Meditating After Mege 2018 Conference and Site Visit: Geohazard and Damages To Zipingpu Reservoir Induced by Wenchuan Earthquake in China

Mege 2018会议和实地考察后的沉思：
中国汶川地震引发紫坪铺水库的地质灾害和破坏

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1. Geological Background for Lungmanshan Fault Zone
龙门山断裂带地质背景

China Earthquake Belt Distribution Map 中国地震带分布图

China Earthquake Belt 中国地震带

China is located in the world's two major seismic belts - the Pacific Rim seismic zone and the Eurasian seismic zone. It is squeezed by the Pacific plate, the Indian plate and the Philippine sea plate. The seismic fault zone is very active. The earthquakes in China are mainly distributed in five regions: Taiwan Province, Southwest China, Northwest China, North China, Southeast Coast, and 23 seismic zones.

我国位于世界两大地震带——环太平洋地震带与欧亚地震带之间，受太平洋板块、印度板块和菲律宾海板块的挤压，地震断裂带十 活跃。中国地震主要分布在 个区域：台湾省、西南地区、西北地区、华 地区、东南沿海地区和23条地震带上。

Longman Shan Fault Zone 龙门山断层

The Longmenshan fault is a thrust fault in southwestern China, located on the eastern edge of the Qinghai-Tibet Plateau and on the western edge of the Sichuan Basin. It consists of three parallel fault zones from west to east. It runs from northeast to southwest and is about 500 kilometers long and 70 kilometers wide. It is an earthquake-prone area.

龙门山断层是中国西南部的一个逆冲断层，位于青藏高原东缘，四川盆地西缘。自西向东三条平行的断裂带组成，东北-西南走向，长约500公里，宽达70公里，是地震多发区。

The Eurasian plate has formed a huge Qinghai-Tibet Plateau uplift due to the backlog of the Indian-Australian plate towards the north and the east. The Qinghai-Tibet Plateau flows eastward at a speed of 10-15 mm per year. It is blocked by hard Sichuan blocks in the Longmen Mountains, accumulating a large amount of tectonic stress and forming faults.

欧亚板块由于遭到印度-澳洲板块朝向北略偏东方向的积压，形成巨大的青藏高原隆起。青藏高原以每年10-15毫米的速度向东流动，在龙门山一带受到坚硬的四川地块的阻挡，积聚了大量的构造应力，形成了断层。

Longman Shan Fault Zone 龙门山断层

It has not been active since April 21, 1657. During the 300 years, the frequency of the earthquake was less than that of the nearby Xianshuihe fault, and the intensity had never exceeded 6 on the Richter scale. Therefore, it was considered to have gradually Quiet ancient fault.

龙门山断层自1657年4月21日之后，不甚活跃，在300多年间其发生地震的频率不及附近的鲜水河断层，强度也从未超过里氏6级，因此曾被认为是已逐渐沉寂的古老断层。

The Longmenshan tectonic belt consists of three fault zones: Wenchuan-Maoxian fault, Beichuan-Yingxiu fault and Anxian-Gengxian fault from west to east. The activity characteristics of these three faults have changed from southwest to northeast. Backward thrust with a right strike sliding component.

龙门山构造带主要有三条断裂带组成：从西向东分别为汶川-茂县断裂、北川-映秀断裂和安县-灌县断裂,这三条断裂新生代以来的活动特征均表现出由南西向北东斜向逆冲，并伴随右旋滑动分量。

Longman Shan Fault Zone 龙门山断层

The Beichuan-Yingxiu fault, which undergoes a thrust motion under the action of the northwest-south-eastward thrust stress, is a thrust-type earthquake, and the earthquake rupture slides westward with an inclination of about 60.

北川-映秀断裂，该断裂在北西西-南东东向挤压应力作用下，发生逆冲运动，属于逆冲型地震，地震破裂滑动面向西倾，倾角约60°。

Characteristics for Longmanshan Fault Zone
龙门山断裂带的特征

Many continent earthquakes in the world are translational fracture earthquakes or normal fault earthquakes. The Wenchuan earthquake movement is a plot that is thrust over another plot. This type of earthquake mainly occurs in the boundary zone of the plate convergence, such as the Himalayan tectonic belt, the Taiwan seismic belt, and the Tianshan structural belt.

世界上许多大陆地震为平移断裂地震或正断层地震，而汶川地震运动是一个地块逆冲到另一个地块之上。这种地震类型主要发生在板块汇聚边界带上，如喜马拉雅构造带、台湾地震带、天山构造带等。

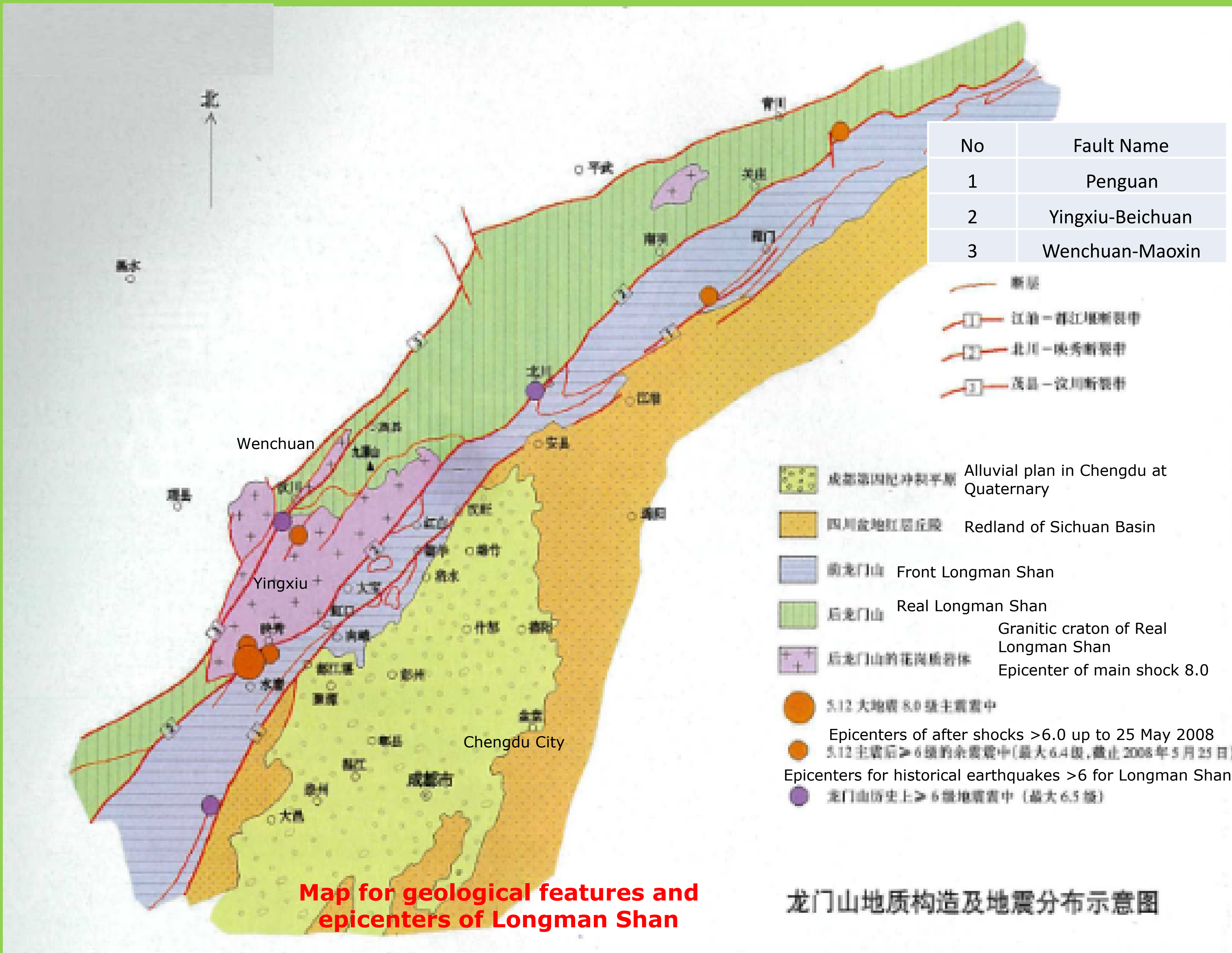
Another feature of the Wenchuan earthquake is that the focal depth is shallow and belongs to shallow earthquakes. The US Geological Survey estimated that the focal depth was located at 10 kilometers, and later has been adjusted to be 19 kilometers. The focal depth determined by the China National Digital Seismic Network is 10 kilometers.

汶川地震的另一个特征是震源深度浅，属于浅震。关于震源深度，美国地质调查局开始认为位于10千米，后来定在19千米。中国国家数字地震台网确定的震源深度为10千米。

Characteristics for Longmanshan Fault Zone
龙门山断裂带的特征

Shallow earthquakes are enormously destructive. The depth of the Kobe 7.2 earthquake in 1995 was also about 1 kilometers. The de0pth of the 7.8 Tangshan earthquake in 1976 was 22 kilometers, which are also the shallow earthquakes.

浅层地震具有巨大的破坏性，1995年神户7.2级地震的震源深度也约10千米，1976年唐山7.8级地震深度22千米，也属浅源地震。



No	Fault Name
1	Penguan
2	Yingxiu-Beichuan
3	Wenchuan-Maoxin

Map for geological features and epicenters of Longman Shan

Shallow to Deep Earthquake
浅层到深层地震

Very shallow earthquake:0 to 30Km
地震震源深度在0~30公里者称为极浅层地震

Shallow Earthquake：31 to 70Km
在31~70公里者称为浅层地震

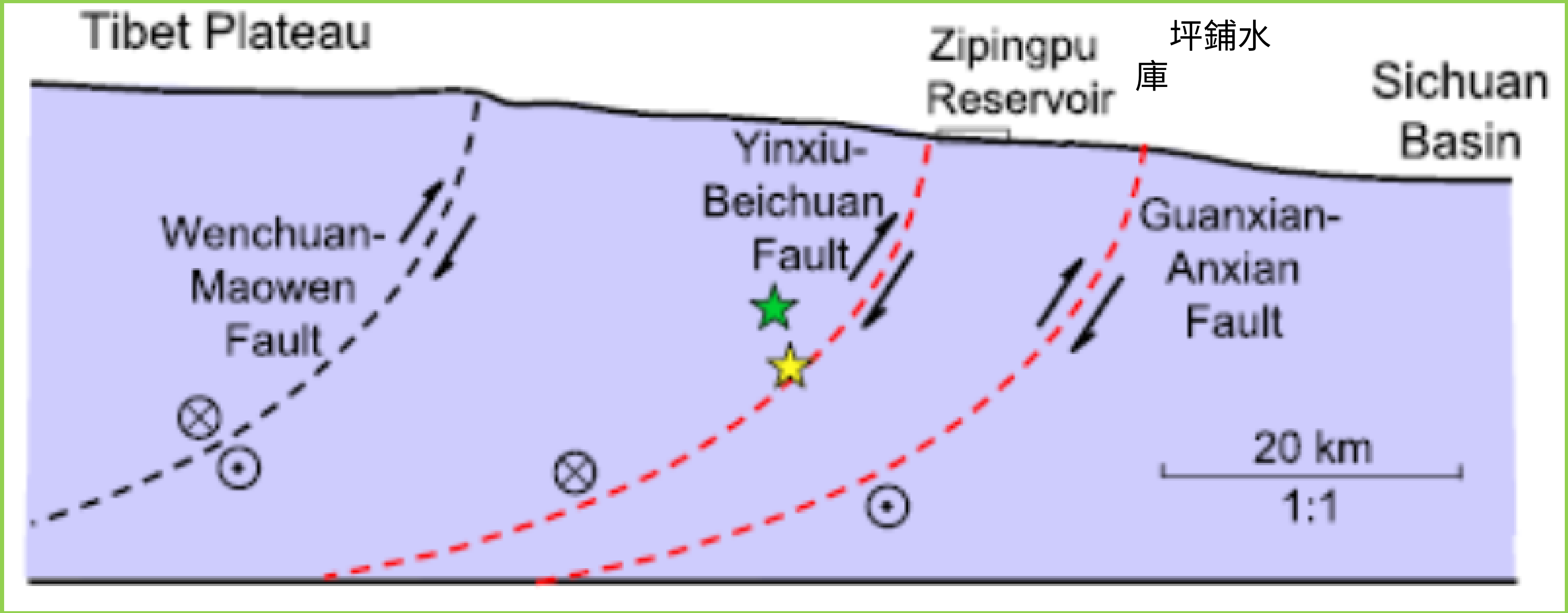
Intermediate Earthquake: 71 to 300Km
在71~300公里者称为中层地震

Deep Earthquake: 300 to 700Km
在301~700公里者称为深层地震

Shallow earthquakes have a high frequency of earthquakes, accounting for 72.5% of the total number of earthquakes, and the released earthquakes account for 85% of the total released energy. Among them, the focal depth is less than 30 kilometers, which is the main producer of earthquake disasters, and has the greatest impact on humans. The impact of such earthquakes can range from 700 to 800 kilometers, and the chance of serious casualties is relatively large.

