Engineering Geology for a Habitable Earth

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Field Trip #1

THE XIV CONGRESS OF THE INTERNATIONAL ASSOCIATION FOR ENGINEERING GEOLOGY AND THE ENVIRONMENT

第14届国际工程地质与环境大会

Chengdu, China | Sept. 21-27, 2023

Sponsor

- International Association for Engineering Geology and the Environment (IAEG)

Organizers

- IAEG China National Group
- Engineering Geology Commission, China Geology Society
- State Key Laboratory of Geohazard Prevention and Geoenvironment Protection, Chengdu University of Technology

XIV IAEG Congress 2023 Field Trip

Field Trip #1: Chengdu---Dujiangyan---Yingxiu---Chengdu

Time: September 26, 2023 (Whole day trip, lunch included)

Meeting point: Century City International Convention Centre (1F)
Date and Time: Sept. 26, 07:40 am.

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Topic: (1) Two engineering masterpieces will be introduced at first (Dujiangyan Irrigation System and Zipingpu Reservoir Dam), (2) Some post-earthquake geohazards consequent on the Wenchuan earthquake in 2008 will be introduced. (3) Overview large-scale debris flow mitigation structures

General description:

Fig. 1 The sketch map of the field trip itineraries

DATE	TIME	ROUTING
Sept. 26	07:00-08:00	Breakfast at Hotel
	08:00-09:00	Departure from Chengdu
	09:00-10:30	Visit Dujiangyan Irrigation System
	10:30-11:40	Visit Zipingpu Dam
	12:00-13:00	Lunch
	13:00-13:30	To Yingxiu Town
	13:30-14:40	Visit Xukou Middle School Ruins
	14:40-17:30	Visit Niujuan Gully and Hongchun Gully
	17:30-19:00 (expected time)	Departure to Chengdu

1. Dujiangyan irrigation system

The Dujiangyan Irrigation System, an engineering masterpiece, is a well-known attraction in Dujiangyan city and has been recognized as a UNESCO World Heritage Site for its stunning beauty. Remarkably, this irrigation system functions flawlessly without a dam or reservoir, efficiently preventing floods and irrigating arid lands.

Dujiangyan irrigation system located in Dujiangyan City, Sichuan, China was constructed around 256 BC by the State of Qin to regulate floods and manage irrigation. The system continues to serve its purpose even today. The infrastructure of the system spans across the Min River, which is the longest tributary of the Yangtze, in the western region of the Chengdu Plain, between the Tibetan Plateau and the Sichuan Basin. Before the construction of the system, the Min River would rapidly descend from the Min Mountains and decelerate abruptly upon reaching the Chengdu Plain, and the silt-laden water would elevate the river bed and making the nearby areas highly susceptible to flooding.

Commissioned by King Zhao of Qin, the Dujiangyan project utilized a novel technique of channeling and dividing the river's water rather than constructing a dam. As a result, during the dry season, 60% of the discharge naturally flows into the Chengdu Plain, while in the rainy season, the water management system prevents flooding. Additionally, 80% of the sediments in the flow are drained out to the outstream. Today, the water management scheme continues to irrigate over 5,300 square kilometers of land in the region, providing significant benefits in flood control, irrigation, water transport, and general water usage. Dating back more than 2,250 years (coinciding with the Punic wars between Rome and Carthage), the Dujiangyan irrigation system now irrigates approximately

668,700 hectares of farmland.

Geography

The Dujiangyan irrigation system is situated at the convergence of the Sichuan basin and the Qinghai-Tibet plateau, in the western part of the Chengdu flatlands. The site is located at the intersection of two topographic steps, where the western plateau mountains meet the Chengdu Plain. It is the southwest extension of the Longmen Mountains and falls within the region traversed by the Longmen Mountain Fault Zone. The irrigation system's elevation is higher in the northwest and lower in the southeast. The west region belongs to the southern areas of Longmen Mountains, with the mountain elevation below 3000 meters. The east is Chengdu Plain, with an altitude of 720 meters.

Fig. 2 The dujiangyan irrigation system

History

During the Warring States period, the Min River's annual floods were a major problem for the residents living along its banks. Li Bing, a Qin hydrologist, investigated the problem and discovered that the river was swelled by fast flowing spring melt-water from the local mountains that burst the banks when it reached the slow moving and heavily silted stretch below.

