地震工程与工程振动
JOURNAL OF EARTHQUAKE ENGINEERING AND ENGINEERING VIBRATION
ISSN 1000-1301
CN 23-1157/P

汶川8.0级地震
工程震害概览

GENERAL INTRODUCTION OF ENGINEERING DAMAGE
OF WENCHUAN Ms 8.0 EARTHQUAKE

第28卷 增刊 2008年10月
Vol.28 Supplement Oct.2008

ISSN 1000-1301
9 771000 130028 10>

中国力学学会
中国地震局工程力学研究所 主办
科学出版社 出版

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汶川 Ms 8.0 级地震工程震害概览

General Introduction of Engineering Damage of Wenchuan Ms 8.0 Earthquake

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1 PREFACE

At 14:28:04 on May 12,2008 (Beijing Time), a great earthquake (Ms=8.0) occurred in west part of Chinese continent. The earthquake epicenter was located at latitude 31.021°N and longitude 103.367°E, in Wenchuan, Sichuan province, and the focal depth was 14 Km. Meizoseismic area was a long and narrow belt area, along the seismogenic fault, and the epicentral intensity was up to Ⅺ. The earthquake affected areas of six provinces, Municipal and Autonomous Regions including Sichuan, Gansu, Shaanxi, Chongqing, Yunnan, and Ningxia. People in over half of China and as far as in Vietnam felt the shaking of this earthquake.

There are three striking characteristics of this huge event, that is, the large magnitude, the high casualty and the extremely huge property and economic loss. The causative fault of the earthquake ruptured and outcropped to the surface along a length over 240km, which resulted in not only large numbers of building collapse but also a widespread issue of heavy landslide, rolling stones, mudslide, liquefaction, and other geological hazard. The landslide induced quake lakes aggravated the risk of disaster. A large number of buildings collapsed or were damaged to a various degree because of the fault movement and strong ground motion. The basic lifeline systems such as transportation, electricity, communications, water supply and drainage, gas, hydraulic structures and many others were damaged badly, with damage not seen in Chinese history. The heavily damaged roads, bridges, power and other systems severely obstructed earthquake relief work, cascading the human and economic loss. Industrial enterprises, forestry, agriculture, tourism and other industries were all badly affected.

Right after the earthquake, China Earthquake Administration responded quickly by dispatching many teams to earthquake-stricken areas a few hours after the event on the same day. The dispatched teams actively participated in emergency response, search and rescue efforts as well as in carrying out damage assessment and scientific investigation. Institute of Engineering Mechanics also dispatched at the peak time more than 70 people to the area with many members entering the most severely damaged areas such as Yingxiu and Beichuan for emergency response and detailed investigations of the damage of buildings, the lifeline system, water system and other engineering structures. Their work also included the observation of the typical construction during aftershocks, strong motion observation and collecting abundant earthquake disaster data with a maximum length of stay up to 4 months. The original data of the earthquake damage occurred at the cost of hundreds of thousands of people's lives will undoubtedly have a vital impact on the development of earthquake engineering, protection against and mitigation of earthquake disasters in the future.

This supplementary issue collected selected seismic damage photos based on the earthquake field investigation for different building and engineering types. The materials and maps used in this collection were mostly accumulated from members of Institute of Engineering Mechanics, China Earthquake Administration who went to the field, with a number of important additions from members of other institutes, including Chengdu University of Technology, Chengdu Hydroelectric Investigation & Design Institute of SPC, China Southwest Architecture Design Institute, Traffic Designing Institute of Sichuan, Technological Co., Ltd. of the China, Sichuan Relic and Archaeological Institute, etc. Although many teams has been sent to the field ever since occurrence of the earthquake and collected many valuable pieces of information, we are still in the early stages of the investigation. This publication serves as a preliminary report on the earthquake damage, for which there are many more detailed reports planned and you advice is welcome to make the future publications more valuable.

This pamphlet is supported by Field Investigation Project of Wenchuan Earthquake, CEA.

2 SEISMOGENIC STRUCTURE AND GEOLOGIC HAZARD

2.1 Geologic-Tectonic Background and historical Earthquake

The earthquake occurred at the middle segment of China's south-north seismic belt, specifically with an NE direction along Longmenshan Fault Zone in Eastern Margin of Tibetan Plateau. This Fault Zone locates at the transitional region from mountains to a plain. Using the Longmenshan Fault as a boundary, the west part is in a mountain area while the east is in the basin (Photo 2.1.1). Landform nearby the Fault Zone is typical for an alpine-gorge area. In the area, rivers are deep, the valley side is steep, and the height difference can reach as high as 3600m-3800m (Photo 2.1.2).

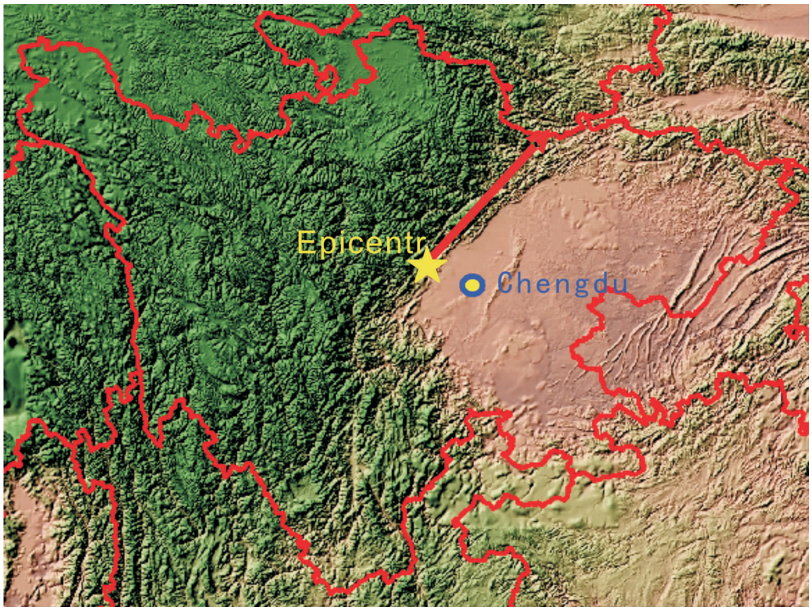


Photo 2.1.1 The epicenter of Wenchuan earthquake and Landform Map of surrounding area

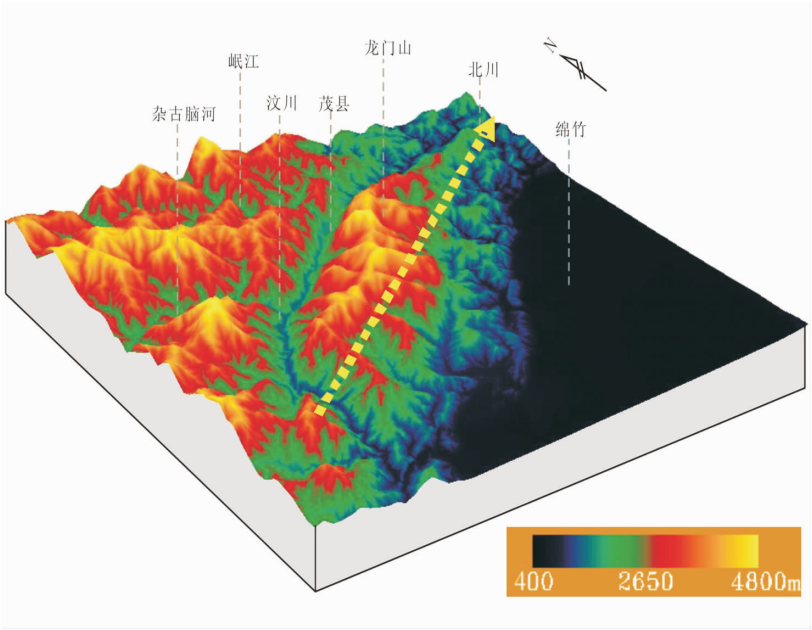


Photo 2.1.2 Landform schematic diagram nearby the Longmenshan Fault Zone

On the geological structure side, Longmenshan Fault Zone belongs to a fault folder which is formed by Mesozoic orogeny. The fault is in a large active fault zone, which moved differently in Cenozoic period and the late Cenozoic. The Fault zone is mainly composed of three major faults. From southeast to northwest in order are Front-range Faults (the middle south section is called Jiangyou-Guanxian Fault, the north section is called Jiangyou-Guanyuan Fault), the Central (the middle south section is called Beichuan-Yingxiu Fault or Zhongtangpu Fault, the north section is called Chaba-Linganshi Fault) and the Back-range (the middle south section is called Maoxian-Wenchuan Fault, the north section is called Qingchuan Fault). Three major faults all show right-lateral strike-slip, characteristic of a thruster(Photo 2.1.3).

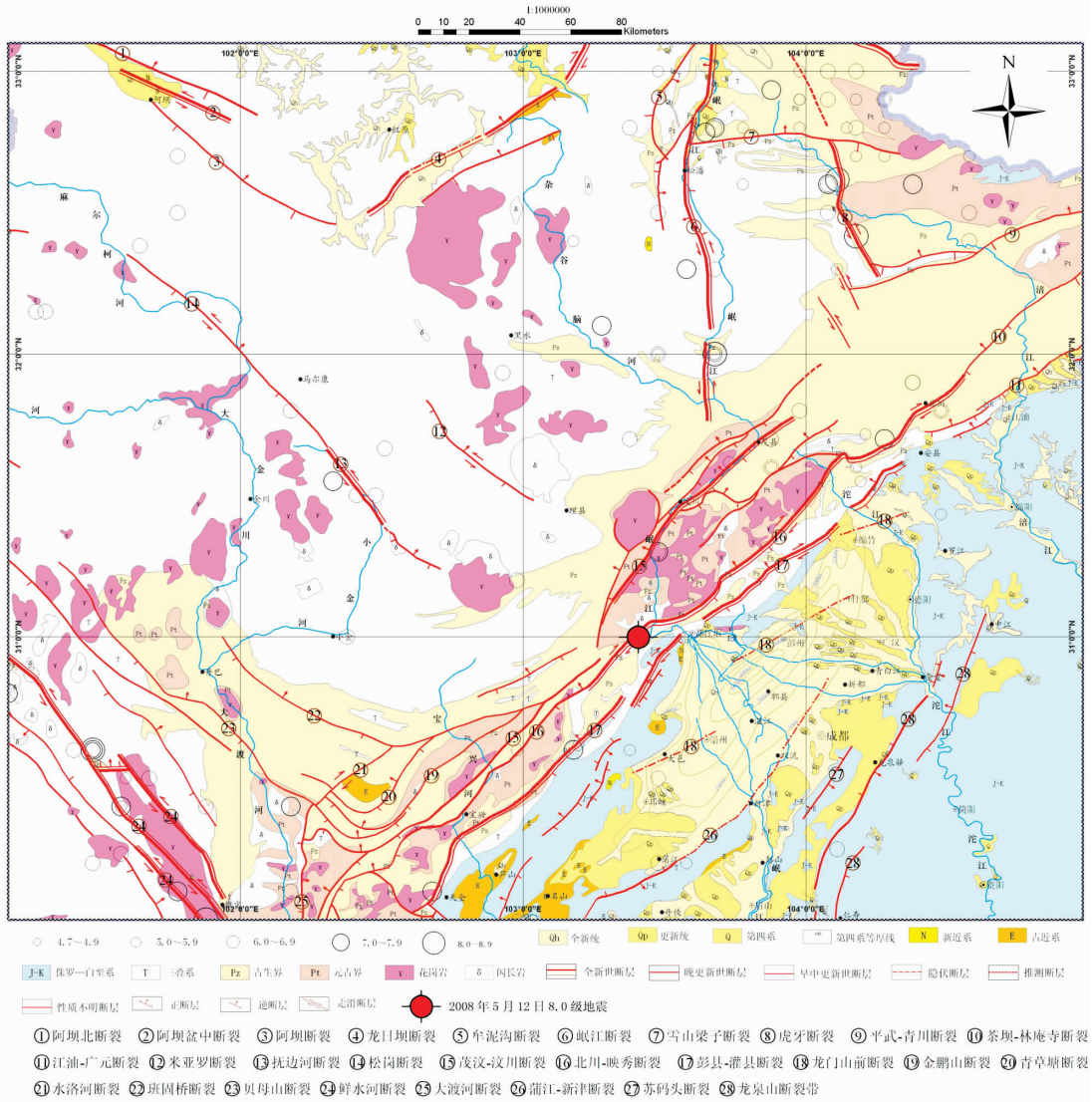


Photo 2.1.3 The distribution of Longmenshan Fault Zone and surrounding faults (Offered by Lei Jiancheng)

The major surface rupture zone of Wenchuan earthquake is spreading along the central fault of Longmen mountain fault zone(Beichuan -Yingxiu fault, the most southern segment of Chaba-Linansi fault)、and a fault between Qingchuan fault and Chaba-Linansi fault. The major surface rupture zone of Wenchuan earthquake began between Yingxiu and Sanjiang in Wenchuan County in the south-west, passing to north-east by Hongkou, Xiange in Dujiangyan, Xiaoyudong, Longmenshan in Pengzhou, Leigu, Qushanin, Chenjiaba, Guixi in Beichuan, Pingtong, Nanba, Shikanzi in Pingwu. Maybe arrived at Qingchuan. The continuous total length is up to more than 200 kilometers. Meanwhile, when the earthquake occurred, the frontal fault (Jiangyou-Guan County fault) of Longmen mountain also had surface rupture spreading from the east of Tongji in Pengzhou to Suishui in Anxian County, passing by

Bailu in Pengzhou, Bajiao, Hongbai Town in Shifang, Hanwang Town in Mianzhu, the total length is more than 50 kilometers(Photo 2.1.4).