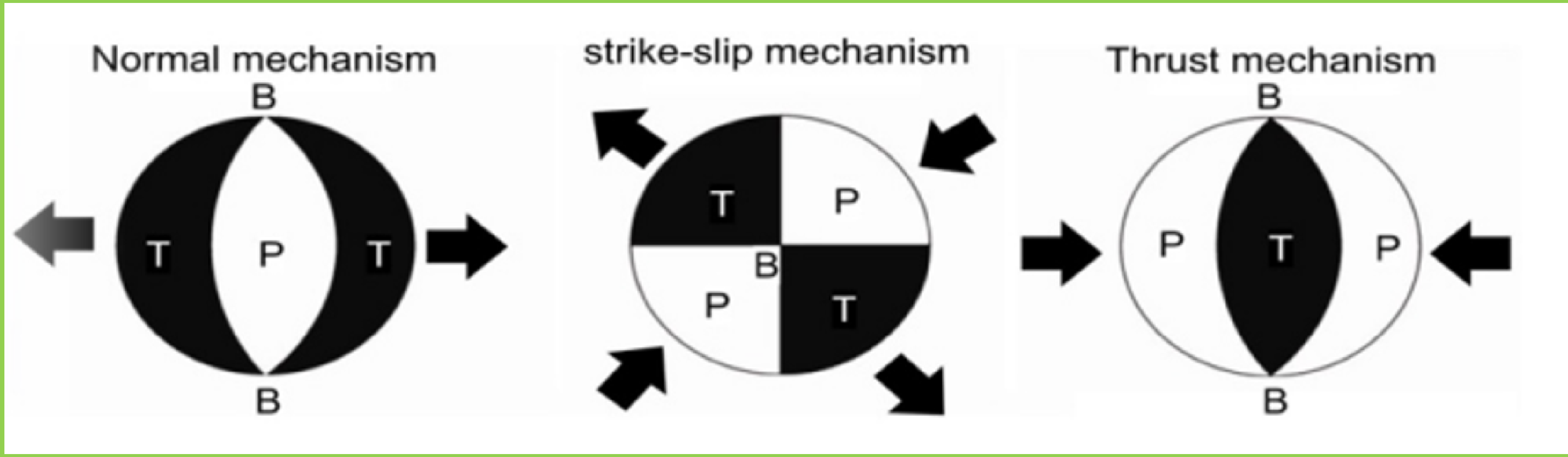
浅层地震的发震频率高，占地震总数的72.5%，释放的地震能占总释放能量的85%。其中，震源深度在30公里以内的占多数，是地震灾害的主要制造者，对人类影响最大。这种地震的影响范围可以广达700至800公里以上，造成严重伤亡的机会比较大。

Characteristics of Major Faults主要构造断裂的特征



No 號	Fault Name 断层名稱	Dip Direction 倾角方向	Dip 倾角
1	Wenchuan-Maowen 汶州-茂县	310- 330	50-70
2	Yingxiu-Beichuan 映秀-北州	305-315	50-70
3	Penguan (Quanxian Anxian) 江泅-都江堰	310	

Focal Mechanism and Principle Stress 震源機制和主應力



Normal Fault 正断层
Reverse/Thrust Fault 逆断层
Strike Slip Fault 走滑斷層

P:Compression Zone of Focal Mechanism
震源機制的壓縮帶
T: Tension Zone of Focal Mechanism
震源機制的張力帶

Sv: Vertical Principle Stress 垂直主應力
S_{Hmax}: Max Horizontal Principle Stress 最大水平主應力
S_{Hmin}: Min. Horizontal Principle Stress 最小水平主應力

Distance of Hypocenter: 震源深度
14Km (Information from CEA)
19Km (Information from USGS)

Table for Chinese Earthquake Intensity
中国地震烈度表

Inensity	Judgement	M
I	No sense, only the instrument can record;	<3
II	Individual sensitive people feel in complete stillness;	3.5
III	A few people in the room feel at rest, the suspension swings slightly;	4
IV	Most people in the room, there are a few people in the outdoor, the hanging objects swing, the unstable utensils sound;	4.5
V	Most people feel outside, livestock is restless, doors and windows squeak, cracks appear on the wall surface	5
VI	People stand unstable, livestock flee, utensils fall, simple shed damage, steep slope landslide;	5.5
VII	Minor damage to the house, damage to the archway, chimney, cracks on the surface and water spray;	6
VIII	Many houses are damaged, a few destroy the roadbed collapse, and the underground pipeline is broken;	6.5
IX	Most of the houses are destroyed, a few dumps, arches, chimneys, etc. collapse, the rails are bent;	7
X	The house is dumped, the road is destroyed, the rock is massively collapsed, and the water is rushing to the shore;	7.5
XI	A large number of houses collapsed, a large section of the embankment collapsed, and the surface changed greatly;	8
X II	All buildings are generally destroyed, and the terrain changes drastically;	>8.5

中国地震烈度简表

烈度	地震级称	判　据	相对震级
Ⅰ	微　震	只有仪器能记录	3<
Ⅱ	小　震	室内个别静止中人有感	3.5
Ⅲ	小　震	少数人有感，仪器能记录到。	4
Ⅳ	小　震	活动中人亦有感；吊物摇晃，如重型车辆驶过。	4.5
Ⅴ	中小地震	睡觉的人会惊醒；架上物品掉落。	5
Ⅵ	中　地震	树木摇动；老朽和危、劣房屋轻微损害。	5.5
Ⅶ	中　地震	房屋普遍掉土，墙裂，危、房屋倾倒。	6
Ⅷ	中　地震	房屋破裂，烟囱倒，一般建筑严重破坏。	6.5
Ⅸ	大　地震	地裂，喷水、喷沙；水管撕裂；建筑物多数倒塌，破坏严重。	7
Ⅹ	大　地震	地裂成渠，山崩滑坡；桥梁、水坝损坏；铁轨轻弯；属毁坏性灾害。	7.5
Ⅺ	特大地震	很少建筑能保存；铁轨扭曲；地下管道破坏；水灾泛滥；属毁坏性灾害。	8
Ⅻ	特大地震	全面破坏，地面起伏如波浪，大规模变形，属毁灭性灾害。	≥8.5

2. Controversy for Reservoir Triggered Seismicity(RTS)
水库触发地震（RTS）的争议
Official ICOLD Terminology for RTS and RIS
RTS和RIS的官方ICOLD术语

Old (misleading) term:
Reservoir-induced seismicity (RIS)

New (correct) term:
Reservoir-triggered seismicity (RTS)

The term which in the past often been used, is incorrect as reservoir cannot induce earthquake. However, they can trigger earthquake.

ICOD observed 100 reservoir RTS cases with water depth higher than 100m,the largest magnitudes of RTS events reached 6.3

旧的（误导性的）术语：
水库引发地震活动（RIS）

新（正确）术语：
水库诱发地震活动（RTS）

过去经常使用的术语，因为水库不能引发地震。 但是，它们可以诱发地震。

ICOD观察了100个水库RTS病例，水深超过100米，RTS事件的最大幅度达到6.4

2 Controversy for Reservoir Triggered Seismicity(RTS)
水库触发地震（RTS）的争议

The main reason for the reservoir-induced earthquake is twofold:
认为水库诱发地震的主要原因有两个方面：

The heavy load pressure attached to the reservoir bottom fault after the reservoir is filled, breaking the original stress of the fault balance; infiltration of water filled into the fractures of the bottom of the reservoir will create additional pore water pressure.

水库蓄水后对库底断层附加的重荷压力，打破了断层受力状况原有的平衡；渗入充填到库底岩体裂隙中的水，会产生附加的孔隙水压力，

At the same time, water penetration, soaking and pore water pressure soften the rock and lubricate the fault plane. The rock mass is more likely to rupture and the rupture is easier to expand. And the earthquake is the underground rock along the fault. A shock that occurs when it breaks.
同时水的渗透、浸泡和孔隙水压力软化了岩石，对断层面起到润滑作用，使岩体更容易破裂，破裂也更容易扩展。而地震，就是地下的岩石沿断层破裂而发生的震动。

The Most Significant Cases in the World 世界上最重要的案例:

1962年3月19日，中国广东新丰江，6.1级；Xinfengjiang Dam in China
1963年9月23日，赞比亚卡里巴（Kariba），6.1级；Kariba dam on the Zambia-Zimbabwe border
1966年2月5日，希腊科列马斯塔（Kremasta），6.3级；
1967年12月10日，印度科因纳（Koyna），6.4级。

Table for Major Reservoirs Induced Earthquake in the World
世界一些主要的水库诱发地震表

Reservoir (Country) 水库(国家)	Height of Dam 坝高/m	Storage Capacity 库容(10^8 m3)	Storage Time 蓄水时间	Time for Initial Earthquake 初震时间	Time for Max. Earthquake 最大诱发地震时间	Tither Magnitude 震级 Ms
Koyna (India/印度)	103	27.8	1962-06	1963-10	1967-12	6.4
Xingfengjiang (China) 新丰江(中国)	105	115	1959-10	1959-11	1962-03	6.1
Kinnersani (India/印度)	61.8		1965	1965	1969-04	5.3
齐尔克依 (USS/前苏联)	233	27.8	1974-07		1974-12	5.1
Marathon (Greek/希腊)	63	0.4	1929-10	1931	1938	5
Kremasta (Greek/希腊)	165	47.5	1965-07	1965-12	1966-02	6.2
Monteynard (France/法国)	155	2.75	1962-04	1963-04	1963-04	5
铜街子(China/中国)	74	3	1992-04	1992-04	1994-12	5.5
Bajina Basta(Yugoslavia/南斯拉夫)	89	3.4	1967-06	1967-07	1967-07	5
Kariba (Zambia/赞比亚)	123	1750	1958-12	1959-06	1963-09	6.1
Aswan (Egypt/埃及)	111	1640	1968		1981-11	5.6
Oriville (USA/美国)	235	4.4	1967-11		1975-08	5.5
Volia Grande (Brazil/巴西)	56	23	1973		1973	5

Conditions Required for Reservoir Triggered Earthquake
水库诱发地震需要具备的条件

1. The reservoir is located on an active seismic fault.
2. The dam is high enough that the water depth is large enough.
3. The water storage capacity of the reservoir is also large enough.
4. High frequency for impounding and discharge of water with large change in height of water column.

1. 水库位于活动性的地震断层上，
2. 水坝足够高即水深足够大，
3. 水库的蓄水量也足够大，
4. 高频率用于蓄水和排水，水柱高度变化大。

The supporters consider that the Zipingpu Dam fulfill the four adverse condition to trigger the earthquake
支持者认为紫坪铺大坝能够满足诱发地震的四种不利条件.