One solution would have been to build a dam, but the Qin wanted to keep the waterway open for military vessels to supply troops on the frontier, so instead an artificial levee was constructed to redirect a portion of the river's flow and then to cut a channel through Mount Yulei to discharge the excess water upon the dry Chengdu

Plain beyond King Zhao of Qin allocated 100,000 taels of silver for the project and sent a team said to number tens of thousands. The levee was constructed from long sausage-shaped baskets of woven bamboo filled with stones known as Zhulong held in place by wooden tripods known as Macha. The construction of a water-diversion levee resembling a fish's mouth took four years to complete.

Fig. 3 Statue of li bing and his son, the hydraulic engineer responsible for dujiangyan construction

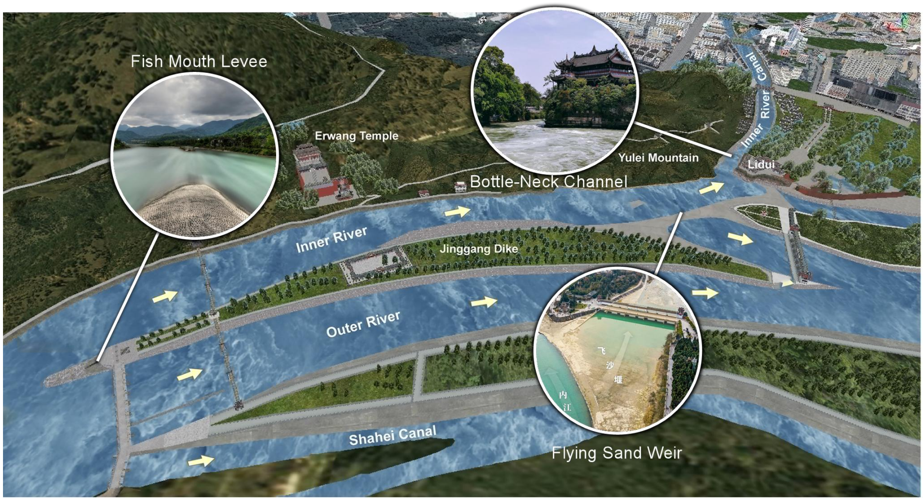


Fig. 4 The position of the fish mouse levee (yuzui), the flying sand weir (feishayan), and the bottle-neck channel (baopingkou) consist the three main constructions of the dujiangyan irrigation system.

However, cutting the channel proved to be a greater challenge, as the tools available at the time, before gunpowder was invented, could not penetrate the hard rock of the mountain. People used fire to heat the rocks and cooled them down rapidly with water, so the dramatic distinctions in temperature made rocks to fragment. After eight years of hard work, a 20-meter (66 ft)-wide channel had been gouged through the mountain.

After the completion of the system, no more floods occurred, and the irrigation made Sichuan the most productive agricultural region in China. The construction is also credited with giving the people of the region a laid-back attitude towards life, as it eliminated disasters and ensured a regular and bountiful harvest, leaving them with plenty of free time.

Hydraulic engineering marvel

The irrigation system consists of three main constructions that work in harmony with one another to ensure against flooding and keep the fields well supplied with water:

The Yuzui or Fish Mouth Levee (Chinese:鱼嘴), named for its conical head that is said to resemble the mouth of a fish, is the key part of the construction. It is an artificial levee that divides the water into inner and outer streams. The inner stream is deep and narrow, while the outer stream is relatively shallow but wide. This special structure ensures that the inner stream carries approximately 60% of the river's water into the irrigation system during dry season. While during flood, this amount decreases to 40% to protect the people from flooding. The outer stream drains away the rest, flushing out much of the silt and sediment.

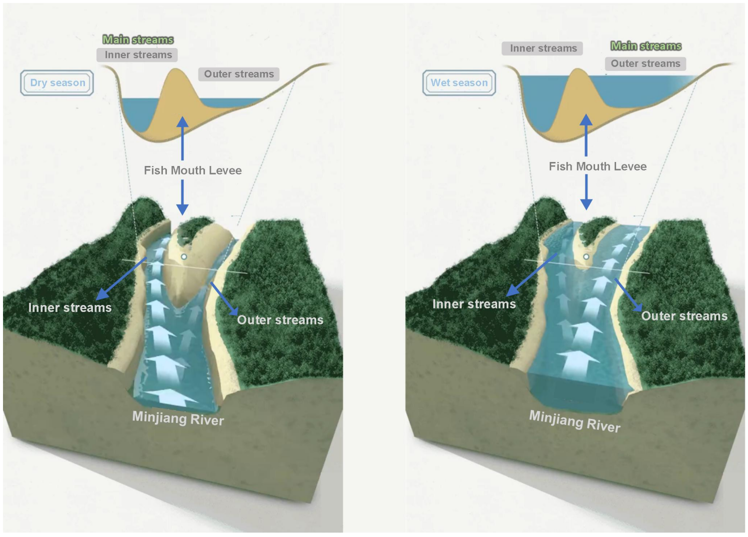
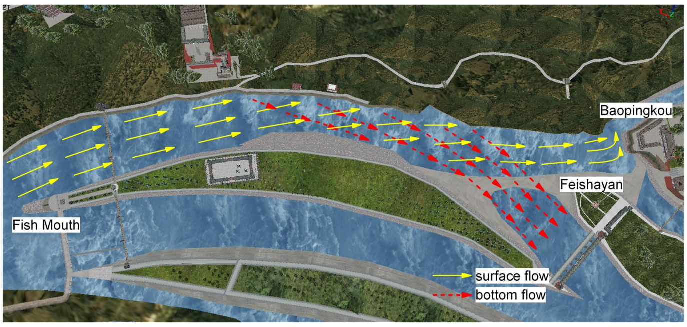