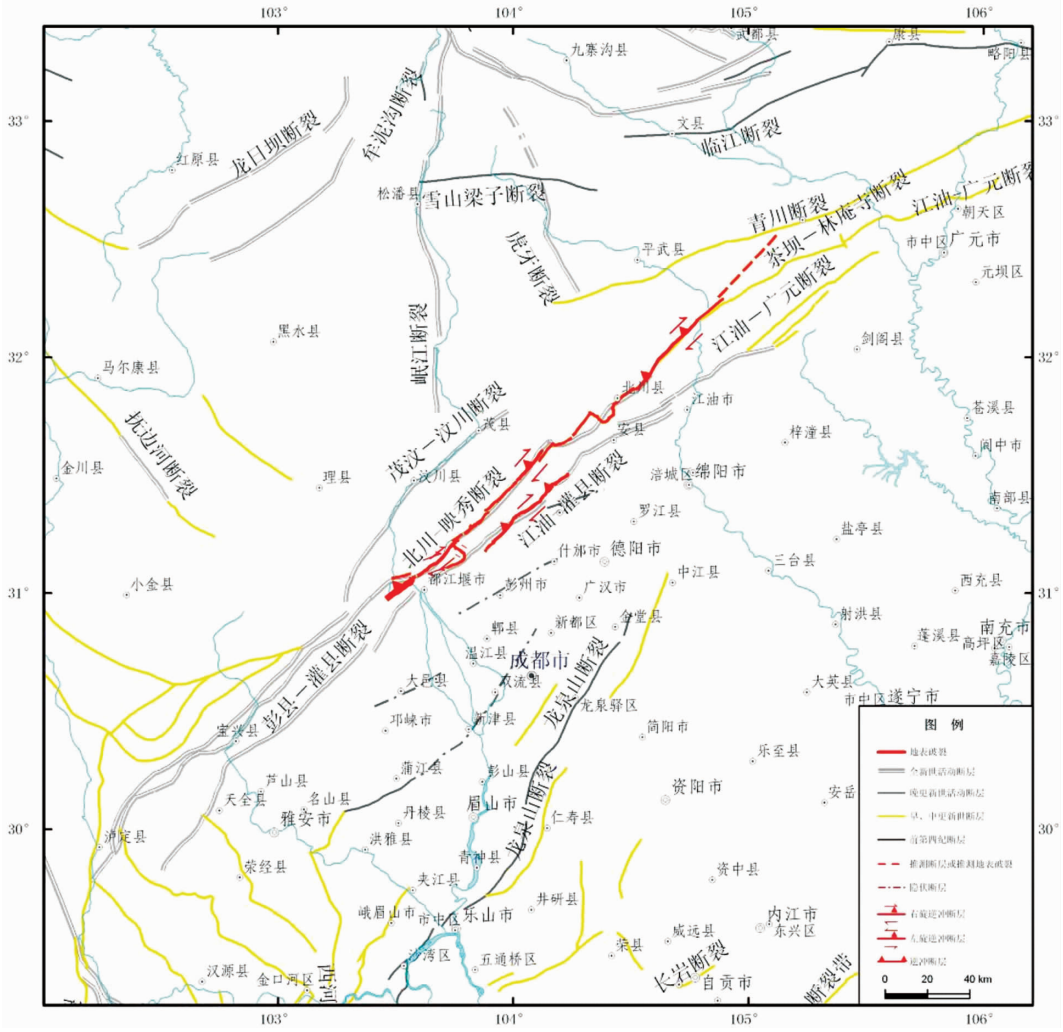


Photo 2.1.4 The geological layout of surface rupture zone of Wenchuan earthquake (the red line in the graph)
(Offered by Wen Xueze)

Kinematics characteristics of surface rupture zone reflect the causative fault, is a reverse-thrust fault, which the north-west board of the fault is moving relatively towards north-east and up thrusts at the same time. Along the main surface rupture zone, most of the coseismic vertical and horizontal dislocations are between 2m and 4m, and proportion of vertical and horizontal dislocations is about 1:1; The largest dislocations discovered located near Hongkou Town, Dujiangyan City, of main surface rupture zone, and largest vertical dislocation was 4.8m, largest horizontal dislocation4.7m (Photo 2.1.5 a). Oblique fault scarps are generally along the surface rupture zone and take shape in the bank while passing riverbed (Photo 2.1.5 b). Along the secondary surface rupture zone of the front fault (Jiangyou-Guanxian Fault), most of the vertical and horizontal dislocations are between 0.5m and 2m, and the vertical dislocations are larger.

Fault outcrop brings about uplifts and translations of the ground with great displacement, and buildings and structures are destroyed directly if the fault passes through cities and towns or highways, bridges directly. When earthquake fault crossed the old town of Beichuan County, a ruin area nearly 100 meters wide was formed (Photo 2.1.5 c). A newly built building that located on the earthquake fault collapsed in Beichuan new urban (Photo 2.1.5 d); Along the street of Xiaoyudong Town, Pengzhou, only the building that crossed by the fault was destroyed (Photo 2.1.5 e). Dujiangyan-Wenchuan highway was broken by the fault in Yingxiu Town (Photo 2.1.5 f).

Photo 2.1.5 Surface rupture zone of Wenchuan Earthquake and photos of damages of near field
(a) Hongkou Town, Dujiangyan City (b) Pingtong Town, Pingwu County (c) Old town of Beichuan County
(d) Beichuan new urban (e) Xiaoyudong Town, Pengzhou City (f) Yingxiu Town, Wenchuan County
((a) was offered by Li Xiguang, others were offered by Wen Xueze)

According to the historical documents and instrument record data, three times M6 ~ M6 $_{1/2}$ strong earthquakes had occurred in the middle and south parts of the Longmenshan fault, which are M6 $_{1/2}$ earthquake of Wenchuan on Apr. 21, 1657, M6$_{1/4}$ earthquake of Beichuan on Feb. 8, 1958 and M6.3 earthquake of Dayixi on Feb. 24, 1958. But above M6 earthquake hadn't occurred in north part of the Longmenshan fault based on records. By contrast, four times M7.0 ~ M7.5 earthquake and five times M6.0 ~ M6.9 earthquake had occurred from 1630 in the area of Songpan-Pingwu and Diexi of Maoxian County (Photo 2.1.6).

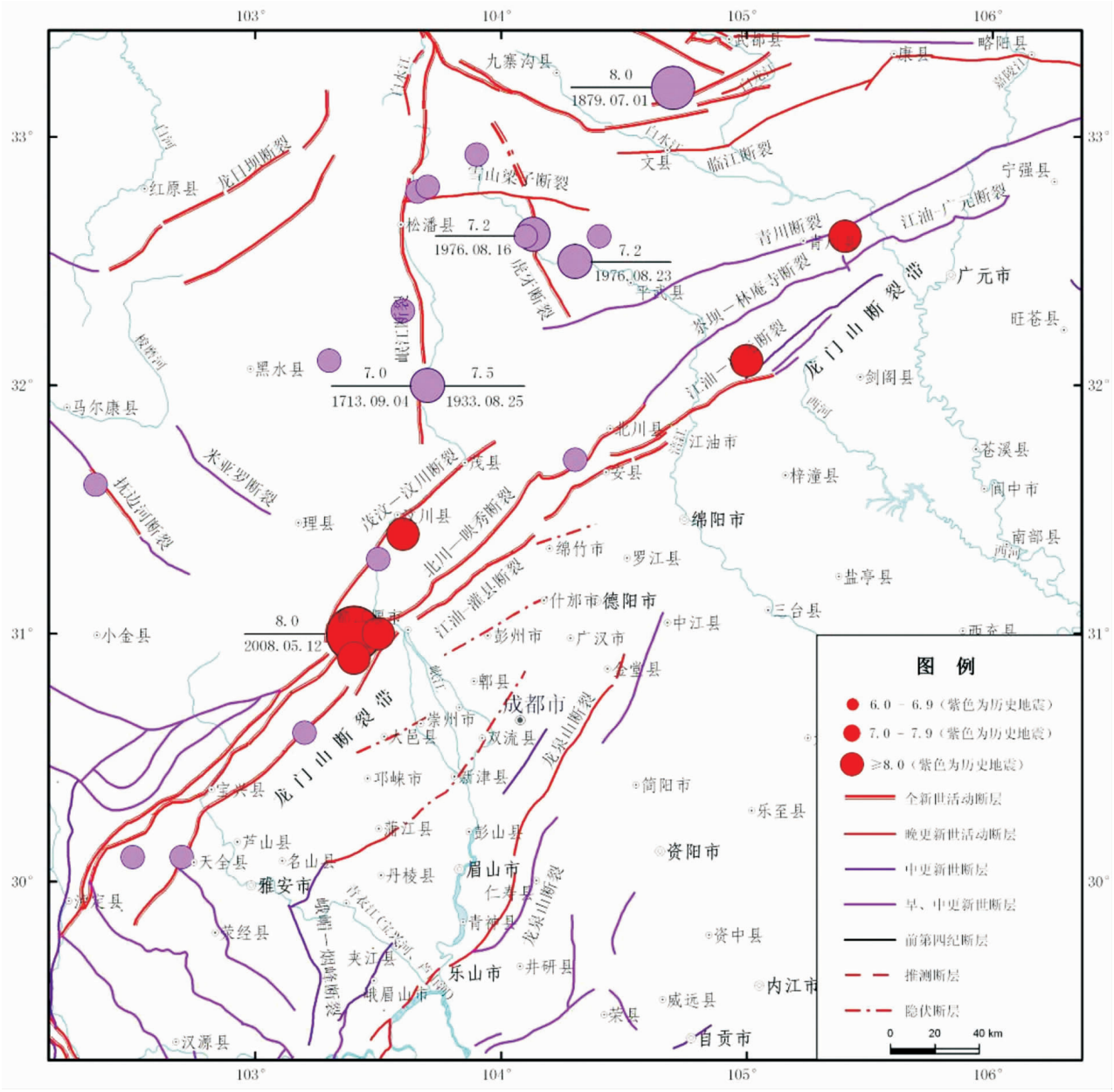


Photo 2.1.6 Distribution of historical earthquakes around Longmenshan fault zone (Offered by Wen Xueze)

2.2 GEOLOGICAL HAZARD

(1) Seismic Landslides

Due to the great height and steepness of slopes and their loose geotechnical structure in the mountainous terrain, there were literally scores of thousands of landslides and collapses in the Longmenshan fault zone during the earthquake, resulting in a great amount of geotechnical disasters, such as destroy or bury the roads, villages, towns, bridges and culverts. Based on the survey statistics conducted by the State Key Laboratory, for Geohazard Prevention, Chengdu University of Technology, a total of 8627 geological disasters occurred, among which there were 3627 landslides, 2383 slop collapses, 837 debris flows, 1694 unstable slopes and 86 places with hidden danger of geological hazard. Over 800,000 people and their properties in the affected area were under a directly serious threat (Photos. 2.2.1- 2.2.4). Table 2.2.1 shows a list of Catastrophic landslides and collapses happened in Wenchuan Earthquake, during each of which more than 30 people died.

Table 2.2.1 Catastrophic landslides and collapses happened during Wenchuan Earthquake (Offered by Huang Runqiu)

Place	Hazard type	Scale ($\times 10^4 m^3$)	Death toll
Wangjiayan (Qushan townTown), Beichuan countyCounty (Fig. Photo 2.2.1)	Landslide	1000	1600
New Mmiddle Sschool of Beichuan (Qushan townTown), Beichuan countyCounty (Fig. Photo 2.2.1)	Landslide	1000	906
Yingtaogou, Chayuanliang Vvillage, Chenjiaba townshipTownship, Beichuan countyCounty (Fig. Photo 2.2.4)	Landslide	188	700
1# landslide Landslide in Chang town Town, Chenjiaba townshipTownship, Beichuan countyCounty (Fig. Photo 2.2.5)	Landslide	1200	400
Donghekou village Village, Hongguang township Township, Qingchuan countyCounty	Landslide	1000	260
Hongyan vVillage, Chenjiaba township Township, Beichuan countyCounty	Landslide	480	141
Liming Village, Zipingpu Town, Dujiangyan cCity Zipingpu town Liming village	Landslide	20	120
Xiejiadian, Jiufeng villages Village, Pengzhou city City	Landslide	400	100
Xiaolongtan, Yinchanggou, Pengzhou cityCity	Collapse	5.4	100
Gullies of Dalongtan, Yinchanggou, Pengzhou cityCity	Collapse	10	100
2# landslide Landslide in Taihong villageVillage, Chenjiaba townshipTownship, Beichuan countyCounty	Landslide	500	100
Taian villageVillage, Qingcheng urban Dujiangyan cityCity	Collapse	120	62
Zhengjiashan, Xinping villageVillage, Nanba town Town, Pingwu countyCounty	Landslide	1250	60
Hanjiashan, Dujiaba villageVillage, Guixi township Township, Beichuan countyCounty	Landslide	30	50
Jianxin villageVillage, Quhe tTownship, Qingchuan countyCounty	Collapse	70	41
Maanshi villageVillage, Shuiguan township Township, Pingwu countyCounty	Landslide	400	34
Liangaiping Tuanshan villageVillage, Pengzhou cityCity	Landslide	40	30

Photo 2.2.1 Serious damage and casualties caused by landslide in Wangjiayan (shown at the left near the bottom), Beichuan County Town and New Beichuan Middle School (Right) (Offered by Huang Runqiu)

Photo 2.2.2 Road and buildings buried by landslide in Wenchuan County

Photo 2.2.3 Landslides along the Minjiang River between Maowen and Wenchuan Counties

Photo 2.2.4 Huge landslide buried a whole village in Chenjiaba Township, Wenchuan County

Photo 2.2.5 Landslides buried the whole villages in Chenjiaba Township, Wenchuan County

Photo 2.2.6 Landslide destroyed bridge

Photo 2.2.7 Aftershock triggers landslide

The field investigation showed that the distribution of landslides is closely related with the causative fault, more landslides occurred at the north of the fault than at the south. (Fig. 2.2.1), and the majority of landslides were in a belt distribution in the Longmenshan Fault Zone and along bank of a river (Fig. 2.2.2).

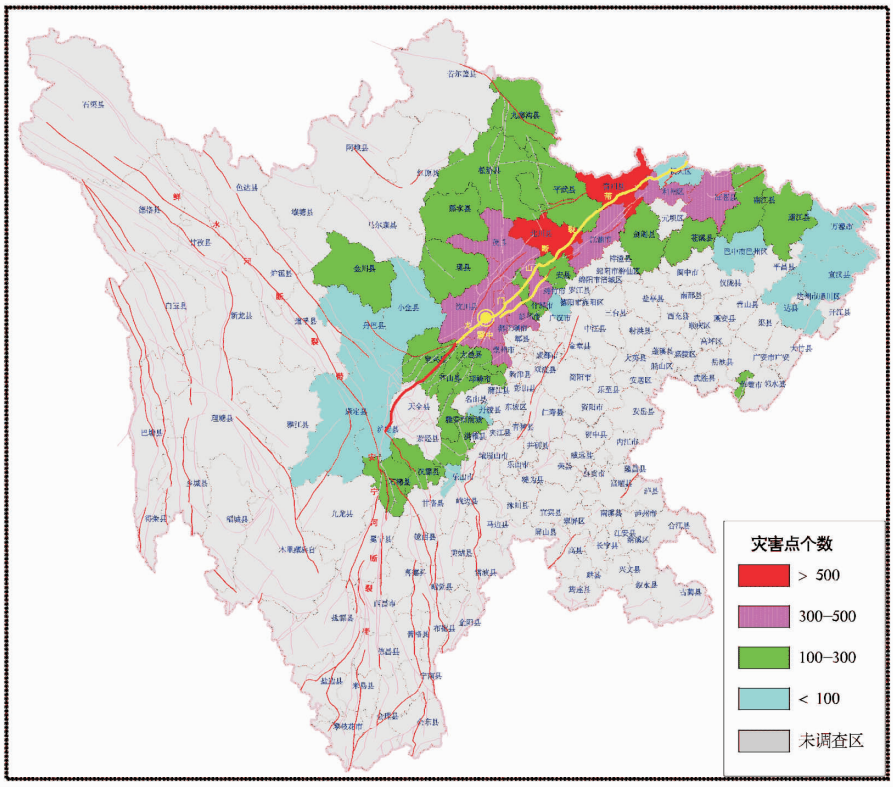


Fig. 2.2.1 Distribution of landslides and causative faults (Offered by Huang Runqiu)

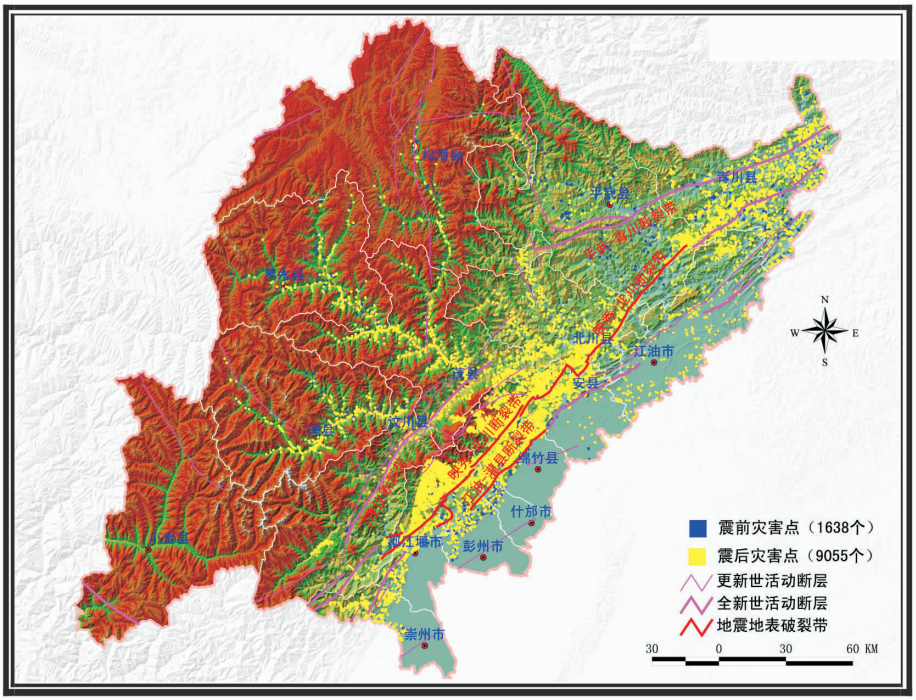


Fig. 2.2.2 Landslide distribution along Longmenshan fault and river (Offered by Huang Runqiu)

Figure 2.2.3 plots the proportion of landslide's number against fault distance. Note that as the distance from

causative fault increases the number of landslide decreases, and when the distance beyond 20 km the landslides is only about 5% of the total number.