Opposite Opinions for Wenchuan Earthquake Triggered by Zipingpu Reservoir

1. The epicenter of the reservoir earthquake is only located within 5 km of the reservoir, and the focal depth is mostly within 5 km, and rarely exceeds 10 km. Wenchuan earthquake, no matter the starting point of earthquake rupture (microscopic epicenter), the distance from the direction of the earthquake rupture is much greater than 5 km.

   水库地震的震中仅分布在水库及其周围，一般位于水库及其附近 5 km范围内， 震源深度大多在5 km内， 少有超过10 km. 汶川地震， 无论是地震破裂的起始点(微观震中)还是地震破裂延伸方向的距离远远大于5 km.

2. The magnitude of the reservoir-triggered earthquake is generally small. The largest reservoir-induced earthquake recorded in the world is only 6.4. However, the magnitude of the Wenchuan earthquake is 8.0. The energy released by the earthquake is more than 200 times greater than the energy of the largest reservoir earthquake in history.

   水库诱发地震震级一般较小. 目前世界上已记录到的最大的水库诱发地震为6.4级,汶川地震的震级为8.0， 该地震释放的能量比历史上最大的水库地震的能量大200多倍.

3. The proportion of reservoir-triggered earthquakes is relatively small. There are more than 10,000 large and medium-sized reservoirs built around the world. However, only 101 earthquakes have been triggered by the reservoirs, which account for only over 10,000 registered in the World Dam Conference. About 1% of the total number of medium-sized reservoirs.

   水库诱发地震比例较小. 全世界已建大中型水库约有1万多座. 但已诱发水库地震的仅101座， 它们仅占世界大坝会议已登记的1万多座大、中型水库总数的1%左右.

4. There is no foreshock in the Wenchuan earthquake, and it is not a series of foreshock-major earthquake-aftershocks. The Wenchuan earthquake and the reservoir earthquakes in the past are obviously different from the phenomenological comparison. The size of the Wenchuan earthquake, the location of the earthquake, the earthquake sequence, etc. In terms of the aspects, it does not meet the basic characteristics of reservoir induced earthquakes.

   汶川地震没有前震, 不属于前震-主震-余震的系列. 汶川地震与过去发生的水库地震, 从现象学的对比, 有明显的不同. 汶川大地震从震级大小、地震位置分布和地震序列等方面上都不符合水库诱发地震的基本特点.

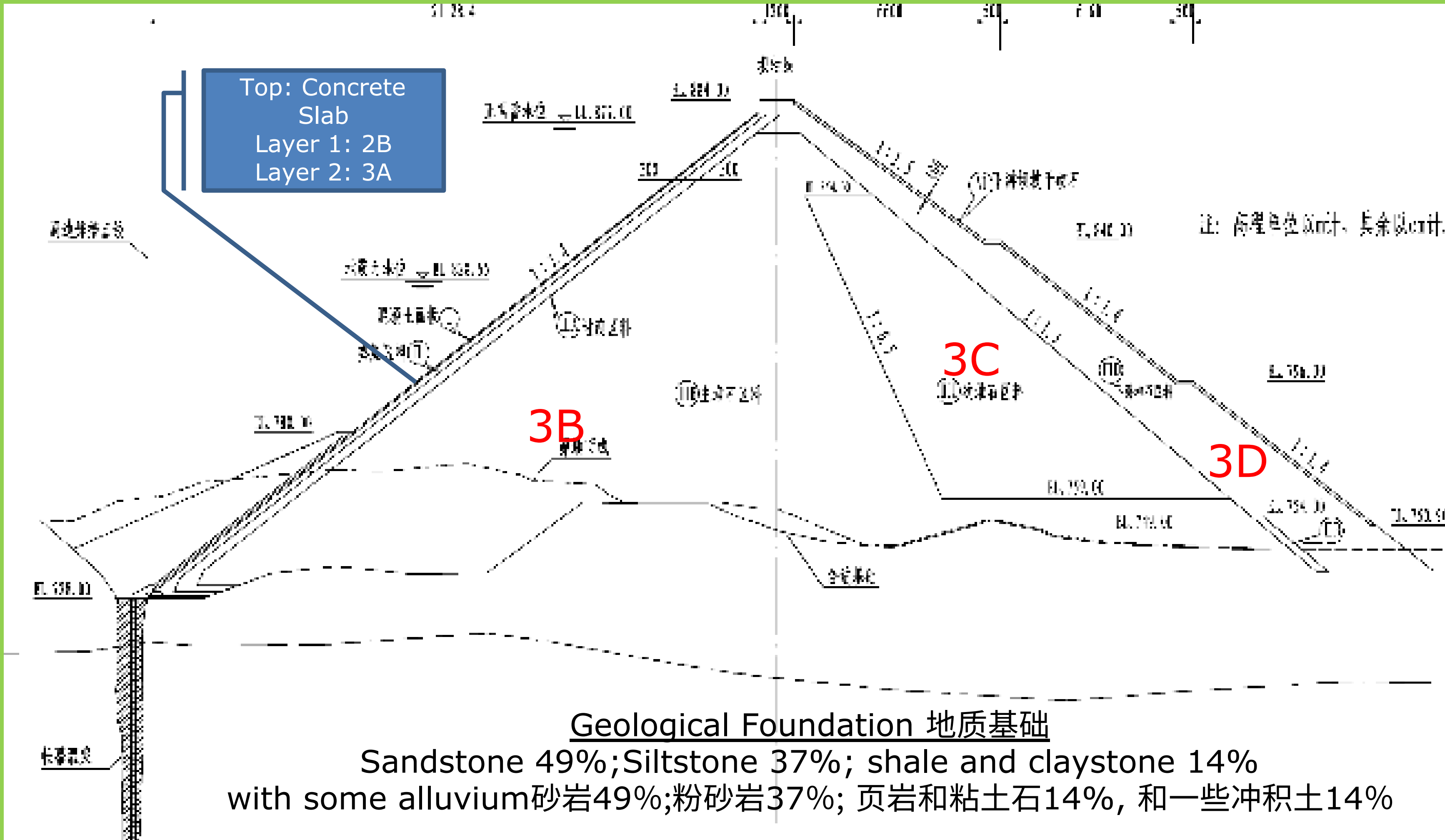
5. The Wenchuan earthquake was caused by the fault thrust movement. So far, no thrust type reservoir earthquake has been discovered.

   汶川地震是断层逆冲运动造成的,迄今尚未发现过逆冲型的水库地震.

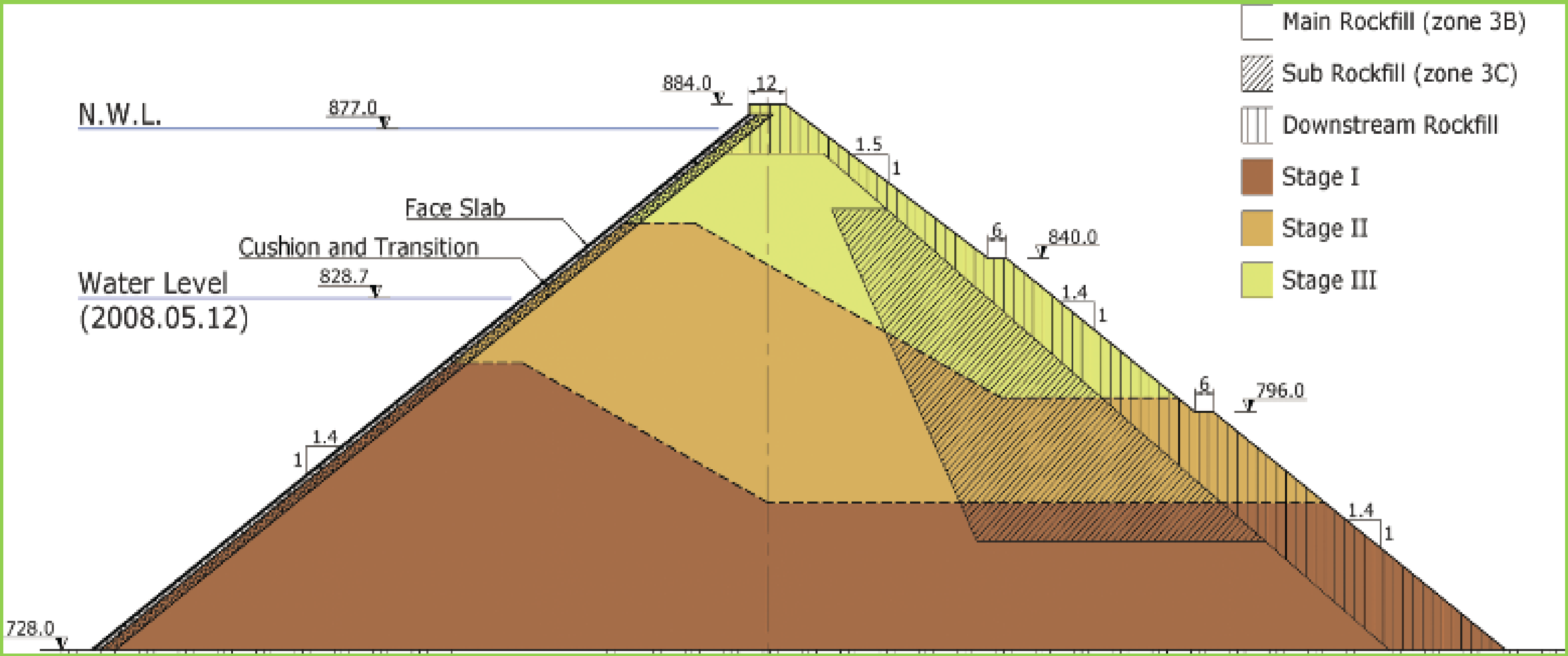
3 Design Parameters and Data for Zipingpu Reservoir
紫坪铺水库设计参数及数据

1. Dam top elevation: 884 meters
2. Toe board foundation elevation: 728 meters
3. Dam height: 156 meters
4. Dam roof length: 663.77 meters
5. Dam top width: 12 meters
6. Normal water level: 877 meters
7. Lowest Level for Water Discharge: 825m
8. Corresponding storage capacity: 998 million cubic meters
9. Limit water level during flood season: 850 meters
10. Total storage capacity: 1.112 billion cubic meters
11. Adjust storage capacity: 774 million cubic meters
12. The peak flow in 1000 years: 12700 cubic meters / sec
13. Average annual flow above the dam site: 469 cubic meters per second

1. 坝顶高程：884米
2. 趾板基础高程：728米
3. 坝高：156米
4. 坝顶长度：663.77米
5. 坝顶宽：12米
6. 正常蓄水位：877米
7. 最低排水高程:825米
8. 相应库容：9.98亿立方米
9. 汛期限制水位：850米
10. 总库容：11.12亿立方米
11. 调节库容：7.74亿立方米
12. 1000年一遇洪峰流量:12700立方米／秒
13. 坝址以上多年平均流量：469立方／秒



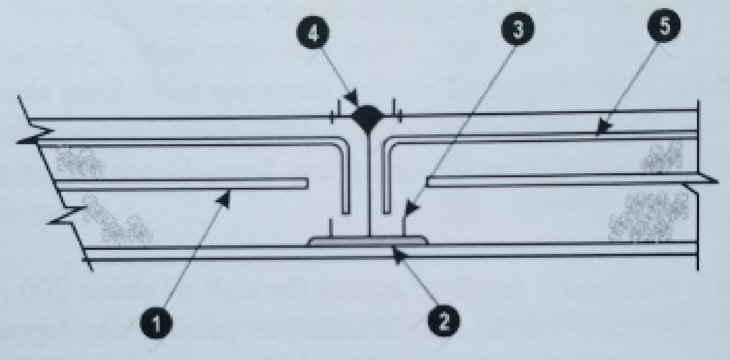
Typical Profile for Structure of Zipingpu Reservoir
紫坪铺大坝典型剖面图