Fig. 5 The fish mouse levee (yuzui) ensures that the inner stream carries approximately 60% of the river's flow into the inner stream (to chengdu plain) during dry season. while uring flood, this amount decreases to 40% to protect the people from flooding.

The Feishayan or Flying Sand Weir (Chinese:飞沙堰) has a 200-meter (660 ft)-wide opening that connects the inner and outer streams. This ensures against flooding by allowing the natural swirling flow of the water to drain out excess water from the inner to the outer stream. The swirl also drains out silt and sediment that failed to go into the outer stream. A modern reinforced concrete weir has replaced the original weighted bamboo baskets.



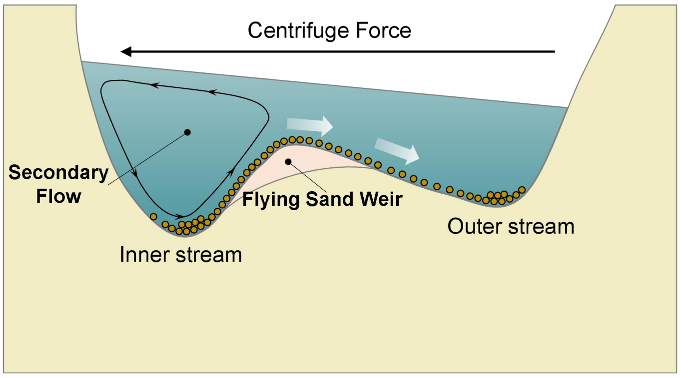


Fig. 6 The flying sand weir (feishayan) can drain out sand into the outer stream by hydraulic principles.

The Baopingkou or Bottle-Neck Channel (Chinese:宝瓶口) , which was gouged through the mountain, is the last component of the system. The channel is responsible for distributing the water to the farmlands in the Chengdu Plain, whilst the narrow entrance The narrow entrance of the channel, from which it gets its name, acts as a check gate, creating a swirling current that discharges any excess water over the Flying Sand Fence, thus preventing flooding.

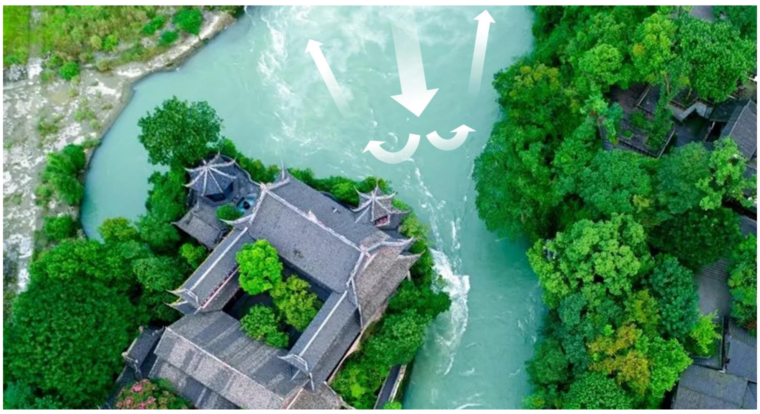


Fig. 7 The bottle-neck channel (baopingkou) controls the discharge to the chengdu plain, and also creates

whirlpool flow to bring back sand to feishayan and fengqiwo upstream.

Fig. 8 The Dujiangyan irrigation system is still in use today to irrigate over 5,300 km^2 in the chengdu plain region and has produced comprehensive benefits in flood control, irrigation, water transport and general water consumption.