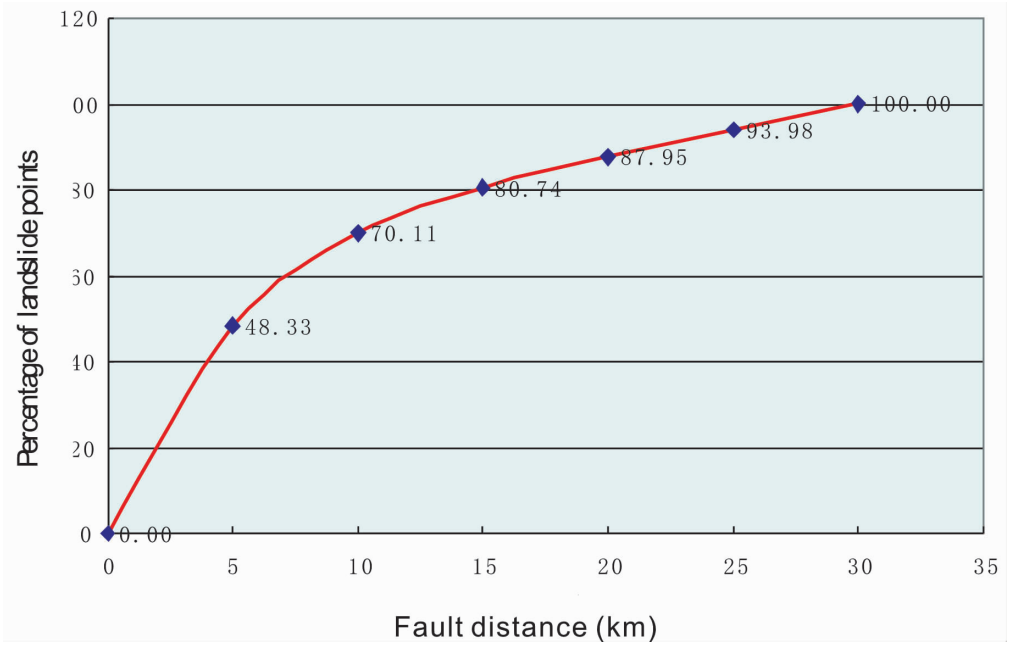


Fig. 2. 2. 3 Relationship between proportion of landslide's number and the fault distance

The density of the landslides on hanging wall of a fault is larger than on foot wall. Figure 2. 2. 4 illustrates statistics results of the damaged roads caused by landslides on two sides of fault in the Zipingpu-Wenchuan-Maoxian section of the National Highway Route #213. Note that the damage on the hanging side is much larger than the foot wall.

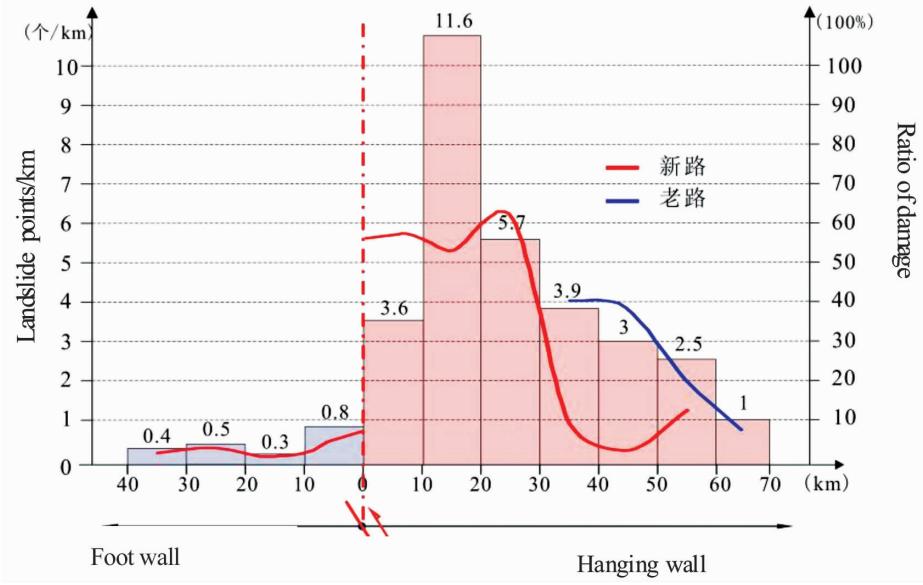


Fig. 2. 2. 4 Variation of landslide induced damage density with fault distance on the fault both sides in the Zipingpu-Wenchuan-Maoxian section of the National Highway Route #213 (Offered by Huang Runqiu)

In addition, the landslide development is related with altitude, gradient, rock mass properties, topography, river valley position, free surface condition and so on.

(2) Earthquake-induced dammed lakes

Landslides mobilized millions of cubic meters of rock and soil that slid across adjacent rivers, creating large landslide dams. The blockage of rivers, especially Minjiang River, was accompanied by the formation of the so-called quake lakes that are flooding the upstream river valleys. As water rises, there is the potential of overtopping and downstream flooding.

Based on the interpretation of Remote-Sensing Treatment Group, China Earthquake Administration and statistics results of China Ministry of Land and Resources, there were 34 quake lakes with certain scale in the affected area, in which the largest one located in the depths of Tangjiashan Mountain, Beichuan County that was flooding the Yuejiashan-Hongbai town section of the main stream of Shitingjiang River. The landslide dam had a height of 71m, the quake lake in the Shitingjiang River direction is more than 800 m long, its largest width is more than 600 m, and its area at the dam crest level is about 300,000 m^2. As of June 7, 2008 the reservoir capacity of the quake lake was 240 million cubic meters, which had been posed a threat to a significantly large area of the downstream zone, it was very lucky that the hidden danger was relieved by dredging and waterdrainage. (Photo 2.2.8)

Photo 2.2.8 Pre-and post comparison of satellite photos of dammed lake's forming in Tangjiashan, Beichuan County Earthquake (According to Chinese news network)

Taking another example, in the north of Pingtong Town, Pingwu County, earthquake-induced landslide blocked Pingtong River, creating quake lake, which submerged buildings on the upper low-lying basin section (See Photo. 2.2.9).

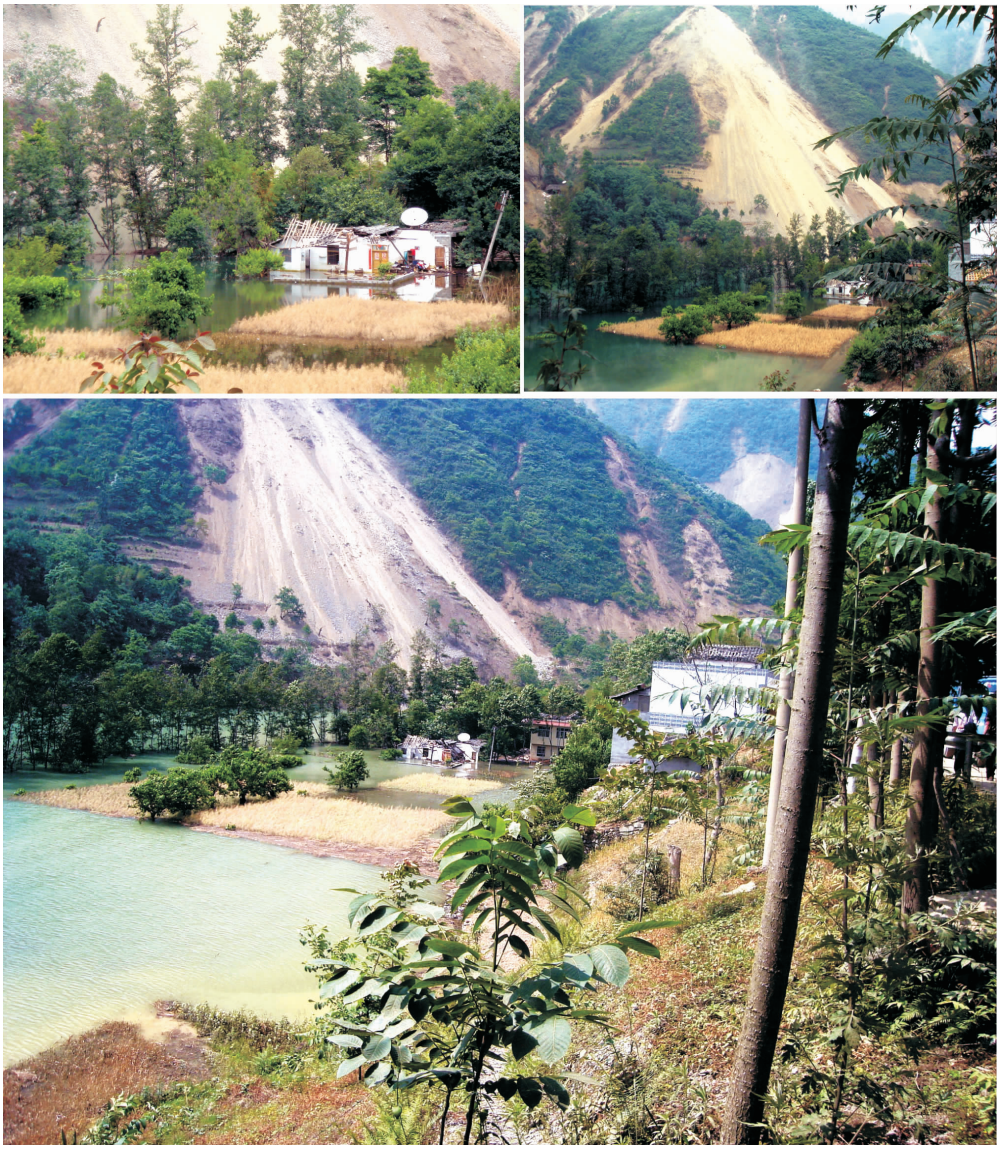


Photo 2.2.9 Landslide and barrier in Pingtong Town submerged field and houses

(3) Rolling Stone

The earthquake touched off a large amount of rolling stones, spreading to a very large area. Rolling stones destroyed houses (Photo 2.2.10, 2.2.11), cracked up vehicles (Photo2.2.12), and blocked roads (Photo 2.2.13, 2.2.14), constituted one of the sources of casualties.

Photo 2.2.10 Rolling Stones destroyed houses in Beichuan County

Photo 2.2.11 Rolling Stones smashed civil houses in Liuhou Town, Hanzhong City, Shaanxi province

Photo 2.2.12 Rolling stones cracked up vehicles

Photo 2.2.13 Rolling stones blocked roads in Beichuan County

Photo 2.2.14 Rolling Stones blocked up roads in Baishigou town, Lueyang County, Shaanxi province

(4) Debris flow

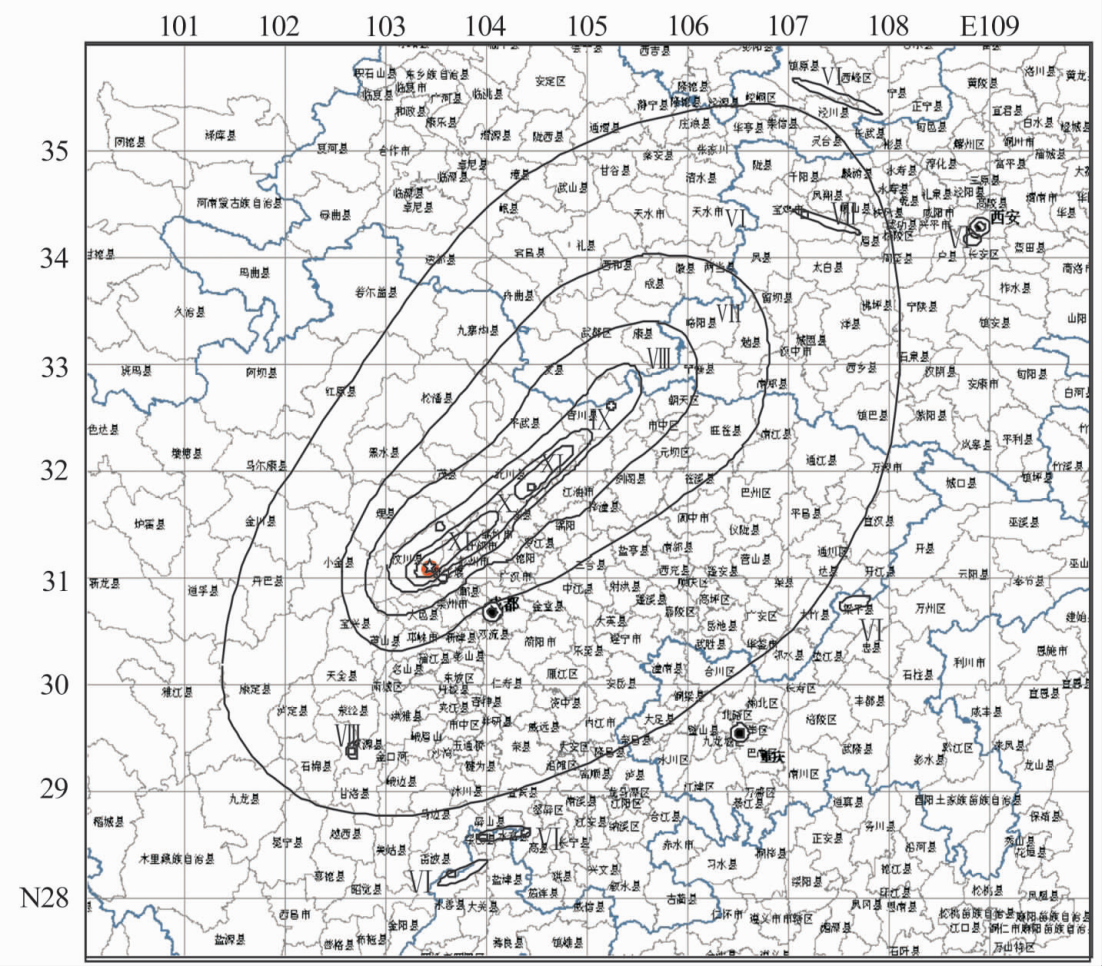
Earthquake caused the mountain surface crashed, then forming debris flow after raining, (Photo 2.2.15) sometimes causing damage.

Photo 2.2.15 Debris flow in the Earthquake in Yinchanggou of Pengzhou

Photo 2.2.16 Debris flow destroyed houses in Yinchanggou of Pengzhou

3 ISOSEISMAL MAP

Applying the national standard "Seismic Intensity Scale of China GB/T17742-1999" to the Wenchuan earthquake the assessed intensity results are in agreement with those of the Modified Mercalli seismic intensity scale". While from the intensity estimated based on field observations it was found that the houses in the affected urban and rural regions in general showed an increased seismic capability due to the economic progress, besides, there were a large number of buildings designed for intensity VII. As a result, buildings were divided into following three categories: Ⅰ(1) Brick-wood buildings or civil houses, including adobe and stone houses, (2) Masonry-concrete buildings without seismic design, and (3) Masonry-concrete buildings designed for intensity VII., and for each building category corresponding macro descriptions of damage are given. The assessed intensity for brick-wood buildings or civil houses is in conformity with the evaluation based on the historical earthquake evaluation standard. Then separately applying the above building categories (2) and (3). to the assessment of cities and towns, including Chengdu, Mianyang, Deyang, Guangyuan, Dujiangyan and the main county towns. The original isoseismal map was rechecked. In the intensity assessment particular emphasis was placed on determining the lowest intensity boundary line and the abnormal intensity regions. The assessed isoseismal map is plotted in Fig. 3.1, it represents the third revised version of the isoseismal map of the Wenchuan earthquake.