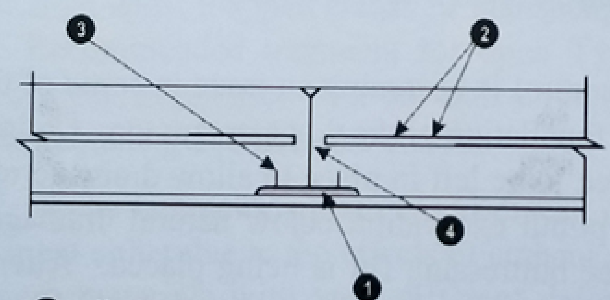
Typical Cross Section of Zipingpu Dam

紫坪铺大坝典型断面

Typical Vertical Expansion and Compression Joints
典型的垂直膨胀和压缩接缝

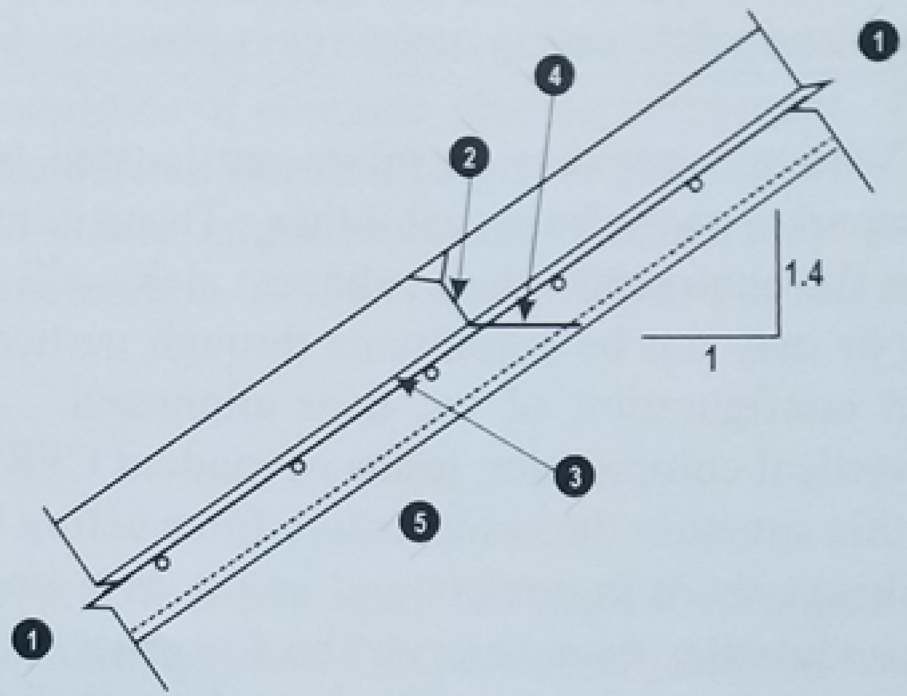


1. Face slab reinforcement
2. Mortar pad
3. Bottom waterstop
4. Upper water barrier
5. Anti-spalling steel for high CFRDs



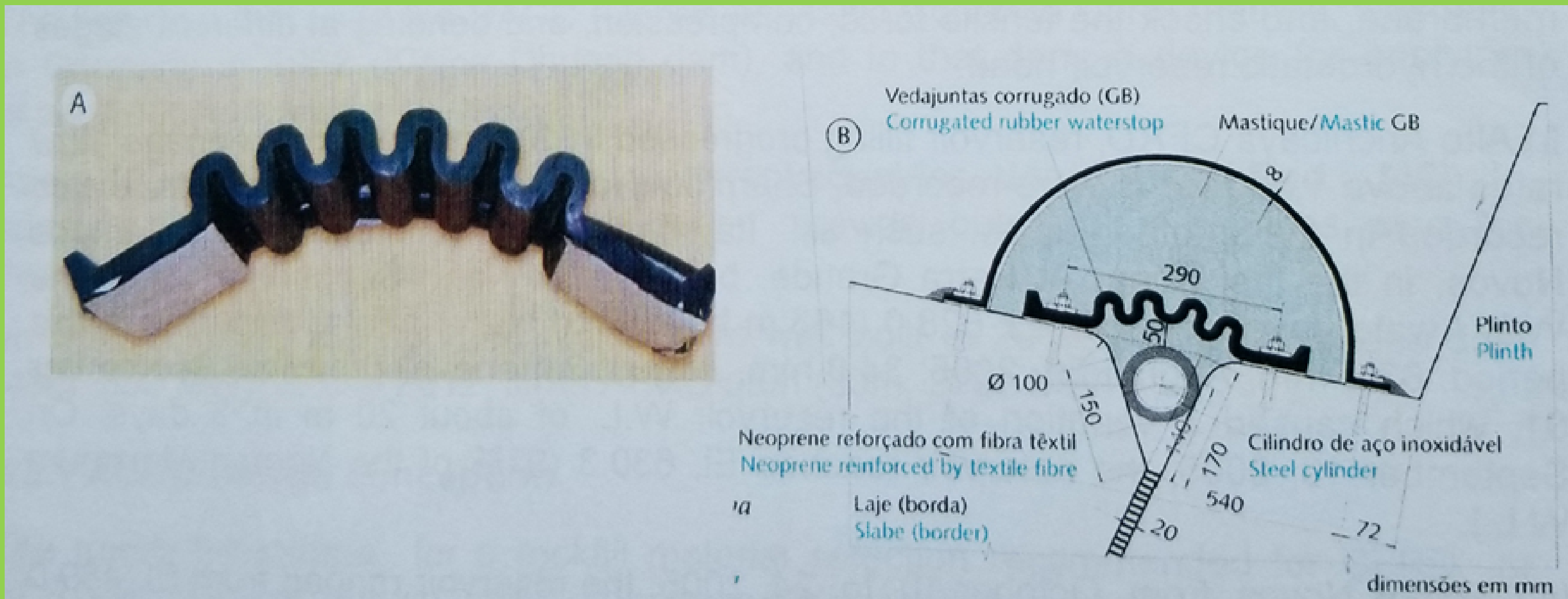
1. Mortar pad
2. Face slab reinforcement
3. Bottom waterstop
4. Continuous reinforcement for broad, flat valleys, not continuous for U- or V-shaped valleys

Typical Horizontal Construction Joint
典型的水平结构接缝

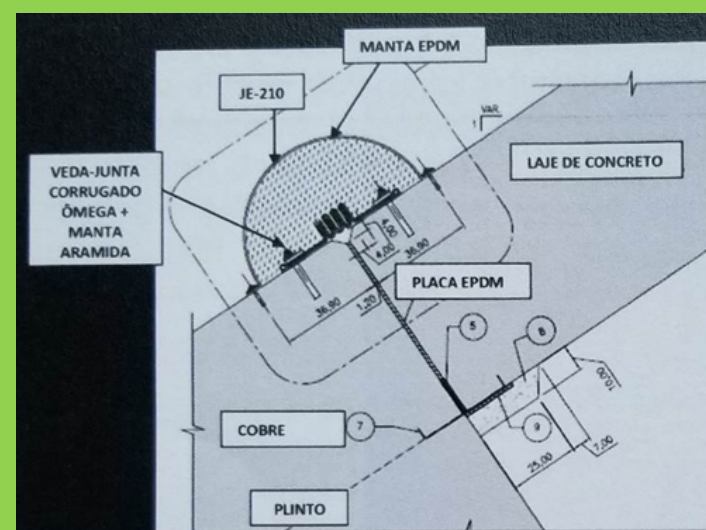


❶ Face slab
❷ Joint formed normal to face above reinforcement
❸ Reinforcement continuous across joint
❹ Joint greencut below reinforcement unless bottom waterstop is used
❺ Face supporting zone

Special Designed Water Stop
特别设计的止水带



Waterstop before placement of cover
覆盖之前的止水带



坝料分区			主要设计指标					
编号	名称	来源	干密度 /g·cm^{-3}	孔隙率 /%	渗透系数 /cm·s^{-1}	最大粒径 /mm	d< 5 mm 的含量 /%	d< 0.075 mm 的含量 /%
II	垫层区	灰岩加工	2.30	15.4	2.5×10^{-3}	100	30~45	5.1~6.8
IIA	特殊垫层区	灰岩加工	2.30	15.4	2.5×10^{-3}	40	49.1~66.7	6.7~10.3
IIB	反滤料	河床沙卵石筛分	2.35	16.1		200	17.5~25.5	5~7.3
IIIA	过渡料	灰岩料	2.25	17.3	5.3×10^{-1}	300	10~20	< 5
IIIB	主堆石	灰岩料	2.16	20.6	2.1	800	5~15	< 5
IIIC	次堆石	河床沙卵石	2.30	18.1	1×10^{-3}	1 000		< 5
		灰岩料	2.15	21.0		1 000		< 5
IIID	下游堆石区	灰岩料	2.15	21.0	2.1	1 000		
IV	坝前盖重保护	开挖渣料	2.0					
IVA	坝前辅助防渗	坝基透镜体粉细沙	1.50			5		

3A Transaction (Cushion)Zone
2B Transaction Zone
3B Main Rockfill zone
3C Sub Rockfill Zone
3D Large Rock dozed to face (Riprap)

3A 过渡（缓冲）区
2B 过渡区
3B主要堆石区
3C次堆石区
3D大岩石堆

Dislocation damage observed after cleaning the damaged concrete
清洁损坏的混凝土后观察到位错损坏

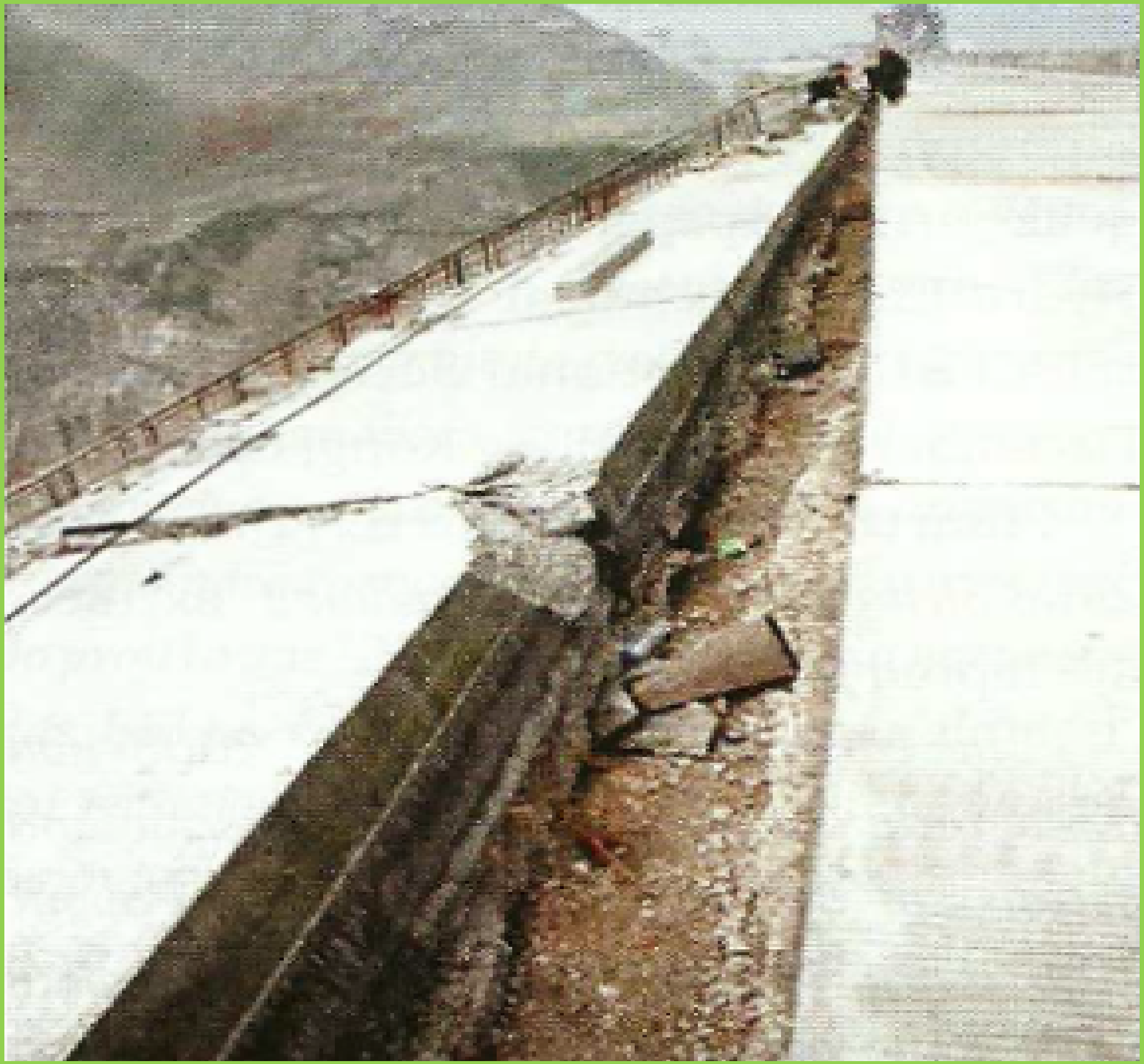
4 Geohazards and Damages Towards Zipingpu Dam
紫坪铺大坝的地质灾害和危害

The top of the reservoir was affected by the earthquake, and the left side of the photo was about 15 cm from the right side

水库坝顶受地震影响，照片左侧相对右侧陷落约15 公分。

The outer dam of the top of the reservoir lands on the downstream backwater slope. The dam is about 70 cm below the center and about 30 cm outside the downstream.

