joints and gently dipping bedding planes form the discontinuous rockmass



崩塌巨石堵塞公路, 体积达 2000m^3 (下部)
Massive boulder with a volume of 2000 m^3 blocked a road (lower part)



崩塌巨石堵塞公路, 体积达 2000m^3 (上部)
Massif boulder blocked road with a volume of 2000 m^3 (upper part)



岩体被压裂形成膝折溃屈
Squashed rockmass in knee-shaped

甘肃高速公路黄土边坡及防护工程

Engineered Slope and Protection Work on a Highway, Gansu Province



兰州－天水高速公路黄土边坡
General view of the engineered slope in loess on the highway from Lanzhou to Tianshui, Gansu Province



兰州－天水高速公路边坡整治工程
Retaining wall and modification for engineered slope highway from Lanzhou to Tianshui, Gansu Province

(本版照片由余志山提供)



兰州－天水高速公路下部重力挡墙护坡，上部修坡
Retaining wall in the lower part and revetment in the upper part of an engineered slope in loess, the highway from Lanzhou to Tianshui, Gansu Province



兰州－西宁高速公路下部重力挡墙护坡，上部喷锚网护坡
Retaining wall in the lower part and shotcret in the upper part of an engineered slope in loess, the highway from Lanzhou to Xining



兰州－西宁高速公路边坡 (挡墙 + 喷锚网 + 格构防护)
Comprehensive protection with retaining wall, shotcrete and concrete lattice for an engineered slope in loess, the highway from Lanzhou to Xining



兰州－西宁高速公路边坡 (挡墙 + 喷锚网 + 格构防护)
Comprehensive protection with retaining wall, shotcrete and concrete lattice for an engineered slope in loess, the highway from Lanzhou to Xining

(本版照片由余志山提供)



兰州－西宁高速公路紫红色泥岩边坡防护
Protection work for an engineered slope in purple-red mudstone, the highway from Lanzhou to Xining



兰州－天水高速公路紫红色泥岩和黄土边坡防护
Retaining wall for a purple-red mudstone slope and protection work for a loess slope, the highway from Lanzhou to Tianshui, Gansu Province



兰州－西宁高速公路边坡防护及上部山体绿化
The retaining wall for an engineered slope in loess. The upper is vegetated, the highway from Lanzhou to Xining



兰州胡洼山隧道东出口泥岩边坡防护工程失稳
Shotcrete failure in an engineered slope in mudstone, exit of the Huwashan tunnel, Lanzhou, Gansu Province

(本版照片由余志山提供)

·国道 318 川藏公路业拉山下“108 拐”远景·

国道 318 川藏公路业拉山下“108 拐”远景

Switchbacks of the Sichuan-Tibet Section of National Highway 318



嘎玛沟 1 处滑坡防治工程

Prevention works on No.1 landslide of the Gama valley



国道 318 川藏公路金沙江西岸边坡
Slope in the Sichuan-Tibet segment of national highway 318, Zhubalong, the western shore of the Jinshajiang River



国道 318 川藏公路澜沧江如美斜坡概貌
Slope in the Sichuan-Tibet segment of national highway 318, Lanchangjiang River



国道 318 川藏公路然乌河段边坡
Slope in the Sichuan-Tibet segment of national highway 318, Ranwu River



国道 318 川藏公路通麦段边坡
Slope in the Sichuan-Tibet segment of national highway 318, Tongmai, Palongzangbu River



乌江河谷武隆段顺向坡远眺
Overview of a slope along the Wujiang River, a branch of the Yangtze River



河谷陡峻，上部岩体形成压裂带，公路穿行在人工凹槽中
Highway development along a steep-walled valley, the over hanging cats were made in slightly jointed limestone



利用钢筋砼棚硐防止碎屑流毁坏交通
Concrete shed for protection from debris sliding



利用钢筋砼棚硐防止崩塌毁坏交通
Another view of concrete shed for protection from rockfall



乌江河谷公路边坡岩体损伤, 形成松动裂隙带
Damaged rockmass due to slope cutting, with loosening stress-relief zone



乌江河谷岩溶槽隙边坡
Engineered slope in karst



乌江河谷石灰岩体卸荷松动裂隙发育, 边坡稳定性差
Stress reliet fractures parallel to slope surface in the Wujiang River valley. The slope is unstable



乌江河谷石灰岩体边坡岩体损伤, 形成压裂带
Damaged limestone rockmass in a zone of over-pressure,
Wujiang River valley