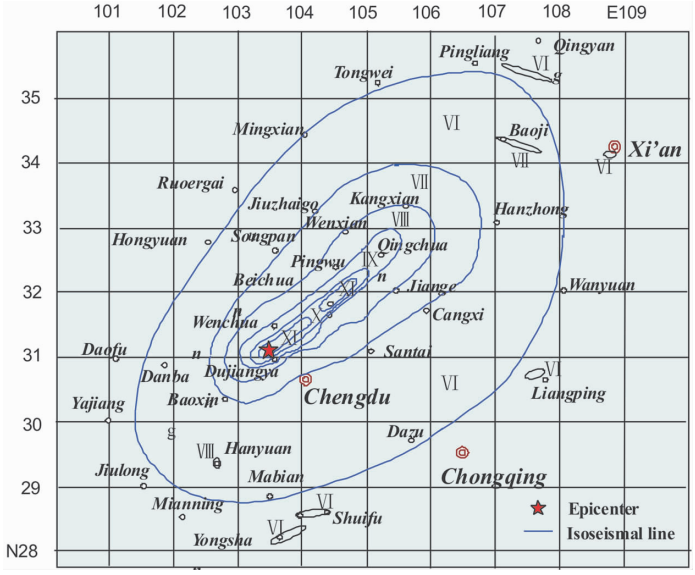


Fig. 3.1 The isoseismal map of Wenchuan earthquake

Note that the isoseismal map of Wenchuan earthquake has the following characteristics:

(1) The epicentral intensity reached Ⅺ;

(2) The regions with intensity larger than Ⅸ are in a narrow belt around the seismogenic fault;

(3) Intensity in the direction perpendicular to the fault decreases quickly.

(4) The regions of intensities Ⅹ and Ⅸ protrude outward at Counties of Mianzhu and, Shifang and Dujiangyan City due to the influence of the fault rupture in front of the Longmenshan Mountains.

(5) The areas of the regions with intensity Ⅵ to intensity Ⅸ in the north (east) of the Fault are larger than in the south (west). This shows the directivity effect of fault rupture, which orientates from south towards north.

(6) An anomalous area of intensity Ⅷ emerged at a distance of about 150 km in the south-west of the fault rupture, at the country town of Hanyuan.

(7) Anomalous areas of Ⅸ degree emerged in Qingyang, Gansu Province (in the west of the seismic affected area), along the Weihe River centred at Chenchang District in Baoji City, Shaanxi Province, in the suburbs of Xi'an, in Liangping, Chongqing, in Suijiang, Shuifu, Yongshan, and Yanjin in Yunnan Province. This can be explained by the mountainous terrain and the old buildings existed in these areas. Tall buildings and high chimneies along the Weihe River and in the suburbs of Xi'an were destroyed. It is obvious? that they were impacted by long-period ground motion components. Soil layer with thickness of more than 100 m in Loess Plateau in Qingyang, Gansu Province may result in amplification of ground shaking.

4 THE MAIN RESULTS OF STRONG MOTION OBSERVATION

478 seismic stations (in mainland) of Chinese Digital Strong Motion Network triggered in Wenchuan earthquake, including 141 stations in Sichuan province and 337 stations in other provinces and cities. The distribution of statios which have obtained the records is shown in Figure 4.1. The distribution of stations triggered in Sichuan Province is shown in Figure 4.2.

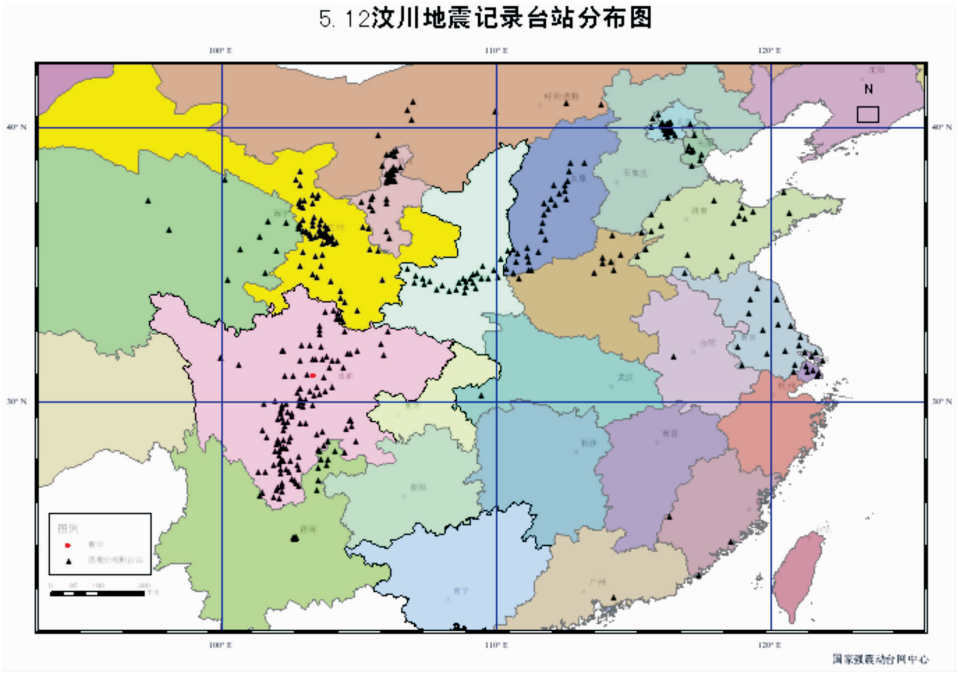


Fig. 4.1 The distribution of strong motion observation stations triggered by Wenchuan earthquake

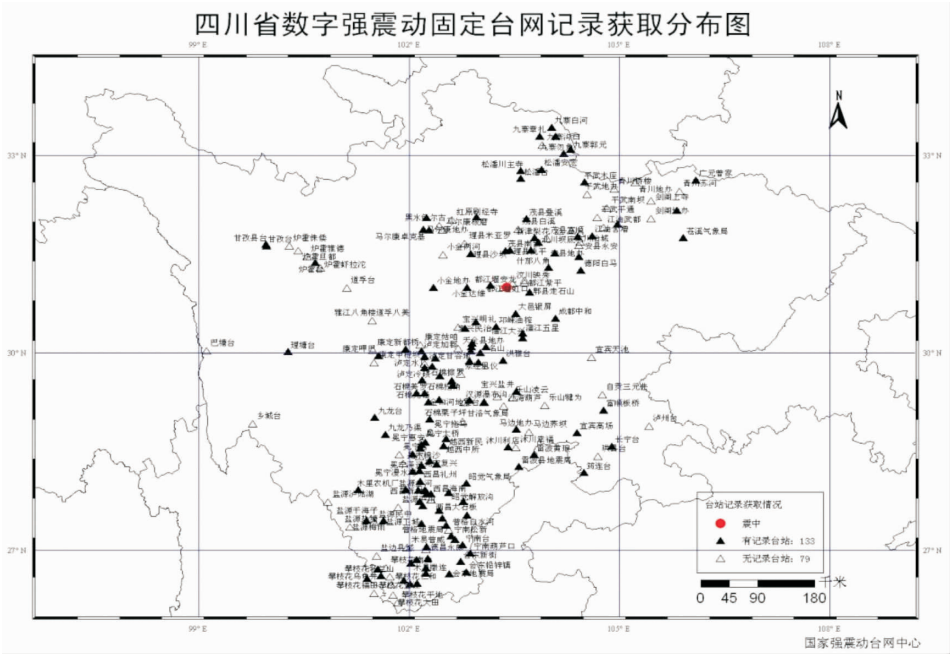


Fig. 4.2 The distribution of stations triggered in Sichuan Province

450 seismic events have been recorded, and 1347 records acceleration records have been obtained. There are 19 stations less than 100 km away from the epicenter, 34 stations between 100 km and 200 km, 107 stations between 200 km and 500 km. There are 12 stations less than 20 km away from the fault, 11 stations between 20 km and 50 km, 22 stations between 50 km and 100 km. The Wolong station in Wenchuan county, the nearest strong

observation station away from epicenter, is 22.2 km away from the epicenter. The peak acceleration is 957.7cm/s/s. Qingping station in Mianzhu city, the nearest strong observation station away from the fault, is 0.74 km away from the fault. The peak acceleration is 824.1cm/s/s. There are 120 records of the peak acceleration to be greater than 100cm/s/s.

Fig4.3 ~ Fig4.5 is to show the distribution of peak acceleration of three components recorded by part of stations.

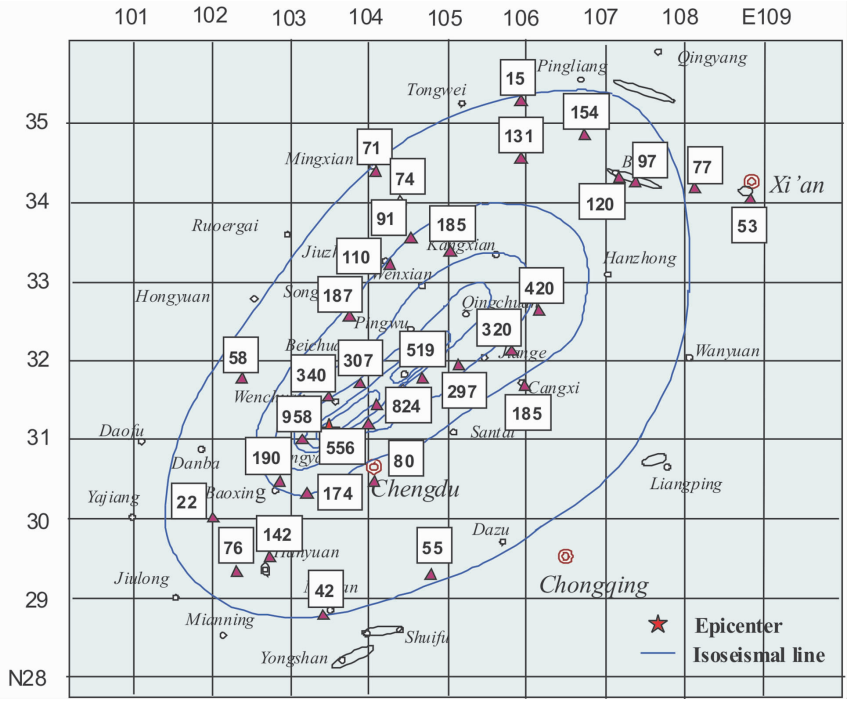


Fig. 4.3 The distribution of peak acceleration of Wenchuan earthquake recorded by some strong observation stations (E-W component)

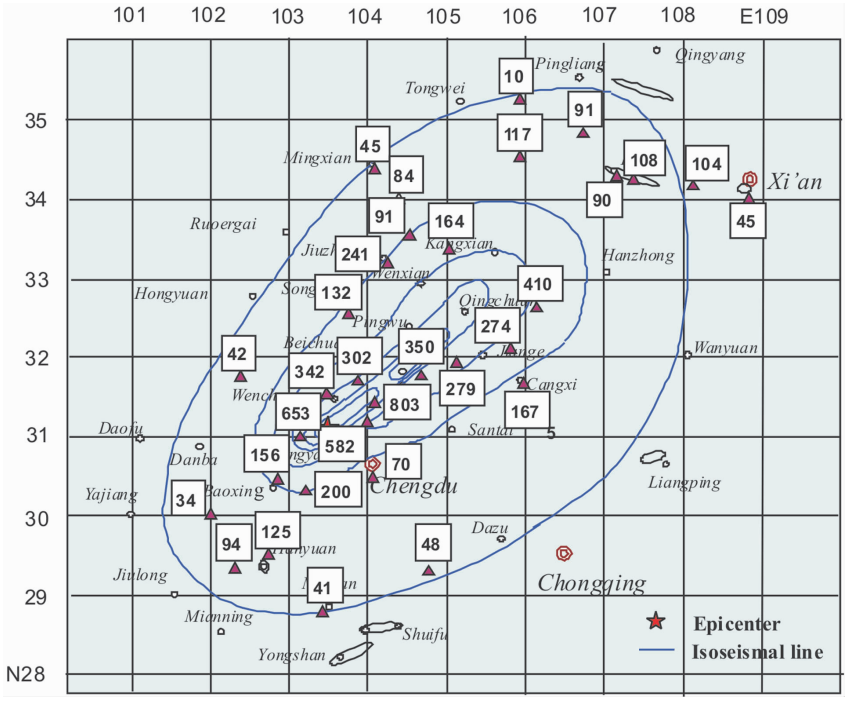


Fig. 4.4 The distribution of peak acceleration of Wenchuan earthquake recorded by some strong observation stations (N-S component)

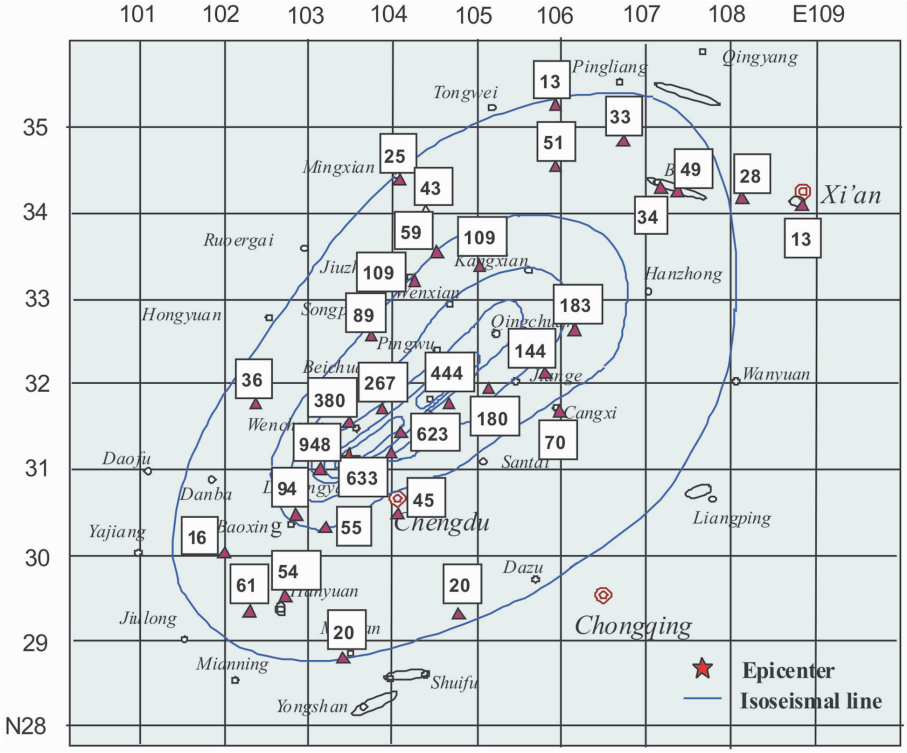


Fig. 4.5 The distribution of peak acceleration of Wenchuan earthquake recorded by some strong observation stations (Vertical component)

Figure 4.6 are uncorrected acceleration velocity, displacement time histories respectively. Figure 4.7 are uncorrected acceleration record, Fourier spectrum and response spectrum obtained from Wenchuan Wolong Station, Mianzhu Qingping Station and Shenfang Bajiao Station.