水库坝顶外侧护欄震落于下游背水坡面，大坝中央下陷约70 公分，向下游面外移约30 公分。



Displacement of access way and the crest of Zipingpu Dam
-This measured up to 630mm
紫坪铺水库进出通道和顶部的位移—最大达630mm

View of landslide boulders from the left slope of the abutment on the dam crown. 31º 02’ 08,89’’ N – 103º 34’ 40,81’’ E

从坝顶桥台的左坡看滑坡巨石。 ***31º 02' 08,89'' N – 103o 34' 40,81'' E***

Compressive failure of Slab No. 23 and 24 at the central parts of Zipingpu Reservoir

紫坪铺水库中部23、24号板受压破坏

The outer guard of the dam crest of Zipingpu Reservoir was shaken by earthquake and fallen to the downstream of the backwater slope

紫坪铺水库坝顶外护栏受地震震动，倒塌至回水坡下游

On May 12, 2008, the dam of the Zipingpu Reservoir on the Minjiang River, which was damaged and formed a huge crack in the Wenchuan earthquake.

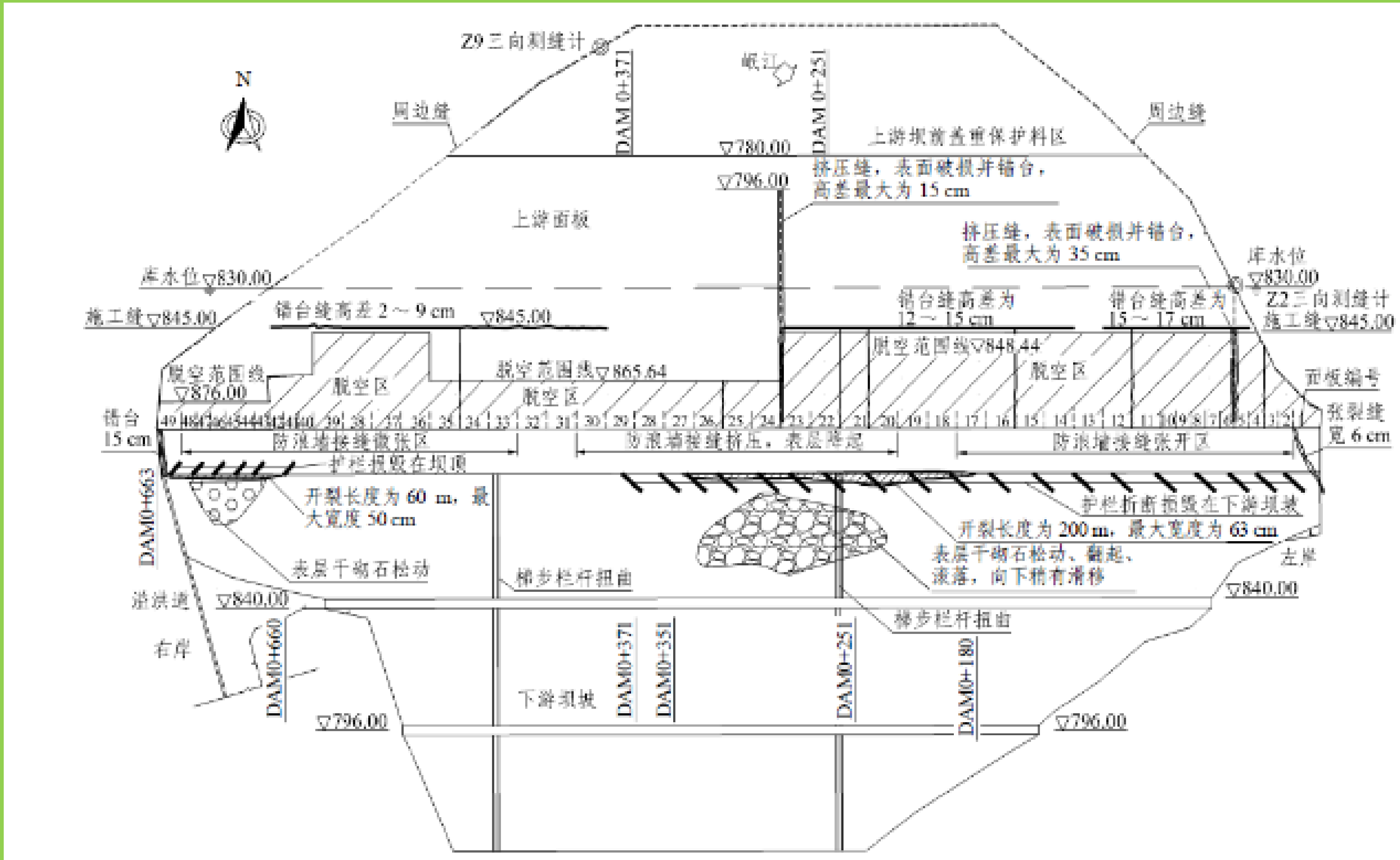
2008年5月12日，汶川地震中遭受破坏、形成巨大裂缝的岷江紫坪铺水库大坝。

Vertical fractures on the right side of the dam axis due to differential subsidence of the dam body in relation to the rigid section of the emergency spillway.   31º 02' 08,21'' N – 103º 34' 18,42'' E

坝体右侧的垂直裂缝是由于坝体相对于应急溢洪道刚性段的不同沉降造成的。31º 02' 08,21'' N – 103º 34' 18,42'' E

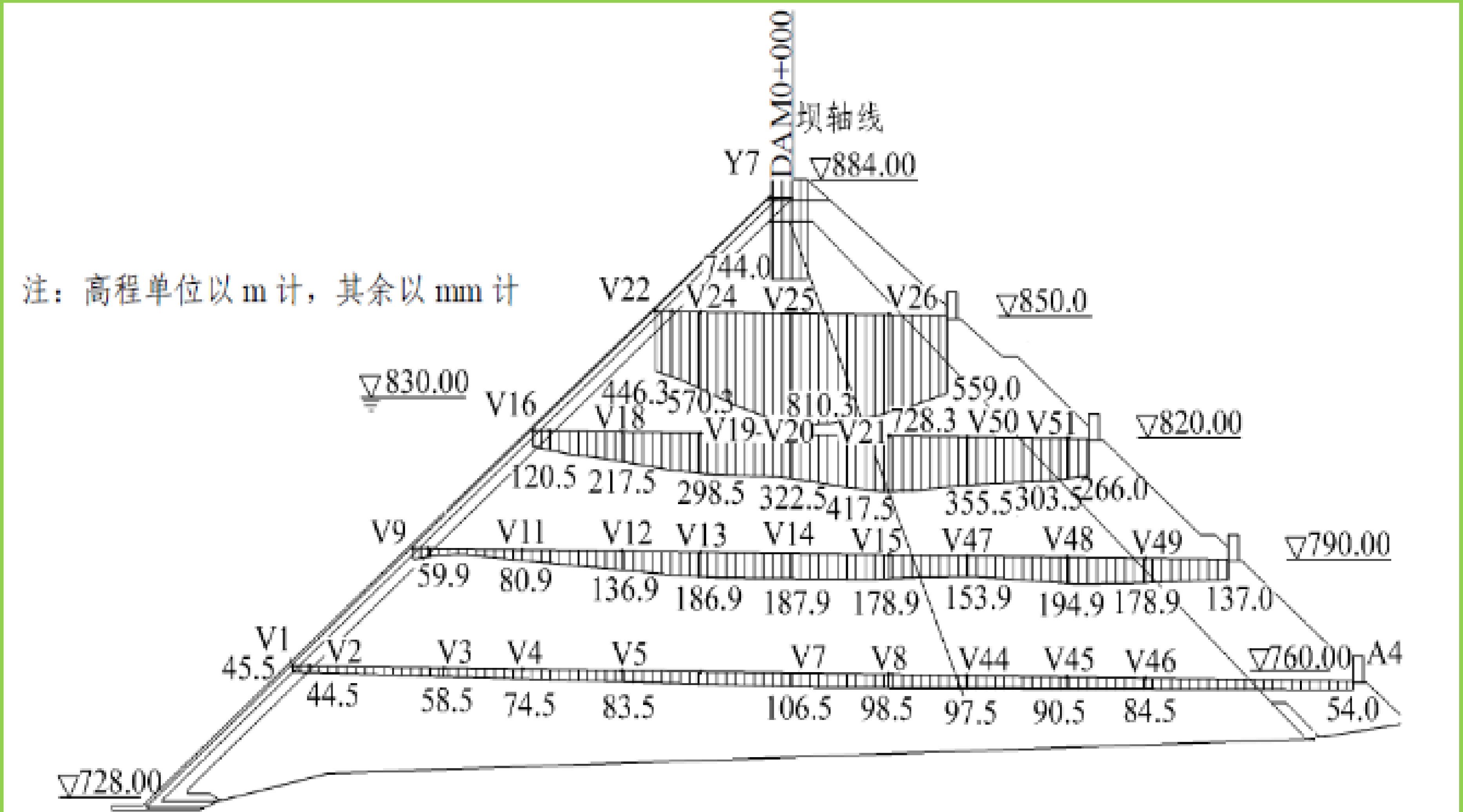
The roof of the buildings on crest of the reservoir was damaged by seismic shearing