2. The Zipingpu water conservancy project

The Zipingpu Water Conservancy Project is located on the MinJiang River, 9 and 60 km respectively upstream from the Dujianyan City and Chengdu City-the capital city of Sichuan Province. The Minjiang River has a catchment area of 22662 km^2 above the dam, with a mean annual flow of 469 m^3 /s and an annual runoff of 14.8×10^{9}m^3. The main functions of the project are irrigation and water supply, with comprehensive benefits in power generation, flood control, environment protection and tourism. The check and design flood levels, the normal and minimum pool levels are 883.10 and 871.20, 877.00 and 817.00 m, respectively. The total capacity of the reservoir is 1.112×10^{9}m^3.

Fig. 9 Panorama of zipingpu water conservancy project.

On May 12, 2008, a major earthquake measured 8 on the Richter scale jolted Wenchuan County in Sichuan Province, China, with the epicentral intensity of XI degrees. Zipingpu Dam is located 17.17 km from the epicenter and the influence intensity at the damsite reached IX-X degrees. It is the first time in the world for such a high concrete-faced rockfill dam (CFRD) in China to experience such a strong earthquake occurring in such a short distance.

Fig. 10 Zipingpu dam after the may 12 earthquake. (a) upstream slabs (reservoir level 830.0 m). (b) downstream slope of the dam and the open channel spillway.

The basic seismic intensity for the Zipingpu project is VII degrees and the designed intensity for the dam is VIII, one degree above the basic seismic intensity according to the scale and importance of the project. The adopted dynamic peak acceleration with an exceeding probability of 2% in 100 years is 0.26 g. Compared with the above-said designs, the earthquake that the dam experienced substantially exceeded the designed earthquake-resistance standard both in seismic intensity and dynamic peak acceleration. According to the newly published revised seismic zoning map after the earthquake, the Zipingpu damsite is located in a zone of VIII degrees in basic seismic intensity and the designed intensity should be IX degrees.

The damages of structures include cracking of the curb stones on the downstream side of the dam crest, tensile cracking and squeezing damage of the "L-shaped" up-stream wave wall, occurring respectively on its both sides and in its middle part.

The horizontal joints between the slab top and the wave wall were dislocated, resulting from the seismic subsidence. The rock fills were loosen and dislocated by the earthquake at the location of about one fifth of the dam height in the middle part of the dam. Some slabs were separated from the cushion layer and some construction joints were dislocated and some vertical joints were damaged by squeezing.

Fig. 11 Earthquake damages to the project structures. (a) loosen rock fills on the downstream side of the dam; (b) open and dislocation of the downstream border of the dam crest; (c) damages of the horizontal joints at the dam crest resulting from subsidence of the wave wall; (d) squeezing damages between the no. 23 and no. 24 slabs.

The No.5 and No.6 slabs on the left abutment were heaved up by squeezing and damaged severely, with a maximum dislocation of 350 mm. The joint between the No. 23 and No. 24 slabs was damaged by squeezing, extending from the dam crest to the elevation 791.00 m, 26.0 m below the dead storage level. The No.23 slab was damaged with a transverse width of 0.5-1.7 m, and a depth of 320 mm and a separation void of 50 mm, according to borehole inspection at the elevation of 843.00 m. The conformal mesh reinforcement between the slabs was separated from the protective layer of concrete. The stress steel bars in the middle of the slab were bended and the longitudinal squeezing damage is severer than that under normal condition.

The third-phase slab, 59 m in length, 420-300 mm in normal thickness, has a total area of 36800 m^2 and a total concrete volume of 15450 m^3. According to the measured data of gap meters and the results of 75 inspection boreholes, separation voids were observed in a large area between the third-phase slabs and the cushion layer above the elevation of 845.00 m on the left bank. However, only one inspection borehole revealed a separation void of 20 mm at the elevation of 870.00 m. The separation voids were extensively observed below the third-phase slabs above the elevation of 880.00 m with a maximum height of 230 mm. Separation voids were revealed locally below the second-phase slabs at the elevation of 843.00 m near the left abutment, with a maximum height of 70 mm. The separation voids under the third-phase slabs make up 55% of the total area of the third-phase slabs.

The construction joints of the second- and third-phase slabs were found dislocated obviously, with a dislocation of 15-170 mm for the slabs Nos. 5-12, 120-150 mm for the slabs Nos. 14-23, and 20-90 mm for the slabs Nos. 30-42, covering a total length of 340 m. After removal of the damaged concrete on the surface, it was found that the dislocation of the No. 8 slab caused "S" shaped bending of the stress steel bars in the middle part of the No. 8 slab, cracking and separation of the concrete below the stress steel bars of the third-phase slabs and breaking of the contact concrete. The horizontal dislocation of the No.10 slab reached 230 mm, resulting in shearing off of the copper seals between the slabs and exposure of the steel bars in the joints.