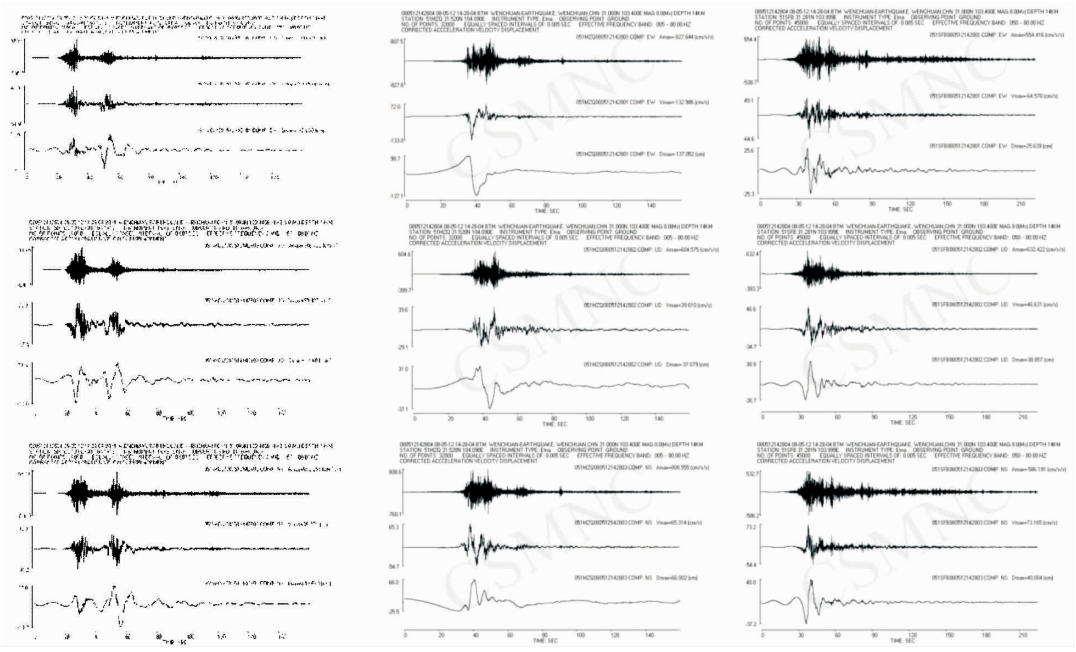


Fig. 4.6 The uncorrected acceleration, velocity and displacement time histories recorded at Wenchuan Wolong Station, Mianzhu Qingping Station and Shenfang Bajiao Station.

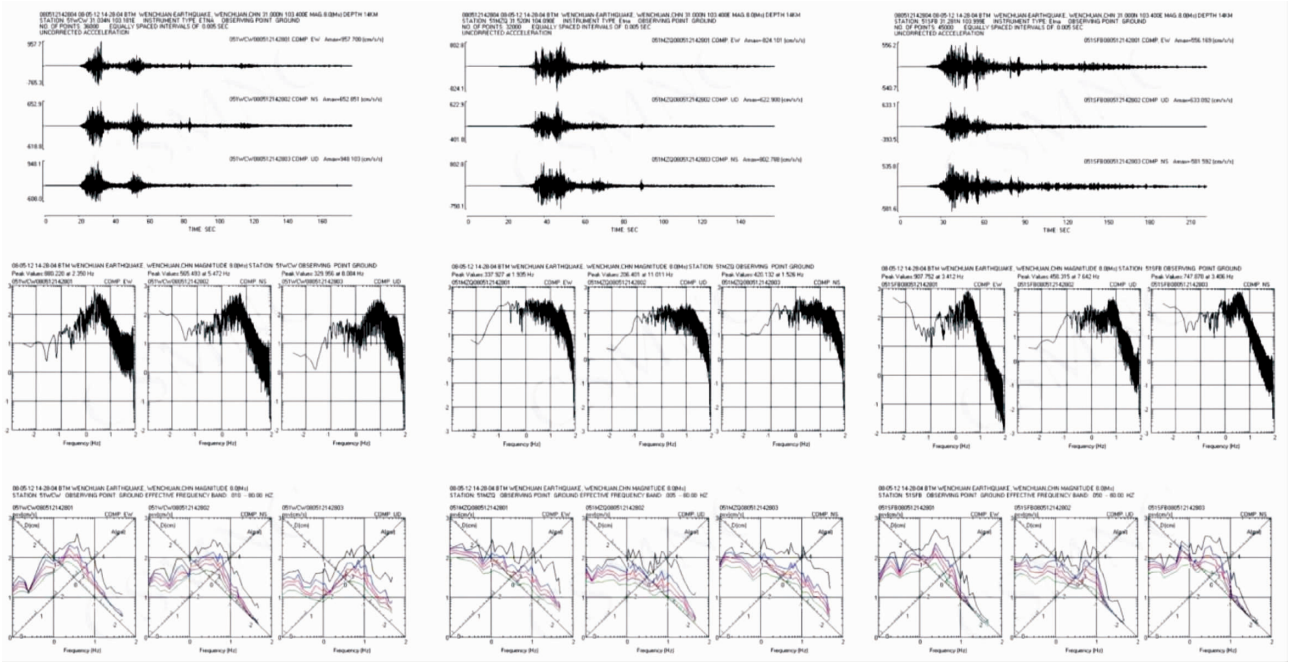


Fig. 4.7 The uncorrected acceleration record, Fourier spectrum and response spectrum obtained from Wenchuan Wolong Station, Mianzhu Qingping Station and Shenfang Bajiao Station.

Figure4.8 and 4.9 show far field records.

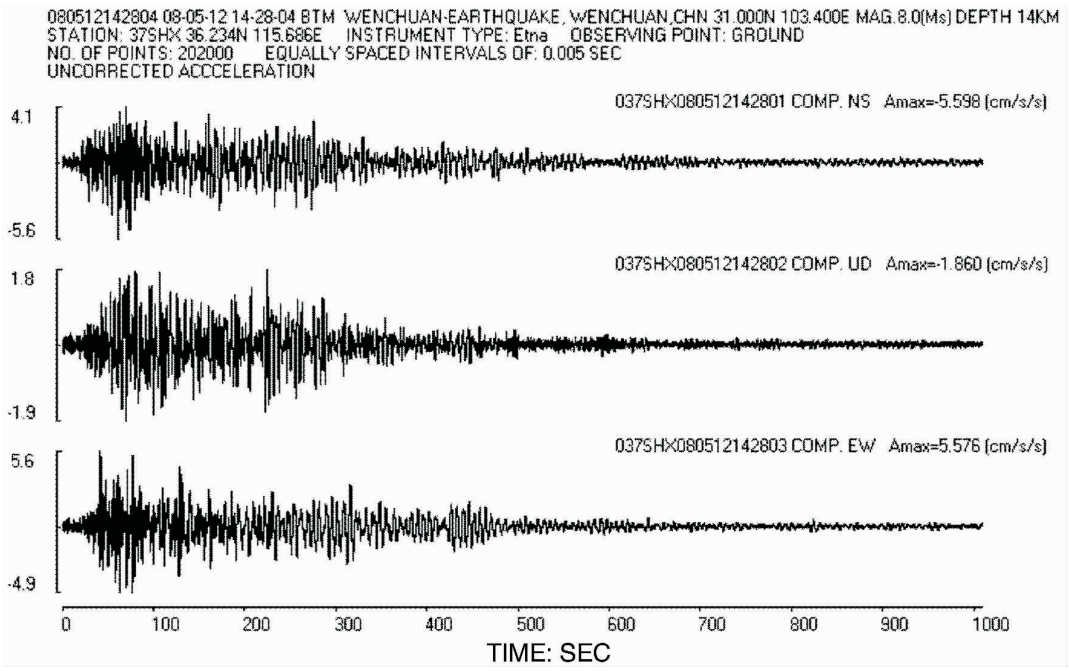


Fig. 4.8 The uncorrected acceleration time histories curves recorded by Shenxian Station in Shandong province.

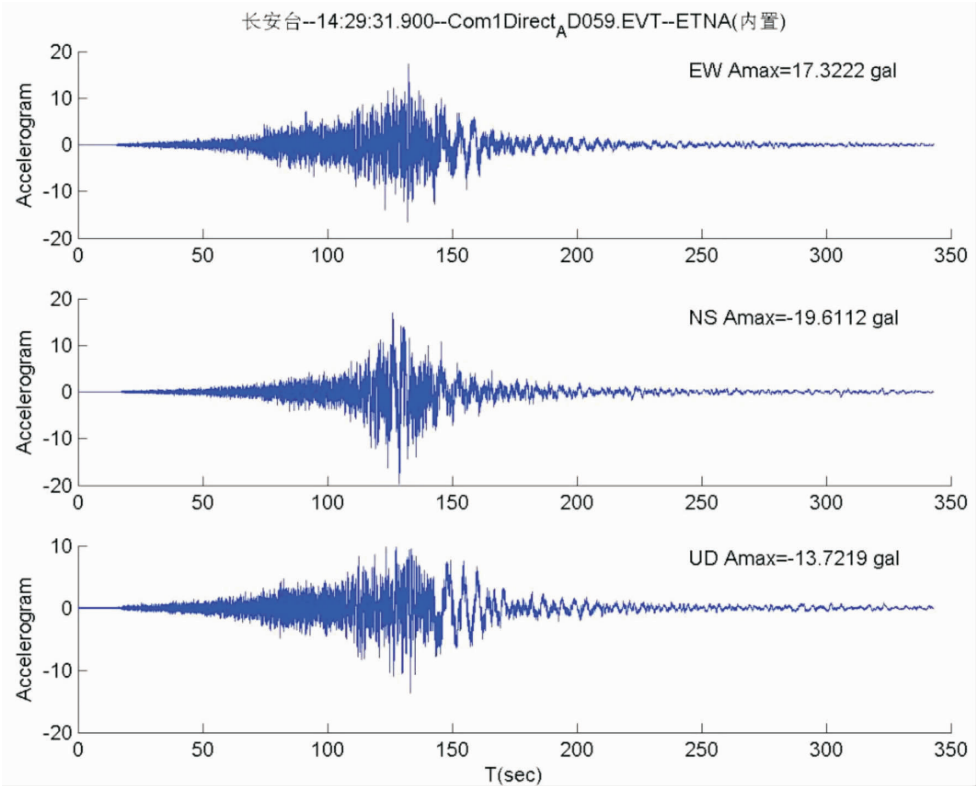


Fig. 4.9 The uncorrected acceleration time histories curves recorded by Chang'an station in Shaanxi province.

From Figure 4.9, it shows that there is an obvious long-period component in the latter of the records. It may be a reason to long-period structural damage in abnormal intensity region of Shaanxi province.

5 SITE EFFECTS

Earthquake affected area mainly including two parts: mountain and basin hills. The topography is very complicated due to geologic process as the rivers incision. Therefore, site condition is also complicated. It can be seen that the severe and slight damage area are alternately distributing. In the east of Sichuan, Gansu, Shaanxi, Yunnan, the effects of site topography is very obvious. The typical site effects are the influences of river valley and the precipitous ridge or mountain. Another important site effect is the sand liquefaction, the liquefaction of sand causes the destruction of the house.

5.1 Abnormal intensity region in Hanyuan County

The county town of Hanyuan lies in the south of Yaan city of Sichuan Province, Dadu River and Liusha River crosses in here. The county town includes old town and new one. The new county town which is in construction is an immigrant's project of the waterfall ditch hydropower station which lie on Luobugang between Dadu River and Liusha River, facing old county town. The old county town built by the mountain, lie in the foot of the Beihou hill, and in the west of Liusha River, in the south of Dadu River, most urban areas are located the basin like a dustpan (Fig. 5.1.1). The town is located on a ancient landslide and far from seismogenic faults about 150km. The earthquake intensity reached Ⅷ, contrast to Ⅵ in its surrounding area

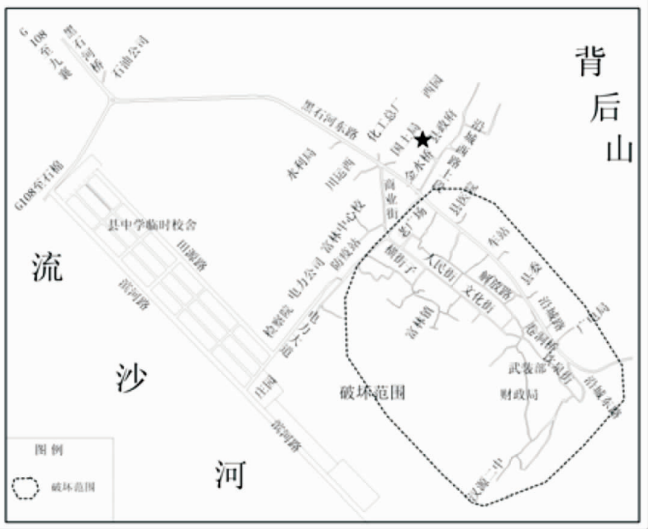


Fig. 5.1.1 The sketch map of county town of Hanyuan

Photo 5.1.1 to Photo 5.1.4 show the typical seismic damages, Fig. 5.1.2 shows the local isoseismal map after the investigation.

Photo 5.1.1 Part collapse of the masonry structure in the old county of Hanyuan

Photo 5.1.2 The collapse of the masonry structure in the county of Hanyuan

Photo 5.1.3 The collapse of the brick-timber structure in the county of Hanyuan

Photo 5.1.4 The collapse of the house in Xili Village, Qingxi Town, Hanyuan County

Fig. 5.1.2 The local iasoseismal map of the intensity abnormal region of Hanyuan

5.2 The effect of the river valley topography

In Sichuan province, most residential area lie in the river valley in mountain area and hills area. For example, most county towns of the west of Sichuan launch along the river valley. In the areas of hills of Sichuan, some villages and small towns of Gansu and Shaanxi all lie in the river valley, become narrow rectangular shape along the river valley, the terrain drops to the river terrace rapidly from mountain. In these sites, foundations are different in short distance. In addition, thick of soil layer change from hill to river, results different amplification. Soil thick and topography cause complicated effect on ground motions, and lead obvious different damage in a limited area.

For example, Guaizao village, Xiasi town, Jiange County, Sichuan, lie on the first terrace of the Qingjiang River, (Photo 5.2.1). The terrace is nearly 10 meters higher than the river surface, about 500 meters wide. East of

the terrace is a hill slope of 25°, 25 meters high. River surface and alluvial flat are about 80 meters wide. On the opposite side it is a series of banks, stand upright approximately. The bank is about 9 meters high. The terrace is relatively levelled, widened in the river, the soil layer is relatively thick, about 14 meters, mixed with the sand and gravel. There is rock of base (sandstone) in the foot of the hill appear and reveal.

The fourth group of this village lies in the first class terrace of river valley. The soil layer is buried deep and relatively thick, about 14 meters, and the building is mainly masonry structure. The seismic damage is heavy (Photo 5.2.2). The third group of this village lies under the foot of the hill by the river valley, the rock of nearby base appears to reveal, the seismic damage of the building on the rock of base is light (Photo 5.2.3), the seismic damage of the building in washing the valley mouth sediment is heavy. The distance between them is less than 300 meters.