水库坝顶房舍受地震剪力作用导致结构受损



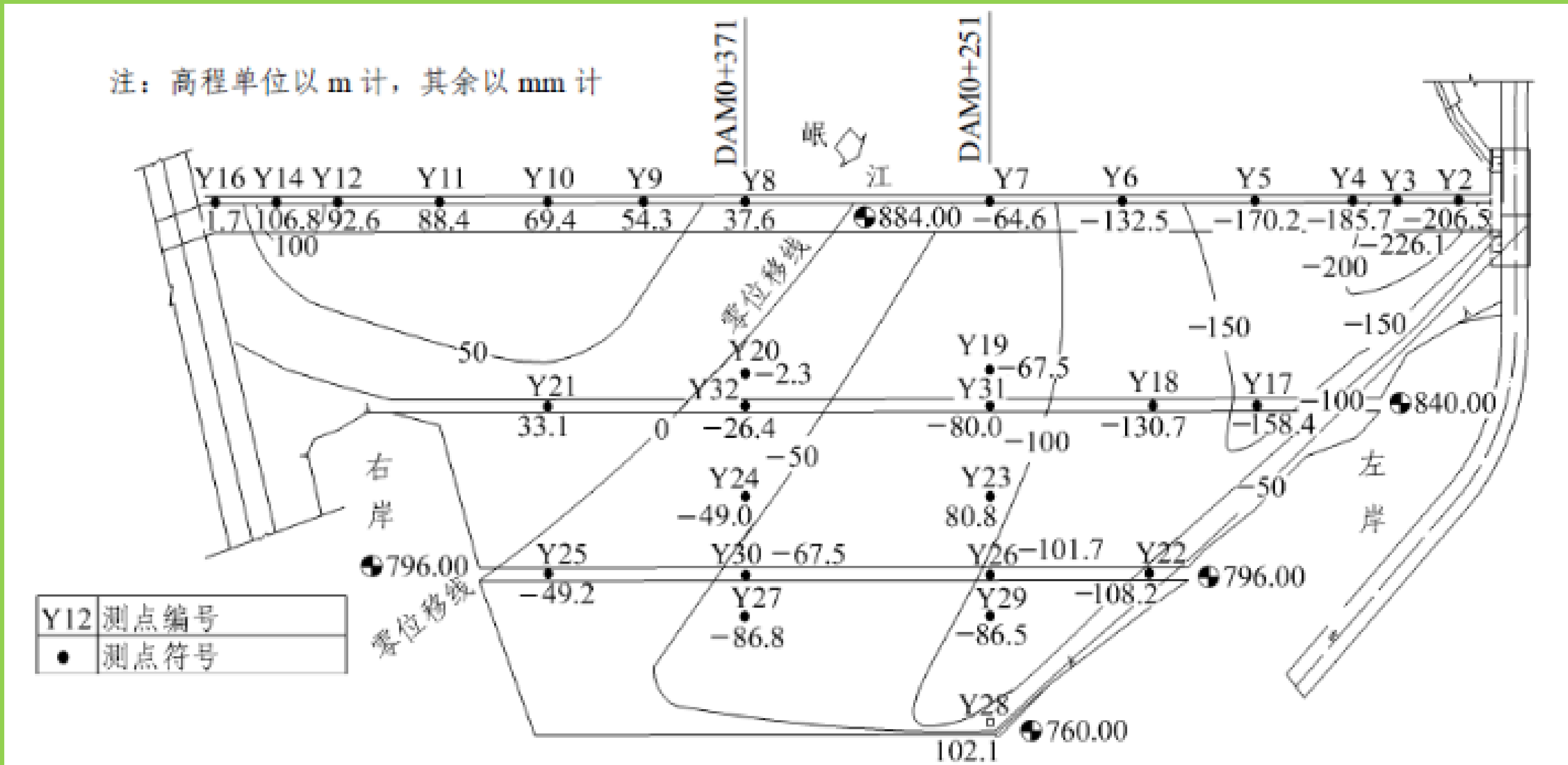
Macroscopic earthquake damage distribution of dam(unit of elevation: m)

大坝工程宏观震害现象分布示意图（高程单位：m）



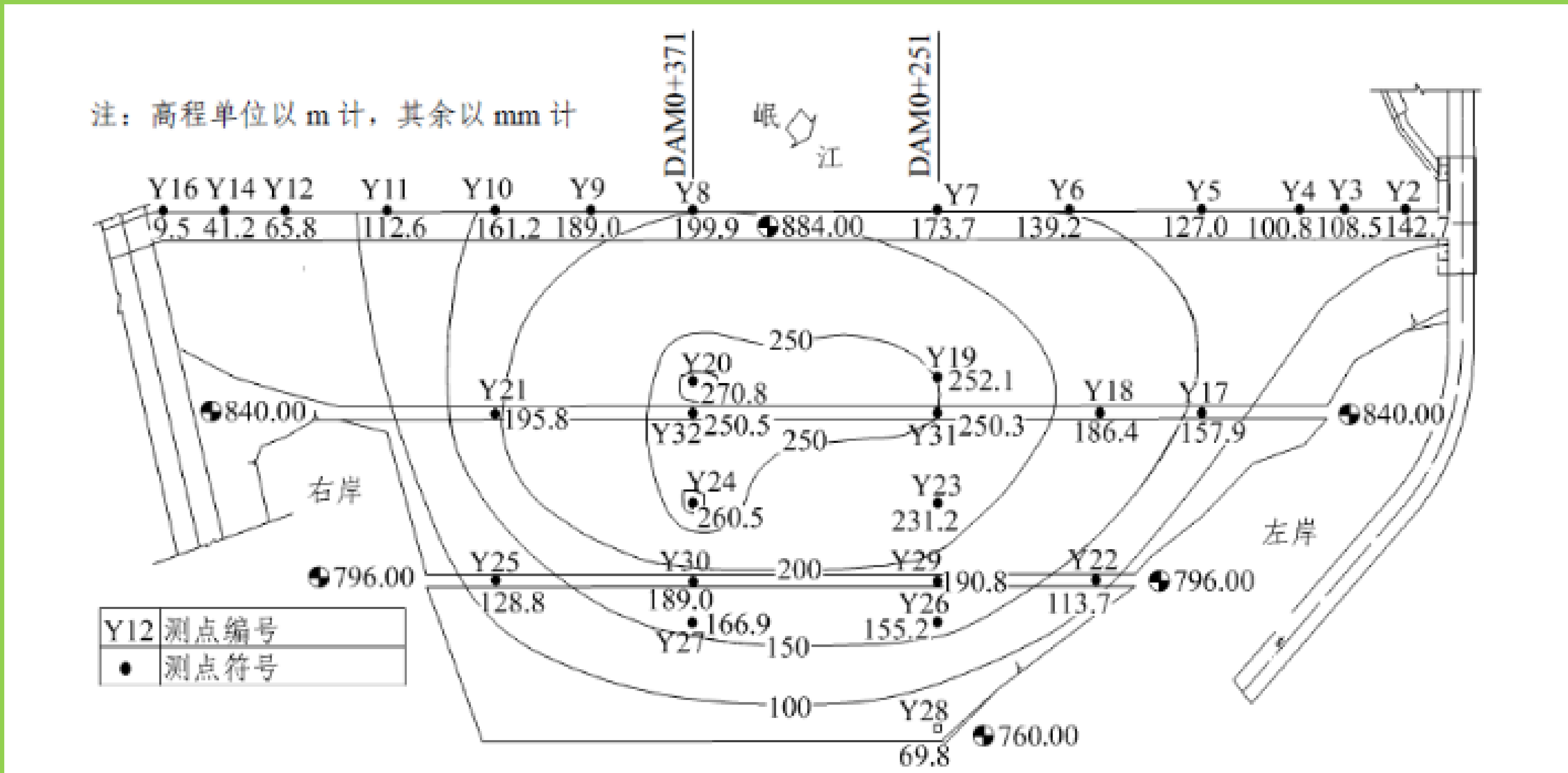
Settlement distribution at dam section 0+371

0+371坝段沉降分布



Contour lines of horizontal displacement parallel to dam axis at dam crest and downstream slope(displacement toward left bank is positive)

坝顶和下游坝坡平行坝轴线水平位移分量等值线(向左岸位移为正)



Contour lines of horizontal displacement perpendicular to dam axis at dam crest and downstream slope(displacement)

坝顶和下游坝坡垂直坝轴线水平位移分量等值线(向下游位移为正)

The permanent settlement and horizontal deformation at Zipingpu dam in the pre-earthquake period were 200mm and 80mm respectively. If the permanent deformation at pre-earthquake period is considered, the earthquake induced permanent settlement or deformation would be reduced obviously.

紫坪铺大坝在震前期的永久沉降和水平变形分别为200mm和80mm。如果考虑地震前的渗透变形，地震引起的永久沉降或变形将明显减少。

Leakage of Dam After Earthquake
地震后大坝渗漏

As the water level of the reservoir increases or decreases, the seepage flow increases and decreases accordingly with slight delay. The maximum seepage flow measured by the dam history is 51.19 L/s on Oct 30, 2006, and the corresponding reservoir water level is 874 m.

随着库水位的增加或降低，渗流量相应增减，但稍有滞后。大坝历史实测最大渗流量为51.19 L/s，时间为2006年10 月30日，对应库水位为874 m。

The seepage flow of the dam gradually increased. The seepage flow increased from 10.38 L/s before the earthquake (May 10) to 18.82 L/s on June 1, 2008 (the current seepage flow is basically maintained at 19.0 L/s). Left and right; compared with before the earthquake, the seepage water quality was turbid after 1 to 2 days after the earthquake, and the sediment was entrained. After that, the water quality became clear and there was no turbidity.

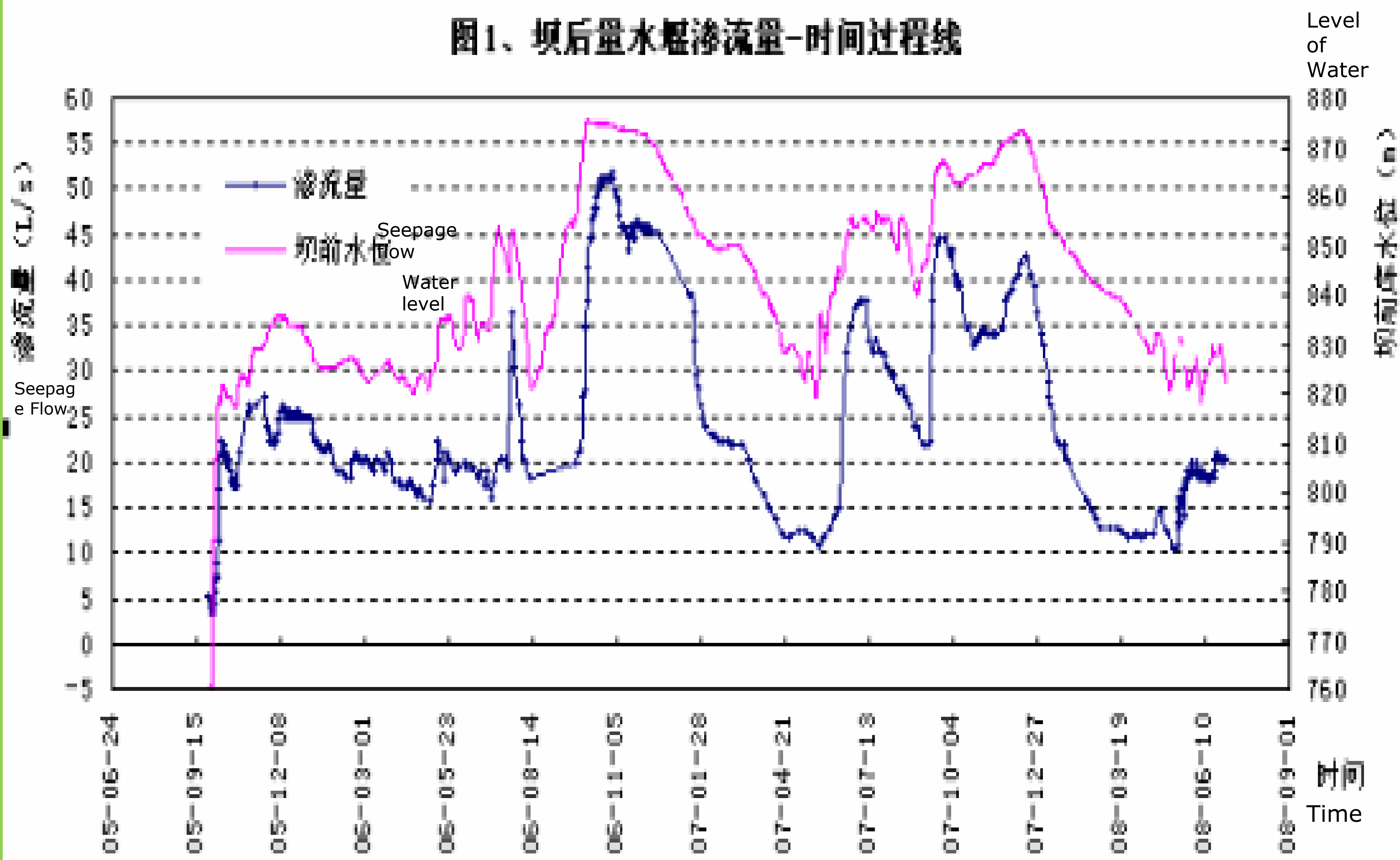
大坝的渗流量,均逐渐增加，渗流量由地震前（5 月10 日）的10.38 L/s上升到2008 年6 月1 日的18.82 L/s（目前渗流量基本维持在19.0 L/s 左右；与震前相比，渗流水质在震后的1～2 d 较浑浊，并夹带泥沙，以后水质变清，至今未出现再次混浊。

It may be caused by fissure water generated by earthquake-activated bedrock fissures. Due to the earthquake, the original joint fissures in the rock formation at the dam site will be vibrated and dislocated, resulting in the opening, enlargement, dislocation and penetration of the joint fissures of the original rock formation, forming a seepage channel, which leads to an increase in seepage flow. As for the turbidity of the dam from 1 to 2 days after the dam earthquake, the preliminary analysis suggests that due to the earthquake, the dam rockfill body is squeezed and displaced, and the granules are broken and fine particles are formed, during rainfall and Under the action of seepage water, fine particles are taken out, which causes the seepage water to become turbid.