Fig. 12 Dislocation of the horizontal construction joints of the slabs. (a) excavation of the damaged longitudinal joint of the no. 23 slab (after removal of the broken concrete). (b) the exposed horizontal joints at el. 845 m after local removal of concrete. (c) repairing the dislocated horizontal joints of the no.8 slab (the stress bar bended in "s" shape). (d) repairing construction of the damaged slabs.

Based on the analysis of the monitoring data, it can be concluded that the main performance of the dam has not been changed, even though the earthquake has brought about obvious damages to the water proof slabs and the horizontal joints, resulting in a certain increase of the total seepage through the dam, which are all local problems and will not affect the whole stability of the dam. The hydraulic structures designed according to China's code for earthquake resistance design can resist an earthquake

with the designed intensity and will be able to work normally even if some local damages occur. The Zipingpu Dam has experienced an earthquake with the intensity far exceeding the designed intensity and its performance can still meet the requirements of the code, which demonstrates that the design and construction quality of the dam are satisfactory. In addition, the good performance of the Zipingpu Dam that has experienced the test of the strong earthquake should also be attributed to CFRD's good capability for earthquake resistance. It can therefore be concluded through comprehensive assessment that the local earthquake damages are repairable. The post-earthquake inspection indicates that the seepage control system is still effective, the flood release structures are operational and the freeboard of the dam is still within the preset range. The dam, as a whole, is stable and safe under present operational condition.

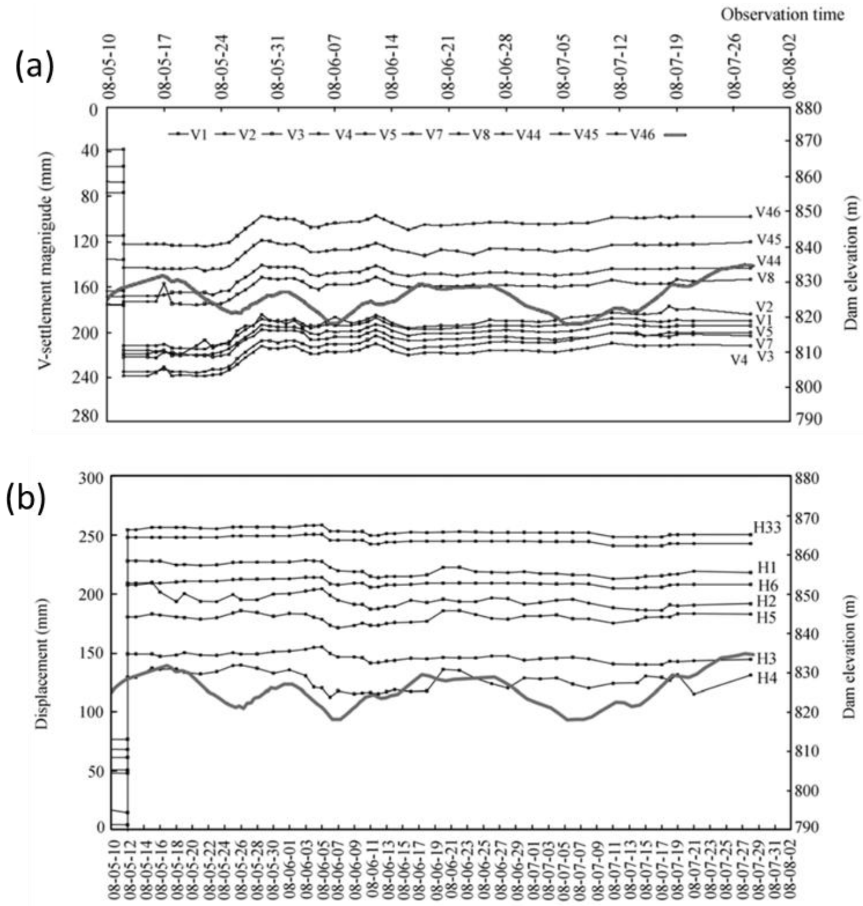


Fig. 13 The interior observation results of the dam. (a) settlement graph of the observation points at el. 760m; (b) horizontal displacement graph of the observation points at el. 760.0 m (positive in downstream direction).