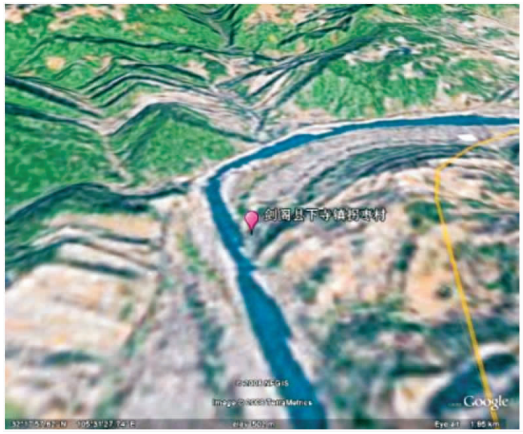


Photo 5.2.1 The topography of Guaizao village, Xiasi Town, Jiange County, Sichuan

Photo 5.2.2 Crack in walls of the masonry building, in the fourth group of Guaizao village (On terrace)

Photo 5.2.3 Crack in walls of the masonry building, in the fourth group of Guaizao village (On terrace)

Photo 5.2.4 The masonry structure is intact in the third group of Guaizao village (On the foot of the hill)

5.3 The effect of the ridge topography

Some residential areas lie on narrow outstanding mountain ridge, which both sides are precipitous. The local seismic wave may propagate along direction of perpendicular to the ridge. The ridge is easy to rock like the single plate, resulted more heavy damage of houses on the ridge. For example, Niujingxiang Village, Tuxing Town, Pingchang County located in a ridge. The ridge is narrow and long. Its length is about 300 meters, but it is fewer than 10 meters in wide on the top. The height of ridge is about 100 meters. Houses are distributed on both sides of the ridge (Photo 5.3.1). The damage of jouses is serious (Photo 5.3.2 and Photo 5.3.3). And the house on the base rock in Datian village on the foot of the hill, only tiles were slide. The houses in Fushun village in the east on the base rock in the foot of the hill are basically intact (Photo 5.3.4).

Photo 5.3.1 The ridge landform of Niujingxiang Village

Photo 5.3.2 The serious damage of masonry structure on ridge

Photo 5.3.3 The serious damage of brick-timber structure on ridge

Photo 5.3.4 The intact of brick-timber structure in Niujingxiang Village at the foot of the hill

5.4 Sand liquefaction

Wenchuan earthquake produce extensive sand liquefaction, with about 500km long, 200 km wide area. It is already found about 100 liquefaction places with interval of 2 km, cove broad area, including intensity of Ⅵ area.. Photo 5.4.1 shows the distributing for some local liquefaction places.

Liquefaction of this earthquake is shown as:

(1) Liquefaction causes the damage of the house or structure, such as the liquefaction area crosses the school building of Banqiao middle school in Mianzhu City; the foundation deformation damaged school buildings (Photo 5.4.2).

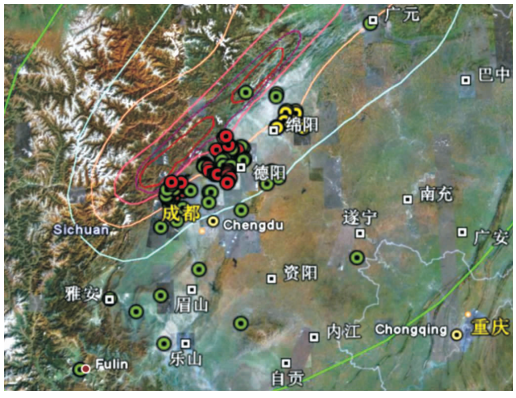


Photo 5.4.1 The distributing for some liquefaction places.

Photo 5.4.2 The liquefaction area crosses the school building of Banqiao middle school in Mianzhu, caused foundation crack

(2) Liquefaction takes place in the low-intensity areas, for example Sanjia town, Suining City in the area of intensity Ⅵ. Farmland and road area liquefaction, gush out sand emit water high 1.5m; The surrounding buildings are basically intact (Photo 5.4.3). There are also spray water and emit the sand in Xinlian Village Guaihuaqiao Town, Emeishan County, Leshan City of intensity Ⅵ.

Photo 5.4.3 The liquefaction area crosses the workshop of furniture factory Nanquan Town of Shifang City.

Photo 5.4.4 Farmland liquefaction in Sanjia Town, Suining City.

(3) The sand liquefaction occurred with many sand types, such as fine sand、medium sand、silt, even the sandy gravel is liquefied. The specific place squirts black sand, some squirt the gravel diameter and reach 10cm. (Photo 5.4.4)

(4) It is found that liquefaction occurred in a site with sand layer deeper than 15 meters, confirmed by drill hole.

Photo 5.4.5 The squirting of big particle gravel

Photo 5.4.6 The liquefaction of large area of playground of middle school in Zhongxing Town、Mianyang City

6 EARTHQUAKE DAMAGE TO BUILDING

The types of building structures are numerous. In the seismic region, there are mainly reinforced concrete frames, frame-seismic wall (shear wall) structures, steel structures, masonry structures, bottom frame structures, informally designed masonry structures, wooden structures and other simple buildings. There are shear wall structures and tube structures in the high-rise or super high-rise buildings in the big cities which have not tabulated here because of without damaged.

Because the economy of our country is developing rapidly, the buildings in the villages and towns generally upgrade, the seismic capacity of which is increased, there are lots of simple buildings in the countryside of mountain area. The bottom frame structure is very general in the seismic zone, especially in villages and towns for business and storage.

From the 1990s of last century, the seismic fortification intensity is Ⅶ in most areas of Sichuan province, the seismic fortification intensity in Deyang, Mianyang, Guangyuan is Ⅵ, the seismic fortification intensity is Ⅷ in some areas in the west of Sichuan province such as Luding, Songpan, Jiuzhaigou, the seismic fortification intensity is Ⅸ in some areas like Kangding, and the seismic fortification intensity is Ⅷ in Longnan City, Gansu Province. A large number of buildings which were designed according to intensity Ⅶ stood the different seismic actions from intensity Ⅵ to Ⅺ. There are very abundant seismic damage phenomena.

The following is the proportion of destruction of different kinds of buildings during the Wenchuan Earthquake.

(1) To investigate the statistics of the seismic damage of 1005 buildings at random for the city of Dujiangyan in Photo 6.1, A, B, C are the simple buildings(230), the buildings without seismic fortification(224), and the buildings with seismic fortification according to intensity Ⅶ respectively(551).

It is obvious that the earthquake resistant capabilities are increased sequentially.

Table 6.1 The proportion of buildings destruction of Dujiangyan urban area (%)

Classification	Intact	Slightly damaged	Moderately damaged	Severely damaged	Collapsed
the simple building (A)	24	7	4	30	35
the masonry structure without earthquake fortification (B)	18	8	23	46	5
the masonry structure with earthquake fortification according to Intensity Ⅶ7 degree (C)	46	21	15	17	1

(2)The urban area in the city of Chengdu (Intensity Ⅵ)

Divided into 6 districts, 81 points of random sampling, 400 buildings.

Table 6.2 The proportion of buildings destruction in Chengdu urban area. (%)

Classification	Intact	Slightly damaged	Moderately damaged	Severely damaged	Collapsed
masonry structure	96.76	3.17	0.037	0.007	0.026
frame structure	96.87	3.13	0	0	0
frame – shear wall structure	99.08	0.92	0	0	0

(3) The urban area in the city of Mianyang (Fucheng area and Youxian area) (Intensity Ⅶ)

Divided into 6 groups, 80 points of random sampling, 199 buildings.

Table 6.3 The proportion of buildings destruction in Mianyang urban area. (%)

Classification	Intact	Slightly damaged	Moderately damaged	Severely damaged	Collapsed
masonry structure	55.93	18.67	15.13	8.39	1.88
frame structure	68.93	17.76	12.62	0.69	0

(4) The urban area in the city of Deyang (Intensity Ⅶ)

Divided into 5 groups, 56 points of random sampling, 199 buildings.

Table 6.4 The proportion of buildings destruction in Deyang urban area. (%)

Classification	Intact	Slightly damaged	Moderately damaged	Severely damaged	Collapsed
masonry structure	50.29	39.19	8.01	2.39	0.12
frame structure	74.48	19,32	2.94	3.26	0
Factory building	71.91	25.53	0.89	1.67	0
One – storey house	38.98	28.72	6.77	22.16	3.37

(5) The urban area in the city of Dujiangyan (Intensity Ⅸ)

There are 58 buildings, the quantity of masonry structure is 45, the quantity of bottom frame structure is 13.

Table 6.5 The proportion of buildings destruction in Dujiangyan urban area. (%)

Classification	Intact	Slightly damaged	Moderately damaged	Severely damaged	Collapsed
masonry structure and bottom frame structure	20.7	13.8	10.3	51.7	3.5

(6) The urban area in the city of Mianzhu (Includes Intensity Ⅷ and Intensity Ⅸ)

There are 83 sample buildings, the quantity of masonry structure is 48, the quantity of bottom frame structure is 35.

Table 6.6 The proportion of buildings destruction in Mianzhu urban area. (%)

Classification	Intact	Slightly damaged	Moderately damaged	Severely damaged	Collapsed
masonry structure	27.1	20.8	25.0	25.0	2.1
bottom frame structure	28.6	28.6	22.7	14.3	5.7
masonry structure and bottom frame structure	27.7	24.1	24.1	20.5	3.6

(7) The urban area in the city of Jiangyou (Intensity Ⅷ)

There are 94 sample buildings, the quantity of masonry structure is 65, the quantity of bottom frame structure is 29.

Table 6.7 The proportion of buildings destruction of Jiangyou urban area. (%)

Classification	Intact	Slightly damaged	Moderately damaged	Severely damaged	Collapsed
masonry structure and bottom frame structure	29.8	40.4	21.3	6.4	2.1

(8) The urban area in Anxian County(Intensity Ⅷ)

There are 64 sample buildings, the quantity of masonry structure is 47, the quantity of bottom frame structure is 17.

Table 6.8 The proportion of buildings destruction in Anxian County. (%)

Classification	Intact	Slightly damaged	Moderately damaged	Severely damaged	Collapsed
masonry structure and bottom frame structure	18.7	46.9	21.9	9.4	3.1

(9) The urban area in the city of Shifang (Intensity Ⅵ)

There are 74 sample buildings, the quantity of masonry structure is 68, the quantity of bottom frame structure is 6.

Table 6.9 The proportion of buildings destruction in Shifang urban area. (%)

Classification	Intact	Slightly damaged	Moderately damaged	Severely damaged	Collapsed
masonry structure and bottom frame structure	83.8	20.8	3.7	2.7	0

(10) the proportion of buildings destruction assessed in earthquake loss assessment area

Table 6.10 The proportion of buildings destruction of frame structure and masonry structure. (%)

Assessing area	classification	Collapse	Severely damaged	Moderately damaged	Slightly damaged	Intact
Assessing area1 One degree of (above Intensity Ⅸ)	Frame structure	28.23	22.86	21.01	14.84	13.06
	Masonry structure	29.32	18.77	44.95	6.49	0.47
Assessing area 2 (Intensity Ⅷ)	Frame structure	3.8	19.35	24.7	20.78	31.37
	Masonry structure	10.81	21.89	23.73	19.26	24.31
Assessing area 3 (Intensity Ⅶ)	Frame structure	0.3	1.75	5.99	9.64	82.32
	Masonry structure	2.95	5.37	10.58	26.4	54.7
Assessing area 4 (Intensity Ⅶ)	Frame structure	0	0.3	2.13	5.27	92.3
	Masonry structure	0.91	1.94	4.32	10.28	82.55

The load-bearing structure of brick-wood structure and civil structure is wooden frame, the enclosure is composed of brick, adobe, rammed earth. There are a small amount of buildings with adobe wall bearing and a roof of wood. This kind of building is divided into three grades of destroying: intact, damaged and collapsed.

Table 6.11 The proportion of buildings destruction of brick-wood structure and civil structure. (%)

Assessing area	Structural classification	collapsed	damaged	intact
Assessing area1 (above Intensity Ⅸ)	brick – wood structure	77.33	22.67	0
	civil structure	78.75	21.25	0
Assessing area 2 (Intensity Ⅷ)	brick – wood structure	40.84	41.73	17.43
	civil structure	68.83	28.19	2.98
Assessing area 3 (Intensity Ⅶ)	brick – wood structure	10.65	35.48	53.87
	civil structure	20.06	47.37	32.57
Assessing area 4 (Intensity Ⅶ)	brick – wood structure	3.68	20.86	75.46
	civil structure	8.86	25.78	65.36

Through investigating, it is obvious that the earthquake resistant capabilities successively decreased: frame - shear wall structure, frame structure, masonry structure, brick-wood structure, civil structure. In Photo 6.1, the frame structure under construction adjoined the bottom frame structure, they lay in the county town of Beichuan (Intensity Ⅺ). The structural column cap of frame was cracked without pouring, but the structural ground floor of the bottom frame collapsed, the brick was mixed and fractured and sloped seriously partly and collapsed partly. The frame structure was destroyed seriously than the masonry structure becaused of designing unreasonably or poor quality of the filled wall. From Photo 6.2 we can find that the frame staircase still stand there, whereas the classroom of masonry structure collapsed.

Photo 6.1 Comparison between the frame structure under construction and the bottom frame structure in Beichuan

Photo 6.2 The staircase of the frame structure still stand there, whereas the classroom of masonry structure collapsed at Juyuan middle school in Dujiangyan

In Photo 6.3 (a), the agent structure of a 6-storey steel reinforced concrete frame building in a fashion garden, Hanwang Town, Mianzhu City (Intensity Ⅹ) is intact. An adjoining 5-storey masonry structure (Building 6 #) (Photo (b)) was destroyed seriously, one-storey outer wall base was cut off and split (picture (c)), Oblique crack of bearing wall linked up in two- storey; The stair was destroyed (Building 4, (Photo (d))).

(a)

(b)

(c)

(d)

Photo 6.3 Comparion between the frame structure and masonry structure in a fashion garden (Hanwang Town, Mianzhu City, intensity Ⅹ)

6.1 Reinforced Concrete Frame Structure

There are a large number of reinforced concrete frame structures in the seismic zone, stood under the different seismic actions from intensity Ⅵ to Ⅺ.. There are very abundant seismic damage phenomena.

(1)The destruction of filled wall

If the mortar quality of the filled wall is very low(this is a common situation), the obvious cracks of filled wall will appear (Photo 6.1.1) in the intensity Ⅶ area, and the filled wall will collapse above intensity Ⅷ. (Photo 6.1.2, the 6.1.3)

Photo 6.1.1 The collapse of the frame structure in Hanwang Town, Mianzhu City(Intensity X)

(a)

(b)

Photo 6.1.2 The destruction of filled wall at Mianzhu middle school in Mianzhu City,(Intensity Ⅸ)

The filled wall should share some seismic loading during an earthquake, its destruction will consume certain energy too. The function of filled wall is different according to building materials and building quality. Some frame structure filled walls make the post become a short column, and cause it to be destroyed (Photo 6.1.4, Photo 6.1.5). Staircase is an important passageway for escaped, and the collapse of filled wall in the staircase may injury people.

Photo 6.1.3 The collapse of the frame structure in Dujiangyan

(a)

(b)

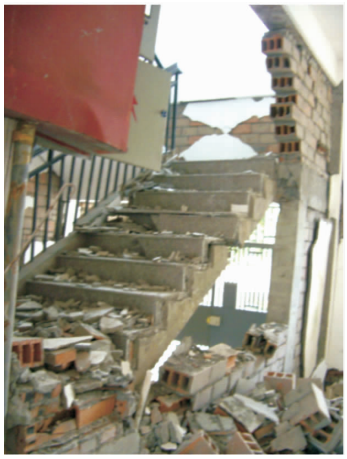
Photo 6.1.4 The narrow wall pier makes the constructional column shear failure (Offered by Feng Yuan)

(a)

(b)

Photo 6.1.5 The narrow wall pier makes the constructional column shear failure (Offered by Feng Yuan)

The staircase is the important pass way for fleeing life; the filled wall collapsing is unfavourable to this(Photo 6.1.6)



(a)

(b)

Photo 6.1.6 The collapse of the filled wall in the staircase (Offered by Feng Yuan)

(2) The destruction of the end column

The serious destruction of the frame structure mainly concentrates on the end of the column, a large number of earthquake phenomena show that the present design method is very difficult in fact to accomplish the weak roof beam and strong column, and the column damaged easier. (Photo 6.1.7, Photo 6.1.8)

(a)

(b)

Photo 6.1.7 The destruction of the frame column at Xuankou middle school canteen in Yingxiu Town

(a)

(b)

Photo 6.1.8 The destruction of the frame column at Xuankou middle school in Yingxiu Town

(a)

(b)

Photo 6.1.9 Material research center of Dong Fang Steam Turbine Works in Hanwang Town, Mianzhu (Intensity X) (a) Slight damage to the exposed wall (b) a lot of the end of post columns were fractured

(3) The ground floor collapsed

(a)

(b)

Photo 6.1.10 The ground floor of the frame structure collapsed in Beichuan (Intensity XI), the glass curtain wall was basically intact.