可能是地震激活的基岩裂隙所产生的裂隙水所致。由于地震作用，坝址处岩层原有的节理裂隙将产生振动、错位，导致原来岩层闭合的节理裂隙张开、增大、错位和贯通，形成渗流通道，从而导致渗流量增加。至于大坝震后的1～2 d 水质较震前浑浊原因，初步分析认为，由于地震作用，大坝堆石体受到挤压、错动，坝料颗粒间产生破碎形成细颗粒，在降雨和渗流水作用下，细颗粒被带出，从而导致渗流水质变混浊

Although the seepage flow of the dam is still in the normal range compared with similar normal-operated dams at home and abroad, considering the seepage flow and the change of water quality are the most important indicators for judging the safety of the dam, it is recommended to strengthen the seepage of the dam in the future. Flow monitoring, paying special attention to the change of seepage water quality, and if necessary, physical and chemical analysis of sediment in seepage water to more accurately determine the source of seepage water.

尽管目前大坝的渗流量与国内外同类正常运行的大坝相比仍属正常范围，但考虑到渗流量及其水质变化是判别大坝安全性最重要的指标，建议今后加强大坝的渗流量监测，特别注意渗流水质的变化，必要时对渗流水中的沉淀物进行物理化学分析，从而更为准确地判别渗流水的来源。



Plot of leakage speed of water against time behind the dam

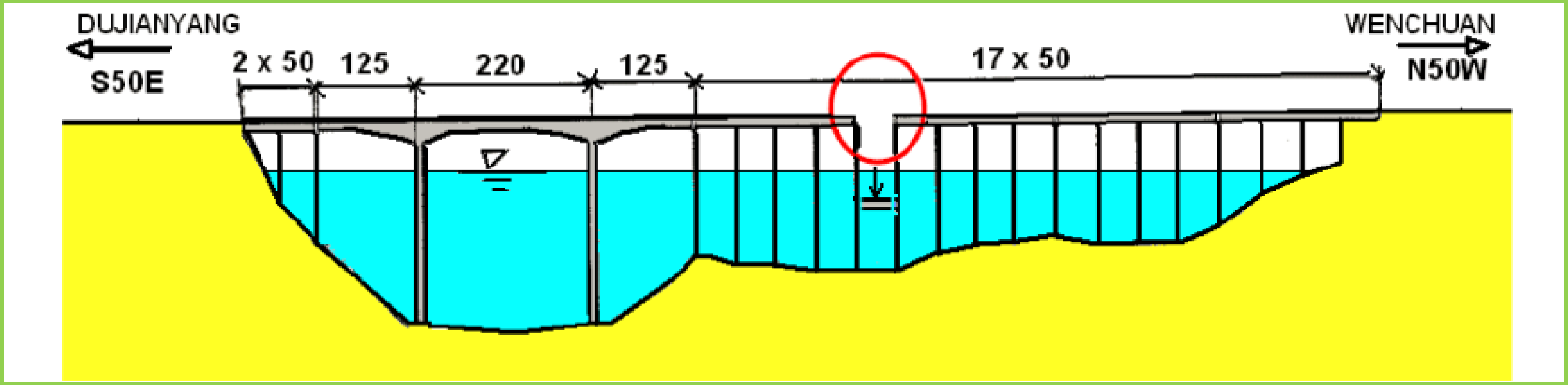
坝后渗水速度与时间的关系图

Affected Reservoirs Near to Wenchuan Earthquake
受汶川地震影响的水库

Name of project 项目名称	Dam type坝型	Dam height (m)坝高（m)	River 河	Distance to Epicentre(Km)到震中的距离（里)	Distance to rupture surface (Km)与破裂表面的距离	Wenchuan Affected Intensity汶川的强度	Designed Intensity 设计强度	Actual PGA During Earthquake (g)地震期间的实际PGA(g)	Design PGA (g)设计峰值加速度 (g)	Damage category*伤害类别*
Zipingpu	CFR	156	Minjiang R.	17	8	X	VIII	0.65 to 0.8	0.26	3
Bikou 碧口	Earth-Rockfill	101.8	Bailongjiang R.	261	73	IX			0.2	2
Shapai 沙牌坝	RCC Arch	132	Minjiang branch	36	32	VIII			0.138	4(power house) 1(dam)
Baozhusi 宝珠寺大坝	Gravity	132	Bailongjiang R.	268	80	VIII			0.15	2

The PGA along the crest of Zipingpu Dam was greater than 2

紫坪铺大坝顶部的PGA大于2



Miaziping bridge is 1436m long with a height of 100m, and has 19 approaches with T-girders. The earthquake caused the shifting of bridge girders longitudinally and laterally. One of the T-type girder approaches collapsed. The distance between piers was increased by more than 50cm and there were all-around fractures, spalling and bending cracks

米子坪桥长1436米，高100米。它有19种采用T型梁的方法。地震导致桥梁纵向和横向移动。　　其中一种T型梁的方法崩溃了。桥墩之间的距离增加了50多厘米，出现了全方位的裂缝，剥落和弯曲裂缝。

Views for the fallen sections of the Bridge
桥梁受损和倒塌的部分

The two-lane tunnel nearby Zipingpu dam is 1km long, and the linings at several locations were damaged. The damaged sections of the tunnel were re-bolted and shotcreted.

紫坪铺大坝附近的双车道隧道长1公里，多个地点的衬砌受损。 隧道的受损部分重新喷浆。

After the Zipingpu Reservoir was emptied, the upstream reservoir was at the bottom of the Minjiang River. The liquefaction side collapsed in the mud and sand part of the beach land.

紫坪铺水库排空后，上游水库位于岷江底部。在滩地的泥沙部分发生液化塌陷现象。

The right bank of the Minjiang River near Miaoziping of the Zipingpu Reservoir was cracked due to the earthquake
紫坪铺水库庙子坪附近岷江右岸受地震影响龜裂

Through the surface rupture zone formed by the Shuimo-Miaoziping fault in the Zipingpu Reservoir in the Wenchuan earthquake, the road was broken, and the vertical and horizontal displacements reached about 5 meters.

通过紫坪铺水库的水磨-庙子坪断裂在汶川地震中形成的地表破裂带，公路被错断，垂直和水平位移均达到5米左右。


Several surficial slope failures in limestone unit in the vicinity of the Weizhou and the Zipingpu dam site. The surficial slope failures in limestone unit was spectacular and continued for several kilometers as they are clearly observed in satellite images.

紫坪铺坝址附近石灰岩单元的几处表层边坡破坏。石灰岩单元的表层斜坡破坏是壮观的，持续了几公里，因为它们在卫星图像中清晰可见。

During construction of Zipingpu Reservoir, rockfill materials were excavated at the slopes near the bank of the river. The original quarry remnant slopes are exposed and collapsed due the earthquake. The exposed rock indicates that the rock is limestone from Carboniferous Age.

在紫坪铺水库施工期间，在河岸附近的斜坡上挖掘出堆石料。因为地震，原来采石场残余斜坡暴露并坍塌。暴露的岩石表明岩石是石炭纪时代的石灰岩。

At the upper reaches of the Zipingpu Reservoir, the peeling type (shallow layer) debris flows on the left bank of the Minjiang River. The debris channels occurred mostly at the top of the slope or the upper sections of the slopes, which are one of the characteristics of earthquake collapse.

在紫坪铺水库上游，岷江左岸有剥离型（浅层）泥石流。碎片通道主要发生在斜坡顶部或斜坡上部，这是地震坍塌的特征之一。

The dense network of anchors protected the slopes but those slopes without anchoring works were severely collapsed.

密集的锚网络　护了斜坡，但那些没有锚固工程的斜坡严重坍塌。

Landslide view on the slopes of the reservoir 200 meters from the crest of the dam

水库斜坡上的山体滑坡景观距离大坝顶部200米

Rock Falls In The Zipingpu Reservoir Area
紫坪铺水库区落石

Slopes next to Zipingpu Reservoir were collapsed due to the Wenchuan earthquake

由于汶川地震，紫坪铺水库水库旁边的斜坡坍塌

Water Wave Impact During Earthquake
地震时的水波冲击

At the time of the Wenchuan Earthquake on May 12, 2008, the huge swell of the Zipingpu Reservoir and the fishermen who were caught in the bottom of the reservoir by huge waves.
The Zipingpu dam management said: The reservoir water waves caused by the earthquake will involve a few people fishing in the reservoirs in the reservoir water! A man who lived next to the Zipingpu Dam said that his son was swept away by the big waves during the earthquake when he was fishing in Zipingpu. A man who escaped from Yingxiu Town, Wenchuan County said: "In the earthquake, I saw the water level of the Zipingpu Reservoir soaring. I also saw the village in the mountain disappearing instantly in the mudslide. The scene is terrible!" The purple caused by the Wenchuan earthquake The lake sluice of the Zipingpu Reservoir may also lead to the 213 National Highway from the Zipingpu Reservoir to the Yingxiu Bridge (2016, Zhong-qi Quentin YUE).

2008年5月12日汶川大地震时刻，紫坪铺水库的巨大涌浪和被巨浪卷入库水底的钓鱼人。

在汶川大地震后，紫坪铺大坝管理人员说：地震引起的水库浪将在库边钓鱼的人卷入库水中！住在紫坪铺大坝旁的一位先生说，他的儿子是在紫坪铺钓鱼时，被震时的大浪卷走了。一位从汶川县映秀镇逃难出来的男子说："地震时，我看见紫坪铺水库的水位猛涨，还看见山上的村庄在泥石流中瞬间消失，场景十分可怕！"汶川大地震造成的紫坪库水库的湖啸，还可能导致了213国道从紫坪铺水库到映秀的一段大桥的跨倒

(博客 2016-6-6,岳中琦)


图 4
白气
涌浪
车


图 5
白气
涌浪
车


图 6
青山
白气
涌浪


图 7
青山
白气
涌浪
码头

The Other Hazards Caused by Earthquakes in Reservoir
水库地震引发的其他危害

1. Formation of barrier lakes upstream.
2. The landslides will generate huge waves that overflow the dam and cause damages (For Vajont Dam in Italy in 1963, the geological failure was in a valley wall leading to landslide at 110 km/h into the lake. Water escaped in a wave over the top of the dam. Several villages completely wiped out with fatality of 2,000 persons).
3. The landslide caused the soil falling into the reservoirs and accumulated in front of the dam. This will seriously reduce the capacity of the reservoir and shorten its life.

1. **上游形成屏障湖泊。**
2. **山体滑坡将产生巨大的波浪，溢出大坝并导致损坏，1963年在意大利的Vajont大坝，地质破坏發生於一个谷壁，导致滑坡以每 小 時 110公里的速度进入湖中,波浪在大坝顶部溢出。几个村庄被完全淹没，死亡人数为2,000）。**
3. **山体滑坡导致土壤落入水库并积聚在大坝前。这将严重降低水库的容量并缩短其寿命。**

Serious road traffic congestion near Zipingpu Dam after the earthquake

地震后紫坪铺大坝附近　路交通受阻　况

Are We Lucky?