3. Lunch Break

4. Xuankou middle school earthquake relic

The earthquake occurred on 12 May 2008 at 14:28, when students were in school, and office workers had returned to their desks from lunch. The epicenter was eighty kilometers away from the megacity of Chengdu (7.6

million inhabitants). The catastrophic earthquake was the country's worst natural disaster since the 1976 Tangshan earthquake, which killed at least 240,000 people. The impact of the earthquake was very large: 87,419 were killed or missing and 374,176 were injured (Huang and Fan,2013; Tang et al.,2012). The Yingxiu area located in the southeast of Wenchuan County is one of the most destructively damaged regions during the Wenchuan earthquake (Fig.14). The government began an ambitious reconstruction project to build about 5 million houses across the 3 provinces within 2 years. By the 1 year anniversary, reconstruction was well ahead of this deadline. By September 2009, nearly 95% of houses were completed in Sichuan. The government also announced 12 May 2010 as the deadline for all non-government organizations to complete all earthquake reconstruction projects (Tang and Westen, 2018).

Fig. 14 The yingxiu town (a. aerial photo taken on may 23,2008, b. iknos image taken on december 21, 2011)

The middle school was built in 2006, and had 1,527 students and 133 teachers, which was a symbolic construction of Yingxiu town before the earthquake. Now it is a memorial site of the Wenchuan Earthquake. 43 students, 8 teachers, and 4 workers were dead during the earthquake. It is the only relatively well-preserved large-scale site in the "5.12" Wenchuan earthquake. It is also the venue for the anniversary memorial ceremony for the "5.12" Wenchuan earthquake in 2009 and the venue for the 10th anniversary of "5.12". It is composed of the white marble sculpture "Wenchuan Moments" (Fig.15) and "5.12" Wenchuan Earthquake Chronicle Wall (Fig.15). The "Wenchuan Moments" sculpture pays tribute to the unfortunate victims of the earthquake, the martyrs who died heroically in the earthquake relief and disaster relief expressed their deep thoughts and engraved the strong will of the Chinese people to dare to overcome all difficulties.

Fig. 15 White marble sculpture "wenchuan moments" (left) and wenchuan earthquake chronicle wall (right)

There were ten reinforced concrete (RC) frame buildings, including three classroom buildings, one office building, five residential or dormitory buildings, and one dining building. And three of the ten RC frames totally collapsed, two partially collapsed, and the other five suffered various levels of damage (Fig.16).

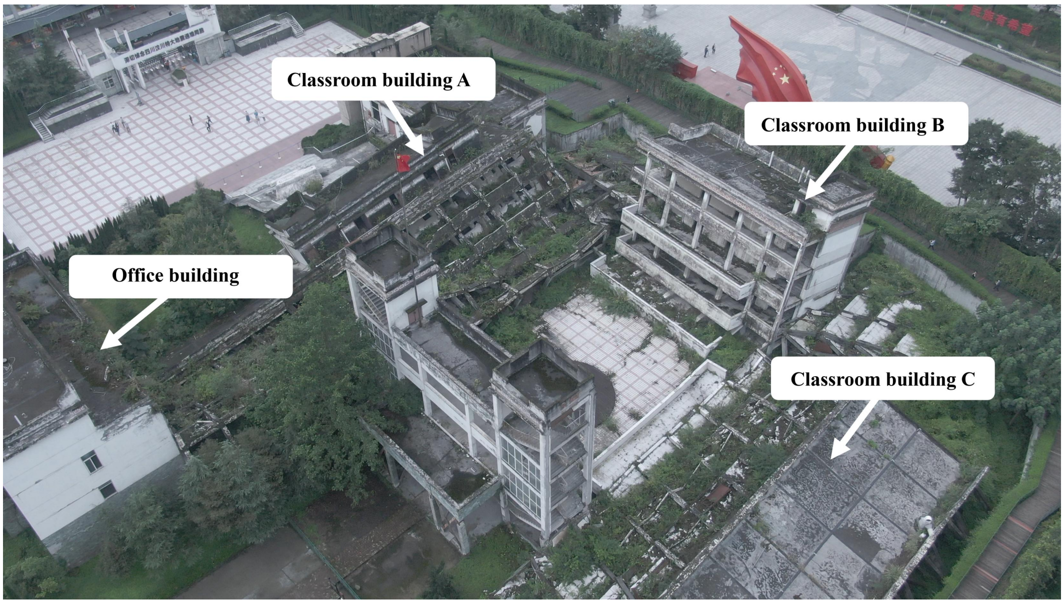


Fig. 16 Panorama of xuankou middle school after earthquake

Xuankou middle school students' dormitory had five stories (Fig.17), the underlying had serious damage and cross gable crack that extended to the vertical walls. In the upper stories, the wall under the windows and the wall between windows had cross damage too. The bottom of the vertical wall had serious damage but did not lose the carrying capacity of the structure. Figure 6 was teaching building. In addition, the foundation and the structure had been collapsed. The structure had collapsed with cross wall damage of each storey. The bottom storey had collapsed too, and the weak area in each storey collapsed and lack of storey yield(Fig.18).