(a)

(b)

Photo 6.1.11 5-storey frame structure in Huaxia Square Dujiangyan, a ground floor of it was crooked, another ground floor and the second storey collapsed

Photo 6.1.12 The second storey of frame structure collapsed in Yingxiu town (Intensity XI)

(4) Collapsed wholly

Photo 6.1.13 The 9-storey frame structure collapsed in Yingxiu town (Intensity XI)

Photo 6.1.14 The frame structure collapsed in Yingxiu town (Intensity XI)

(5) The typical seismic damage to the frame structure

The Golden Garden in Jingyou urban area (Intensity VIII), a 6-storey frame structure, the frame is intact (Photo 6.1.15 (a)), partly filled wall (Photo 6.1.15 (b)), the stair and the ladder roof beam were destroyed (Photo 6.1.15 (c)).

(a)

(b)

(c)

Photo 6.1.15 Damage to the 6-storey frame structure in Golden Garden at Jiangyou urban area (Intensity VIII)

Photo 6.1.16 A 5-storey frame structure was intact in Jiangyou city (Intensity Ⅷ)

6.2 Reinforced concrete frame-shear wall structure

This kind of structure behaved in this earthquake well, even was basically intact under the high earthquake intensity (Photo 6.2.1)

Photo 6.2.1 Main building of Dong Fang Steam Turbine Factory in Hanwang (Intensity X) was basically intact

Some frame -shear wall structure was destroyed in part because the strength of wall structure design was very unreasonable. The qualify of filled wall was poor. (Photo 6.2.2, Photo 6.2.3)

(a)

(b)

Photo 6.2.2 Some staircases of the building of Public Security Bureau in Dujiangyan were destroyed (Intensity Ⅸ)

(a)

(b)

(c)

Photo 6.2.3 Traffic-police's office building staircases and filled wall were destroyed in Dujiangyan (Intensity Ⅸ)

6.3 BRICK-CONCRETE STRUCTURE

Brick-concrete Structure is the most commonly used structure type in housing and office building, in which phenomenon of earthquake damage is rich. There are three types of brick masonry building in earthquake region:① Building with normal earthquake-resistant design and construction which was built after 1992. In this earthquake the brick masonry building fortified according to intensity Ⅶ has fairly big seismic potentiality. For example, many buildings were basically undamaged or only slightly damaged, such as in Dujiangyan (intensity Ⅸ);②Brick-concrete building without seismic fortification and some buildings with incomplete seismic measures, which were built before 1992. Some factories and official buildings that were built in late of 1980s have low seismic ability. These buildings were severely damaged or collapsed, such as school and hospital. It is the main reason for the victims and injuries. ③ Brick masonry buildings without normal design, see the section 6.5.

(1) Cracks in bearing wall is the most common phenomenon. (Photo 6.3.1, Photo 6.3.2, Photo 6.3.3)

(a)

(b)

Photo 6.3.1 The X shaped crack in Brick Masonry Building because of shearing failure.

(2) The horizontal fracture of wall

Example: The No. 4 Building, 8-storey brick-concrete building, in Jiange country Xiashi river bank, south region of Huachen, in which the main damage is that the ground ring beam and the super structure were completely cracked. Right rear displacement is 3mm, Photos show as follows:.

Photo 6.3.2 (a) Structure appearance.

(b) Lower left corner crack and the exposure of constructional column reinforcement.

(c) Right rear lower corner cracks and reinforcement is sheared break.

(d) Crack in the same horizontal position in aisle.

(a)

(b)

(c)

(d)

Photo 6.3.2 The No.4 Building, 8-storey brick-concrete building, in Jiange County xiashi south region of Huachen damage. (Intensity Ⅵ)

(a)

(b)

Photo 6.3.3 Horizontal crack damage in building basement (a) A 7-storey brick-concrete apartment building is in Jiangyou City court, ground ring beam and super structure partly cracked. (b) West Sichuan Oil Production Department staff building in Jingyang, Deyang City, brick-concrete Structure ground ring beam and super structure crack.

(3) The hill aspect crack

(a) Dujiangyan City(Intensity Ⅸ)

(b) Bikou Town, Wenxian County, Gansu Province(Intensity Ⅸ)

Photo 6.3.4 brick-concrete building gable wall crack

(4) Damage and collapse of bottom storey

(a)

(b)

Photo 6.3.5 Wall cracked of First floor of brick-concrete building.

Photo 6.3.6 The first floor of a brick-concrete building was collapsed in Beichuan County (Intensity Ⅺ).

(5) Partial collapse.

(a) Dujianyan City, precast slab of a school remained.

(b) Hanwang Town (Intensity X)

Photo 6.3.7 A brick-concrete building is partially collapsed.

Photo 6.3.8 Hanwang Town (Intensity X) partially collapsed brick-concrete building.

(a) (b)

Photo 6.3.9 (a) Tumen Town, Mianzhu, 3-storey teaching building was collapsed, Staircase and office in two ends keeps intact. (b) Brick-concrete building partially collapsed in Hanwang Town.

(6) Collapse of weak apartment in vertical direction.

(a) Hangwang Town (Intensity, X).

(b) Dujiangyan City.

Photo 6.3.10 Weak apartment collapsed to the ground in vertical direction

Photo 6.3.11 The staircase of the dormitory building collapsed at Leigu Town Beichuan Country(Intensity X) middle school

(7) Collapse of whole building.

Photo 6.3.12 The collapse of whole brick-concrete building in Yingxiu Town(Intensity XI).

Photo 6.3.13 The collapse of many brick-concrete buildings in Beichuan County (Intensity Ⅺ).

Photo 6.3.14 The collapsed brick-concrete building block road in Dujiangyan City. (Intensity Ⅸ).

Photo 6.3.15 The housing loft of a building was skewed in Dujiangyan City (Intensity Ⅸ). (Whiplash Effect)

(a)

(b)

Photo 6.3.16 A teaching building with consideration of seismic action was cracked but did not collapse in Leigu Town Beichuan Country(Intensity X).

Photo 6.3.17 A teachers' department with consideration of seismic action keeps intact during the Earthquake.

Photo 6.3.18 A students' department built in 1969 keeps intact after the Earthquake in Qingchuan County (Intensity Ⅸ).

Photo 6.3.19 Chenjiaba TCM hospital built in 1965, with good quality, wooden roof truss collapsed and the main part keeps intact.

Photo 6.3.20 A school building (right) of Bailu middle school was driven up 2m, keeping intact, another building (left) cracked, buildings (front) collapsed.

Photo 6.3.21 There are still the integrated buildings standing in Beichuan Country(Intensity Ⅺ).

6.4 Masonry House with first floor RC frame

The building with one or two stories reinforced concrete frame at the bottom, has no or very few shear walls, in which the damage usually occur at the top of the column including concrete crushing, reinforcement buckling, integral decline of structure, collapse with instability and completely collapse of bottom with subsidence of whole building. The bottom lateral stiffness of the structure is far less than upper storeys and the contribution of the floor to the flexural rigidity of transfer beam is not considered adequately in the design, which makes the structure flexible at the bottom, rigid at the upper and strong beam-weak column in the bottom.

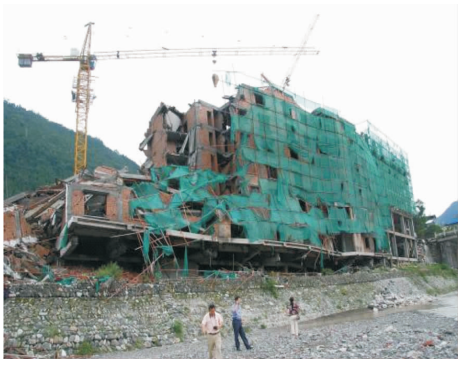
The column on the first floor of the frame structure was damaged.

(a) (b)

(c)

(d)

Photo 6.4.1 (a)(b) Damage to the first floor of residential Building was damaged in Huaxia Square District in Dujiangyan. (c)(d) The top of a Masonry House with first floor RC frame corner column was damaged.



(a)

(b)

(c)

(d)

Photo 6.4.2 (a) The ground floor of a Bottom Frame Residential Building was damaged in Beichuan County. (a)(c)(d) The detail of Bottom Frame was damaged.

(a)

(b)

Photo 6.4.3 The top of a Bottom Frame column was damaged and the column was skewed in spring of Dujiang residential area, Dujiangyan City.

(2) The Bottom Frame column was skewed.

(a) Longman mountains Town

(b) Building in Yingxiu Town

Photo 6.4.4 The first floor of Bottom Frame was skewed.

(3) The fist floor of building collapsed

(a)

(b)

Photo 6.4.5 The first floor of the Bottom Frame building collapsed in Beichuan County (Intensity Ⅺ)

(a)

(b)

Photo 6.4.6 The first floor of the building collapsed to be flat (a) Dujiangyan City (Intensity Ⅸ)
(b) The bottom of the building was damaged

The first storey of the masonry building is often the second or third storey of the structure with bottom layer frame. In Wenchuan earthquake, the upper one or two masonry storeys adjacent to the bottom frame damaged severely or collapsed completely, which is a new destruction phenomenon.

(4) The second floor of the Structure collapsed.

(a)

(b)

Photo 6.4.7 The second floor of the Bottom Frame Structure was collapsed in Yingxiu Town.

(a) Beichuan County (Intensity Ⅺ).

(b) In Dujiangyan City (Intensity Ⅸ).

Photo 6.4.8 The second floor of the Masonry House with first floor RC frame collapsed.

(a) The second floor and a unit in the middle were collapsed.

(b) Apartment building of the NPC in Beichuan County.

Photo 6.4.9 The second floor of Masonry House with first floor RC frame collapsed in Beichuan County.

(5) The upper of brick masonry building was damaged or collapsed.

(a) Hanwang Town (Intensity Ⅹ)

(b) Dujiangyan City(Intensity Ⅸ).

Photo 6.4.10 The upper local of Masonry House with first floor RC frame collapsed.

(a)

(b)

Photo 6.4.11 (a) The upper of Masonry House with first floor RC frame was all collapsed in Beichuan County. (b) The top Floor of Qingchuan Procuratorate was damaged.

(6) Masonry buildings with first two floors RC frames.

(a)

(b)

Photo 6.4.12 The business-living building of the Civil Affairs Department was designed at the level of Earthquake Fortification Ⅶ (a) Intact of the first two frames (b) Shear failure of the exposed wall of the third floor.

Photo 6.4.13 Masonry House with first floor RC frame with seismic fortification according to intensity Ⅸ keeps intact after Earthquake in Heqinyuan Residential Area in Mianzhu City.

Photo 6.4.14 Ruyi Garden Residential Area with seismic fortification according to intensity Ⅸ keeps intact after Earthquake in Jiangyou district.

6.5 INFORMAL DESIGNED MASONRY BUILDING

This kind of building refers to the residents self-built masonry building, neither specially designed, nor considering earthquake resistance protection, but mostly uses the ring beam and constructional column (see Photo 6.5.1), so it has certain seismic abilities. It has generally two storeys, but some are much higher. Masonry House with first floor RC frame form is the most (see Photo 6.5.2), but the column is just set up because some self-built bottom floors need open the door along street. The wall is still bearing in the behind, and the beam is put on the wall directly, so Masonry House with first floor RC frame is the incomplete frame. Sometimes the above two storeys are the brick wall, with the wooden roof truss. It is a mixed structure. Some structures have more than one storey frame, this mainly depends on financial resources of the house-owner and its user.

Because self-built masonry buildings have changed with terrain, they have different behavior in earthquake. Some house-owners pursued large rooms or they didn't have enough money to build their houses well, so plenty of bearing walls(the outer or interior ones) of houses used half-brick wall (120mm), these houses suffered serious damage in earthquake(see Photo 6.5.3),usually serious damage happened in the second floor of houses of brick-wood structure of mixed structure(see Photo 6.5.4),some houses' bottom column feet were snipped(see Photo 6.5.5)。

Plenty of self-built masonry structure and Masonry House with first floor RC frame had good performance in earthquake. (see Photos 6.5.2, 6.5.6)

Photo 6.5.1 Informal Masonry Building in Beichuan Chenjiaba (Intensity X)

(a) Pingtong Town(Intensity X) (b) Xiangyan Town(Intensity X)

Photo 6.5.2 The self-built Masonry House with first floor RC frame in Pingwu County is intact.

(a)

(b)

(c)

Photo 6.5.3 (a) The thickness of wall is 120mm, collapsed in earthquake. (b) The self-built masonry houses in Qingchuan County, whose bearing wall thickness is 120mm, collapsed in earthquake. (c) The classrooms and dorms of high school in Qingchuan County Muyu Town (Intensity Ⅸ), thickness of outer wall was 240mm, thickness of interior wall was 120mm, seriously damaged in earthquake.

(a)

(b)

Photo 6.5.4 (a) The self-built building in Pingtong Town (Intensity Ⅹ), the wall of second floor is half brick, wood truss. (b) The masonry house in Beichuan county Chenjiaba town, two storeys, brick-wood structure, collapsed.

Photo 6.5.5 (a) The self-built masonry house in Anxian County. (b) The self-built masonry house in Qingchuan County (collapsed).

(a)

(b)

Photo 6.5.6 The self-built Masonry House with first floor RC frame in Maoxian County Town (Intensity Ⅷ), shear failure in its column feet of bottom-frame storey.

Photo 6.5.7 The self-built Reinforced Concrete Frame, stone filled wall was damaged.

Photo 6.5.8 The self-built masonry buildings in Beichuan County Chenjiaba Town (Intensity X) are intact, adjacent brick-wood structure was collapsed.

(a)

(b)

Photo 6.5.9 The seismic resistance buildings built by "rural Comfortable Housing Project" of Wenxian County of Gansu Province. (Intact, offered by Wang Lanmin)

6.6 WOODEN BUILDING

This kind of building is generally one or two storeys, and supports the roof with the wooden frame. Its enclosure wall is a brick, or adobe wall. The majority of wooden buildings are old ones (Photo 6.6.1), which are seriously destroyed in this earthquake.

Photo 6.6.1 Old wooden frame house with light wall was not severely damaged in the earthquake.

Photo 6.6.2 Inside of a wooden house

Photo 6.6.3 A wooden frame house (the walls were collapsed, but the frame is still standing.)

Photo 6.6.4 The wooden house was destroyed in Beichuan Chenjiaba (Intensity X).

(a)

(b)

Photo 6.6.5 (a) The wooden and stone wall house was destroyed (Intensity Ⅶ) in Sichuan Baoxing County Qiaoqi Town; (b) The old wooden house was destroyed in Pingwu County Xiangyan Town.

Photo 6.6.6 The wooden frame and adobe wall house was destroyed in Linyou Town, Baoji, Shaanxi Province

(a)

(b)

Photo 6.6.7 (a) The self-built house with good quality in Wenxian Gansu (Intact in the earthquake); (b) The surrounding house was completely collapsed.

(a) (b)

Photo 6.6.8 The wooden houses were damaged.

6.7 SIMPLE BUILDING

These kinds of buildings refer to the adobe wall bearing or other rural buildings.

Photo 6.7.1 Overview of villages and towns building damaged in Wenchuan County, Sichuan.

Photo 6.7.2 The Yingshangelin house (the roof truss and purling were put in the gable directly) was destroyed in Anxian County Feishui Town.

(a) (b)

Photo 6.7.3 (a) The adobe building was destroyed in Maiji District, Tianshui, Gansu. (b) The adobe building was collapsed in Gansu.