The Zipingpu Hydropower Station reservoir area is the first epicenter of the 5.12 Wenchuan Earthquake in 2008. The intensity of the earthquake at the epicenter of magnitude 8 is 11. As early as before February 2006, a few of the experts raised the concern that the design for earthquake resistance for Zipingpu dam was only at seismic intensity of 8 (Because of a reservoir, the regional assessed intensity of 7 should be adjusted to 8), However, it had not been able to attract the attention of relevant departments.

Despite the Zipingpu dam was design to resist earthquake of intensity of 8, but it was lucky enough that there was no collapse at the intensity of 11.

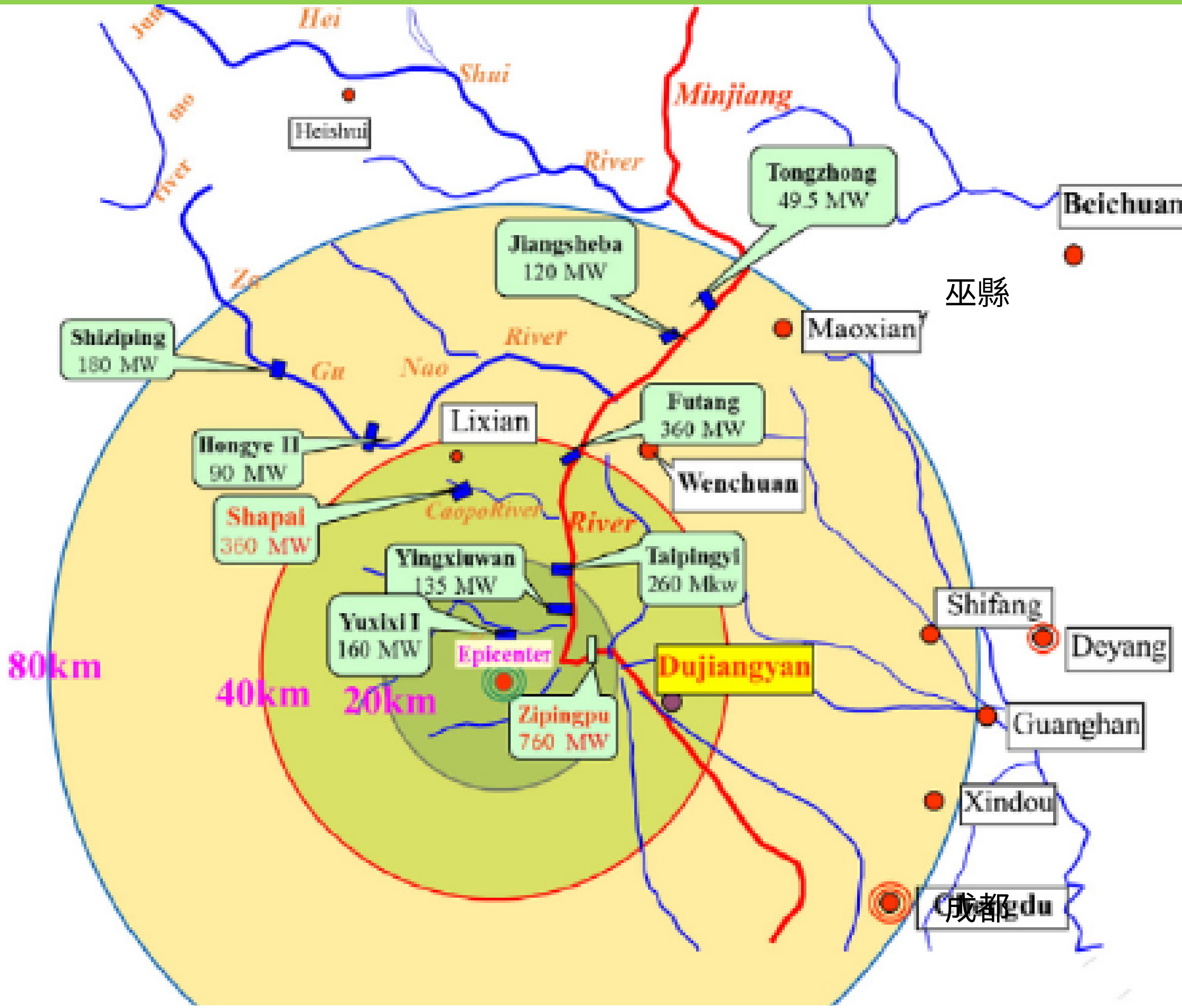
Impounding water will generally be discharged to the lowest capacity of Zipingpu Reservoir for generation of electricity before next rainy season if practicable. Besides, It can get sufficient capacity to hold excessive rainwater for the coming rainy season. Because the actual storage capacity of the Zipingpu Reservoir was only 1/3 of its full capacity (i.e. nearly at the lowest water dischargeable level of the reservoir) just before the earthquake, the reservoir did not collapse. The Chengdu area and the entire Chengdu Plain were then safe. Isn’t it?

我们侥幸吗？

紫坪铺水电站库区， 正是2008年5. 12汶川大地震的第一震中， 8级大地震震中地震烈度为11. 早在2006年2月， 地震专家就提出， 设计抗震烈度仅为8烈度的紫坪铺坝库抗震问题， 但一直未能引起有关部门的重视.

雖然紫坪铺坝库仅能抗8烈度，却侥幸在11烈度的大地震中没有彻底垮塌.

如果可行的话，在下一个雨季之前，蓄水将通常被排放到紫坪铺水库的最低容量以产生电力。 此外，它可以获得足够的容量来承受即将来临的雨季过多的雨水。是否由于紫坪铺水库的实际蓄水量仅为地震前的全部容量的1/3（即几乎处于水库最低可排水水位），紫坪铺大坝在大地震中才未垮塌，成都市区及整个成都平原才幸免于难?



Major Earthquake Impact on Dams with Power Stations Around Minjiang River

地震对岷江流域电站大坝的主要影响

Fig. 2. Major earthquake impacts on the Minjiang river power station.

The High Dams in China To Be Concerned
值得关注的中国的高坝

Name 坝名称	Province or city 省或市	Impounds 蓄水河	Height (m) 高度	Type 类型
Shuangjiangkou Dam	Sichuan	Dadu River	312	Rockfill
Jinping-I Dam	Sichuan	Yalong River	305	Arch
Lianghekou Dam	Sichuan	Yalong River	295	Arch
Xiaowan Dam	Yunnan	Lancang River	292	Arch
Xiluodu Dam	Yunnan	Jinsha River	285.5	Arch
Baihetan Dam	Sichuan/Yunnan	Jinsha River	277	Arch
Nuozhadu Dam	Yunnan	Lancang River	261.5	Embankment, rock-fill
Laxiwa Dam	Qinghai	Yellow River	250	Arch
Ertan Dam	Sichuan	Yalong River	240	Arch
Changheba Dam	Sichuan	Dadu River	240	Concrete-face rock-fill
Wudongde Dam	Sichuan/Yunnan	Jinsha River	240	Gravity
Shuibuya Dam	Hubei	Qing River	233	Concrete-face rock-fill
Goupitan Dam	Guizhou	Wu River	232.5	Arch
Houziyan Dam	Guizhou	Dadu River	223.5	Embankment
Zipingpu Dam	Sichuan	Min River	156	Concrete-face rock-fill

Dam height of greater than 300m: 3 (Including in construction)
Dam height of greater than 200m:20

水坝高度大于300米：3（包括施工）
水坝高度大于200米：20

5. Questions To Be Meditated

1. Can Zipingpu Reservoir sustain for another large Earthquake under the following condition?
   A. Under Earthquake of M8 or higher.
   B. The water is impounded to 877m.
   C. The spill gates are damaged that cannot be opened in two days but the water level raised due to the storm water.
2. What the administrative measure for Zipingpu Reservoir to undermine the hazards from the dam failure? We can consider:
   A. Reduce the capacity and the height of water storage.
   B. Reduce the speed of impounding and discharge of water.
   C. Provide separate and emergent electric power from other source to maintain the function for the gates.
   D. For the above measures, can it be compromised with efficiency and costs without deficit?

思考的问题

1．在下列情况下，紫坪铺水库能否抵御下一次的大地震？
   A. 在M8或更高的地震下。
   B. 水被淹没到877米。
   C. 泄漏闸门损坏，两天内无法打开，但由于暴雨,水庫内水位不断上什。
2. 有什么行政措施能降低紫坪铺水库倒塌的危害? 我们可以考虑：
   A. 减少储水量和高度。
   B. 降低蓄水和排水的速度。
   C. 从其他来源提供单独的和紧急的电力以维持门的功能。
   D. 对于上述措施，是否可以在没有赤字的情况下降低效率和成本？

3. There are a number of large and reservoirs constructed in China particularly in the highly seismic in western China. A few of theme has height greater than 300m. Will they be safe?

4. Is the hydropower exploitation in China is overdeveloped with reasonable plan?

5. Could earthquake be predicted? How about the performance in this aspect after the correct prediction in Hashing, one of the big cities in China?

6. Could the Three Gorges trigger the Wenchuan Earthquake? A few of the experts have raised this point.

7. Regarding the safety problem in reservoir, are we psychologically in mind that " give up eating for fear of choking"?

3. 中国有许多大型水库，特别是在中国西部的高地震区。一些霸的高度超过300米。他们会安全吗？

4. 中国的水电是否过度开发? 开发计划是否合理？

5. 地震可以预测吗？在中国大城市之一，诲城，準正确地预测过地震，这方面的表现如何？

6. 三峡能否引发汶川大地震？ 有個别專家提出过這點。

7. 对於水庫的安全问题，我们心理上是否因为"害怕窒息而放弃进食"？

6. Some Suggestions After Meditation

思考后的一些建议

1. To improve the seismic design idea and codes as well as to contribute advancing studies in the field of seismic safety of dams.
2. To establish regulation to review and control the construction of dams in highly seismic area that directly above active faults.
3. Establish remote, land and built–in seismic and settlement sensor network in high density.
4. Establish alarming system to public with direction.
5. Educate citizen to know more about earthquake with corresponding action.
6. Factual inspection reports should be published by government to rule out rumors and mis-understanding.

1. **改进抗震设计理念和规范，并为水坝地震安全领域的研究做出贡献。**
2. **建立监管，审查和控制直接位于活动断层上方的高地震区坝的建设。**
3. **建立高密度的远程，陆地和内置地震和沉降传感器网络。**
4. **建立面向公众的警报系统。**
5. **通过相应的行动教育公民更多地了解地震。**
6. **政府应公布事实检查报告，以排除谣言和误解。**

Some Suggestions After Meditating

7. Some of damages aftermath earthquake should reasonably be reserved before the inspection and study by professional experts as far as possible.
8. To encourage the evacuation of citizen from highly seismic area to avoid "Damage-reconstruct–damage" vicious cycle situation.
9. Implement scientific rescue to avoid rescue becomes another new burden. The Lushan earthquake demonstrates that China has already improved a lot for response, organization, material levelling and transport, medical treatment as compared with the Wenchuan earthquake that happened five years ago.
10. Provide more rescue shelters and facilities in mountainous area.

思考后的一些建议

7. 在专业专家的检查和研究之前，应尽可能合理地保留地震后的一些损害。
8. 鼓励公民从高度地震区撤离，以避免"损害 - 重建 - 再损坏" 惡性循环的情况。
9. 实行科学救援以避免救援成为另一个新的负担。庐山地震表明，与五年前发生的汶川地震相比，中国在应对，组织，物流平整，运输，医疗等方面已经有了很大的提高。
10. 在安装区域提供更多的救援庇护所和设施。

After Expressing My Viewpoints for the Above Questions, What Are Your Opinions?

END
Thank You!

在上述问题，我已经表达我的观点．您有什么意见？

结束
谢谢！