Fig. 17 The earthquake damage of xuankou middle school students' dormitory

Fig. 18 The earthquake damage of xuankou middle school teaching building

Since the Wenchuan earthquake in 2008, intense rainfall events have triggered a large number of debris flows (Fig.19), leaving more than 2,000 people dead or missing, and creating many problems during the restoration and reconstruction of the earthquake-affected areas (Wang et al., 2022). The Year 2010 was the most tragic disaster year for debris flows in the Wenchuan-earthquake-affected area (Fig.20). In succession, Yingxiu Town, which was located near the epicenter, suffered serious debris flow disaster and coupled flood event on 14 August 2010 (Xu et al., 2012; Chang et al., 2017).

Fig.19 Aerial photo taken on august 15th, 2010 showing the debris flows induced by the august 13th-14th, 2010 heavy rainfall along the minjiang river (from yingxiu to laohuzui)

Fig. 20 The yingxiu town (photo taken n august 14, 2010)

5. Niujuan debris flow

The Niujuan Gully (Fig. 21, Fig. 22) was the epicenter of the "5.12" Wenchuan earthquake. The total length of the valley is 3 km, before the earthquake, a group of 33 villagers in Zhangjiaping Village lived here, the "5.12" Wenchuan earthquake began to tear the earth from here in Niujuan Gully, huge energy to smash the underground rocks, with a terrifying loud noise, millions of cubic meters of rock fragments ejected from the earth's crust, causing strange and terrible rock flows down the valley in a zigzag shape hitting the mountains on both sides of the valley, forming a huge source ejection, nearly 3 km long rock flow and 9 mountains hit such a unique source wonder. Before the Wenchuan earthquake in 2008, Niujuan Gully was a clear water gully. Unfavorable geological phenomena such as collapse and landslides in the basin were not obvious, and only a small volume of loose deposits was observed in the gully, with a total amount of approximately 93.97 × 104 m^3. After the earthquake,

Niujuan Gully was transformed into a high-frequency debris-flow gully. Adverse geological disasters such as collapses and landslides in the study area affected by the earthquake subsequently strongly developed, with the material source amount caused by collapse and landslide having been estimated as approximately 695.22 × 104 m^3, providing abundant loose solid materials for the occurrence of debris flows (Fan et al., 2019).

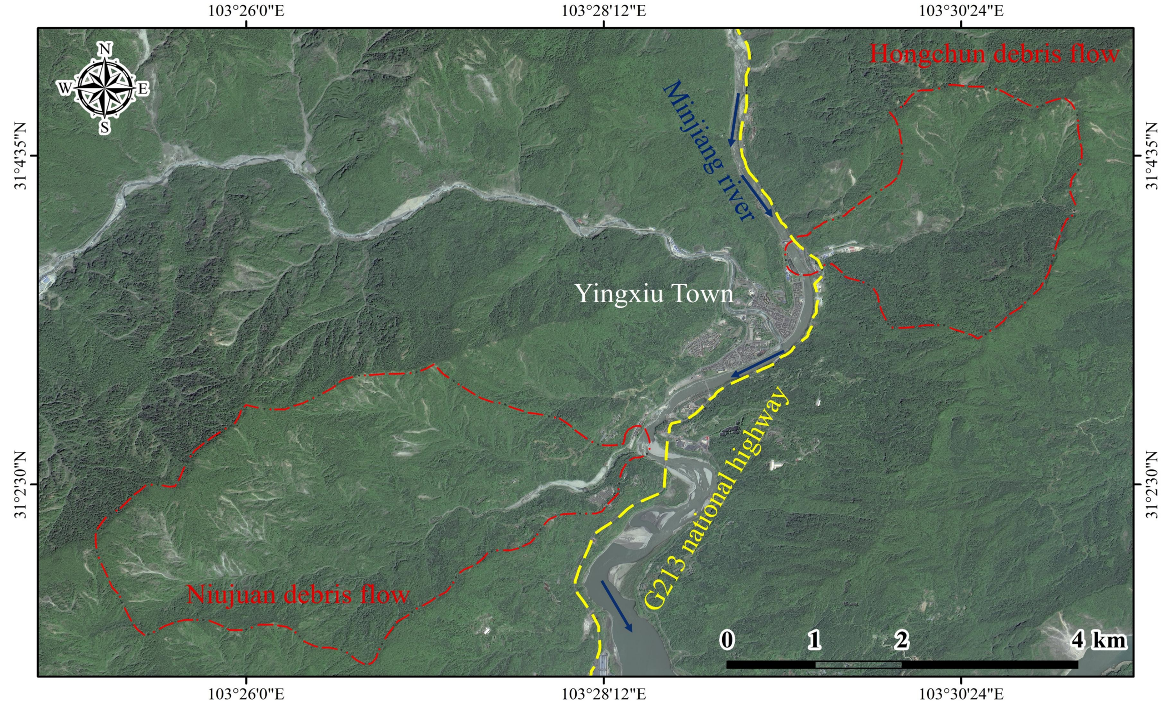


Fig. 21 Location of hongchun debris flow and niujuan debris flow

Fig. 22 Drainage channel of niujuan debris flow

6. Hongchun Debris Flow

The Hongchun gully (Fig.21) is located on the left bank of the Minjiang River and adjacent to the 2008 Wenchuan earthquake's epicenter. It has a catchment area of 5.35 km2 and a height range from 880 m to 1,700 m. The catchment area is an ancient debris flow gully and the total volume of loosely deposited material increased to 350 × 104 m3 after the Wenchuan earthquake. The bedrocks mainly consist of highly fractured and weathered granitic rocks, Sinian pyroclastic rock, Carboniferous limestone, and Triassic sandstone. On August 14, 2010, at 3:00 A.M., triggered by intense rainfall, numerous debris flows occurred near Yingxiu. These flows deposited mud, debris, and rocks onto the G213 national road and the Dujiangyan–Wenchuan highway (at that time under construction), and finally moved down into the Minjiang River (Fig.23). They produced debris dams that entirely or partially blocked the Minjiang River at tributary junctions resulting in severe flooding in Yingxiu. Hongchun Gully, one of these debris flows, produced a huge debris dam, which then changed the course of the Minjiang River and resulted in the flooding of the newly reconstructed Yingxiu Town. The peak discharge of the river increased from 570 m3/s to 1,400 m3/s on August 15th, shortly after the debris flow damming event. The flood depth was 2.0 - 3.5 m and lasted 7 days until the dam was excavated on August 20th, 2010. This catastrophic debris-flow damming event caused 32 fatalities. More than 8,000 residents have been forced to evacuate after the debris flow occurred. To reduce the potential debris flow hazard in the future, control works have been constructed (Fig.24). Prior to this catastrophic event, debris flow hazard had been recognized in the region, but its potential for such widespread and devastating impacts was not fully appreciated.

Fig. 23 Aerial photo showing the depositional fan of the hongchun debris flow (taken on aug 15th, 2010)

Fig. 24 Check dams constructed in the gully for debris-flow hazard mitigation

Responsibilities:

Participants must take responsibility for their safety and the safety of those around them. They are expected to follow all policies and procedures and complete the necessary forms. They must attend any designated information sessions and/or training and provide all required equipment (e.g. enclosed shoes, hats) as instructed.

- Participants **must** carefully read **Informed Risks and Related Matters of Field Trips** and prepare accordingly in advance.
- Participants **must** complete all relevant forms including **Field Trip Responsibility Commitment Form** and **Health Risk Assessment Form** by the date set by the Field Trip Leader;
- Failure to provide adequate information such as relevant medical conditions or emergency contact details will result in the participants not being able to attend the field trip;
- The personal emergency contact details will be included in the field trip documentation and should be available on the field trip.

Health Assessment

If a participant has a medical condition that may cause problems on a fieldwork trip, or if they do not feel they are fit enough to take part in fieldwork, they must speak to the Fieldwork Leader before the work begins. Participants should also inform the Field Trip Leader of any medical conditions that arise before departure. If the participant regularly takes medication e.g. diabetes, epilepsy, or allergies, it is recommended that the Field Trip Leader is informed before the symptoms if they are not taking the medication. Participants should ensure that they have adequate medication or means to obtain further supplies during fieldwork.

When attending a field trip, participants should let the Field Trip Leader know if they are having difficulty keeping up with the trip. If a participant begins to feel unwell or injured, he must inform the Field Trip Leader immediately.

Risk Assessments and Safe Work Procedures

Risk assessment is an important step in protecting people from harm. In doing this we are complying with the law and more importantly, we are ensuring that the likelihood of causing harm is minimized. The definition of harm at field trips is usually considered to be injury or ill-health but harm can also be damage to property, equipment, or the environment.

Safety Equipment

Field Trip Procedures, all relevant safety equipment taken on the field trip, where possible, must be:

- of an approved design.
- meet the appropriate Chinese standards for the equipment being used and the activity being undertaken (when appropriate).
- used for its intended purpose and in accordance with the manufacturer's instructions and where applicable risk assessment / safe work procedures.
- regularly inspected and maintained.

XIV IAEG
CONGRESS

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