(a) (b)

Photo 6.7.4 (a) The simple building was collapsed in Anxian County Xiaoba Town; (b) The brick-wood house was collapsed in Beichuan County Chenjiaba Town;

6.8 STEEL STRUCTURE

The steel structure has no significant earthquake damage. But in the Dongfang Steam Turbine Factory of Hanwang Town of Mianzhu, the steel-structure factories were damaged.

(a) (b) (c)

Photo 6.8.1 The steel-structure buildings were intact in the earthquake. (a) The gymnasium was intact in Dongfang Steam Turbine Factory of Hanwang Town (Intensity X). (b) The steel-structure tennis court was intact in Dujiangyan (Intensity IX). (c) The pendant lamp of the gymnasium fell in the earthquake in the Dongfang Steam Turbine Factory of Hanwang Town.

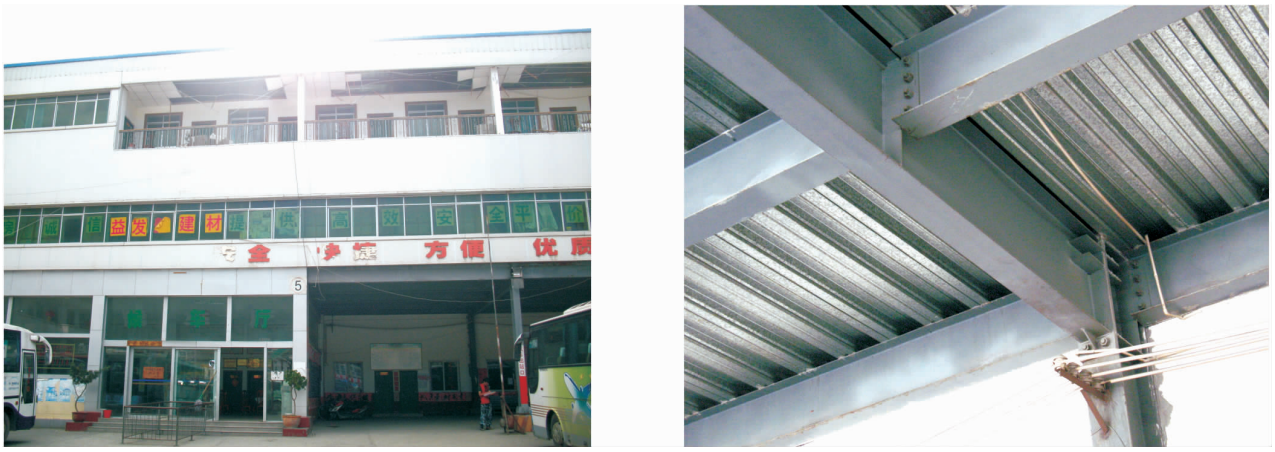


Photo 6.8.2 The steel-structure building of Xiqiang large drugstore was intact in Maoxian County (Intensity Ⅷ).

(a) Intact (b) Collapsed

Photo 6.8.3 The steel-structure factories have different performance in the Dongfang Steam Turbine Factory.

Photo 6.8.4 The factory of light steel roof truss of Haoyisheng medical group company of Sichuan was intact in Anxian County (Intensity Ⅷ).

(a) (b)

Photo 6.8.5 The steel-structure factory was intact in Beichuan County (Intensity Ⅺ).

7 EARTHQUAKE DAMAGE TO TRAFFIC SYSTEM

7.1 Damage to Highway Roadbed

By the post-earthquake emergency investigation and inspection done by the Ministry of Communications combining with the Traffic Designing Institute of Sichuan, Technological Co., Ltd. of the China Traffic Bridge etc 11 units organizied, we found out that 21 highways、15 national or provincial highways、2795 rural roads were destroyed in the Wenchuan Earthquake. The damaged mileage was 28,000km, which included 200km highways、3849km national or provincial highways and 23800km rural roads. Six hundred and fifty six bridges and 389 terminals were damaged seriously.

Main diseases of road surface had 24011 places, total 1792km, accounting for 42.24% of the measured projects. Serious diseases of roadbed and collapsed largerly barricade for slop edges had 1736, total 1687km, accounting for 39.76% of the measured projects.

(1) Roadbed damage caused by Landslide and Collapse

Geological hazard was the main reason of the roadbed and road surface damage, which manifested as highway landslide, roads buried or blocked by rolling rock, collapse of subgrade slope, road surface fracture or slump.

(a) Road slope collapse of Yinchanggou, Pengzhou;

(b) Road surface fracture caused by slope collapse

Photo 7.1.1 Roadbed and road surface damage

(a)

(b)

Photo 7.1.2 Road surface fracture caused by road slope collapse of Yinchanggou, Longmenshan, Pengzhou

Photo 7.1.3 (a) Road surface fractured in Wangdeng Highway; (b) Road surface fractured in Yinchanggou, Longmenshan, Pengzhou (Offered by Ji Suiwang)

Photo 7.1.4 Landslide and collapse buried roads; (a) Landslide buried road in Duwen Highway; (b) Collapse blocked road and broken cars in Duwen Highway (Offered by Ji Suiwang)

Photo 7.1.5 (a) Road rockfall damage in the highway from Maoxian County to Beichuan County; (b) Road rockfall damage in Guangyuan County (Offered by Ji Suiwang)

Photo 7.1.6 (a) Road rockfall damage in Yingxiu-Gengda Section of the Provincial Highway No. 303; (b) Rolling rock blocked the road in Dujiangyan-Yingxiu section of the National Highway No. 213 (Offered by Ji Suiwang)

(a)

(b)

Photo 7.1.7 (a) Collapse blocked road in Baoxing County, Sichuan; (b) Rolling rock blocked road from Guangyuan to Qingchuan (Offered by Ji Suiwang)

(2) Damage of supporting and retaining structure

(a)

(b)

(c)

(d)

(e)

(f)

Photo 7.1.8 (a), (b) and (c) Damage to cement-mortar-masonry retaining wall; (d) and (e) Damage to concrete retaining wall; (f) Dislocation of reinforced concrete pile resisting to slide (Offered by Ji Suiwang)

(a)

(b)

Photo 7.1.9 (a) Anchor bar frame supported well; (b) Landslide caused damage to supporting structure (Offered by Ji Suiwang)

Photo 7.1.10 (a) High slope retaining and protecting structure declined after earthquake; (b) Edge of pavement cracked (Offered by Ji Suiwang)

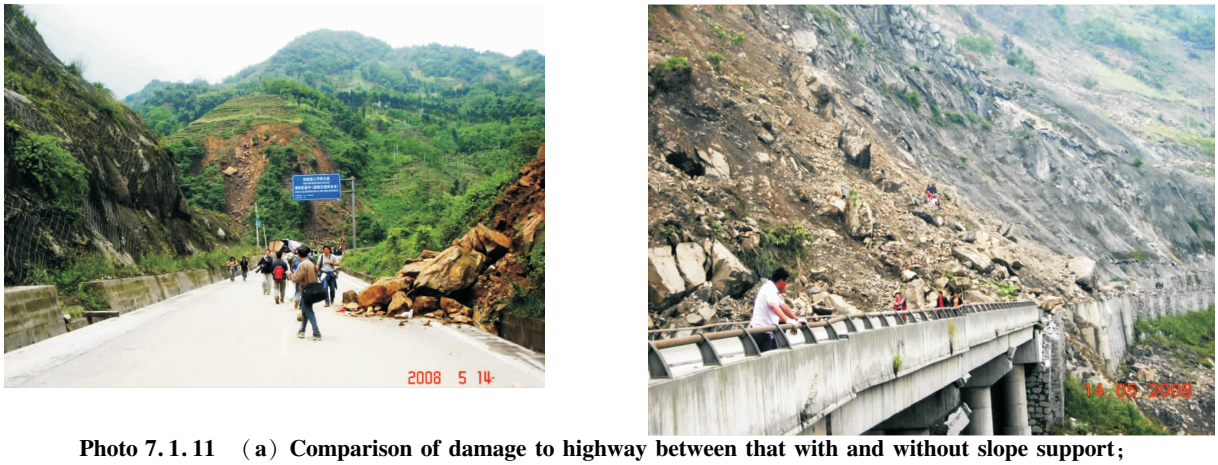


Photo 7.1.11 (a) Comparison of damage to highway between that with and without slope support; (b) Comparison of damage to highway between that with and without wire mesh concrete support after earthquake (Offered by Ji Suiwang)

7.2 Damage to Highway Bridge

A large number of bridges were damaged in various degrees in this earthquake, and especially damage of the bridges located in seismic zone were very serious. Most of damages were affected by geological hazard such as landslide, rock fall, rolling rock, fault movement and so on). By the post-earthquake emergency investigation and inspection done by the Ministry of Communications combining with the Traffic Designing Institute of Sichuan, Technological Co., and Ltd. of the China Traffic Bridge, statistics of bridge damage are as follows:

Table 7.2.1 Statistics of bridge damage in Wenchuan Earthquake (%)

Classification	Damage quantity	Normal	Minor repair	Medium repair	Top overhaul or reconstruct	Reconstruct or rebuild	Damage	Construction
Highways and key projects	576	5.08	34.18	45.68	2.97	11.45	0.53	0.11
Main roads of national highway	1081	7.08	33.90	31.27	11.26	11.55	3.10	1.84

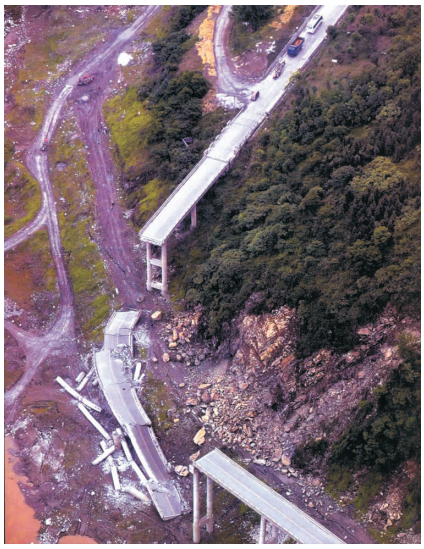


Photo 7.2.1 (a) Comparison of damage to bridge between that with and without slope support; (b) Comparison of damage to bridge between that with and without wire mesh concrete support after earthquake

(a)

(b)

(c)

(d)

Photo 7.2.2 (a) A mixed bridge of rigid frame and beam in Duwen Highway (b) A span falling off girder (c) Details of the falling span off girder (d) A span fall of girder of Hongkou Plateau Bridge in Dujiangyan

Photo 7.2.3 (a) A rigid-framed structure arch bridge in Xiaoyudong, Pengzhou; (b) A span of bridge plate fell off girder nearby a passing fault

Photo 7.2.4 (a) Duwen Road Chediguan Bridge collapsed; (b) Yuzixi curved bridge collapsed on Duwen Road (Offered by Ji Suiwang)

Photo 7.2.5 (a) Landslide destroyed bridge on Duwen Road; (b) Landslide buried bridge, river and road on Duwen Road (Offered by Ji Suiwang)

Photo 7.2.6 (a) Shunhe Bridge collapsed on Duwen Road; (b) Balang Middle Bridge was submerged by dammed lake's water (Offered by Ji Suiwang)

(a) (b)

Photo 7.2.7 Damage to beam bridge in South Dam of Pingwu County

(a) (b)

Photo 7.2.8 (a) Guangyuan Jialing River Bridge was destroyed with cracks on the beam; (b) Another Jialing River Bridge Deck was also damaged

(a)

(b)

Photo (a)7.2.9 Minjiang Bridge was dislocated 1.8m along cross range in Yingxiu County
(b) Main girder of New-house bridge was dislocated (Offered by Ji Suiwang)

(a)

(b)

Photo 7.2.10 (a) Fall of girder on Shoujiang Bridge, Yingxiu Town; (b) The abutment of Shoujiang Bridge cracked (Offered by Ji Suiwang)

(a)

(b)

Photo 7.2.11 (a) Bearing abscission of Minjiang Bridge in Yingxiu Town;
(b) Displaced bearing of Jinmahe Bridge

(a)

(b)

Photo 7.2.12 (a) Blocks of Miaoziping Bridge was damaged; (b) Collision of Chengguan high-speed bridge resulted in destruction

(a)

(b)

Photo 7.2.13 (a) Top of pier of Huilan Bridge was destroyed; (b) Details of damaged column cap

(a)

(b)

Photo 7.2.14 (a) Partial beam bridge collapsed in Longwei, Beichuan County; (b) Beam bridge collapsed in Beichuan County;

(a) (b)

Photo 7.2.15 (a) Collapsed Jingtian dam bridge in Guangyuan County; (b) Collapsed stone arch bridge in Leigu Town of Beichuan ;

(a) (b)

Photo 7.2.16 (a) Collapsed masonry arch bridge in Chenjiaba, Beichuan County; (b) Collapsed stone arch bridge in Yinchanggou, Pengzhou

(a) (b)

Photo 7.2.17 (a) Collapsed Zhongfa Bridge in Bailu Town, Pengzhou; (b) Damaged masonry arch bridge in Anxian County

(a)

(b)

Photo 7.2.18 (a) Intact arch bridge of Zipingpu Dam; (b) Intact Jinhua arch bridge.

7.3 Damaged Tunnel of the Highways

The general tunnel was damaged lightly, which centralized on tunnel portal, and tunnel liner formed cracks, but it can be open to traffic. Statistics of the damaged tunnel is as follows.

Table 7.3.1 Statistics of the damaged tunnel in Wenchuan Earthquake

Project classification	Total (number)	Normal (%)	Minor repair (%)	Medium maintenance (%)	Overhaul or transform (%)	Reconstruct or rebuild (%)	Constructing (%)
The expressway and key project	23	39.56	14.54	8.66	1.95	35.29	/
Main road of national highway	28	40.21	22.32	12.43	5.54	9.18	10.32

(a)

(b)

Photo 7.3.1 (a) Blocked opening of Maojiawan Tunnel on Duwen Road;
(b) Cracks on a concrete-lined tunnel

(a) (b)

Photo 7.3.2 (a) Damaged portal of a tunnel fromYingxiu to Wolongpanlong Mountain; (b) Landslide-submerged structural opening

(a) (b)

Photo 7.3.3 (a) Collapse above Duwen Road Tunnel, the tunnel is basically intact; (b) Basically intact Longwei Tunnel with some cracks at its portal

7.4 THE DESTRUCTION OF THE RAILWAYS SYSTEMS

This earthquake caused the railway system to destruction: Baoji- Chengdu Railway Lines 4, Chengdu-Kunming Railway Lines 4, Chengdu- Chongqing Railway Lines 7, many places of relevant branch lines collapse and smash the rail with rolling stone, causing the railway bridge to be damaged, the most serious one is that the body of rock comes down and closes in the tunnel of No. 109 Baoji-Chengdu railway line, the oil truck just the tunnel is on fire bungle, lasts 12 days to repair. Some truck stand apparatus of the buildings damage in various degree along the line.

Photo 7.4.1 (a) The earthquake caused the rail to crook; (b) The train turned over

(a)

(b)

(c)

Photo 7.4.2 Rail and roadbed were smashed by huge rolling stones

(a) Before the earthquake (b) After the earthquake

Photo 7.4.3 landslide caused Macao Beach Railway Bridge in Shifang to destroy.

(a)

(b)

Photo 7.4.4 (a) The railway bridge girder in Shifang was shifted;
(b) The road bed of the railway bridge in Shifang City collapsed

(a) (b)

Photo 7.4.5 No. 109 Tunnels of Baoji-Chengdu Railway Line in Huixian County, Gansu collapsed and stop up (a) It caused the oil truck to break out a fire and break the locomotive; (b) Another exit of the tunnel collapsed on a large scale

8 EARTHQUAKE DAMAGE TO ELECTIRCAL POWER SYSTEMS

8.1 The Power Plant and Electric Substation Building Destroy

The buildings (construction works) are generally damaged in the power plants and substations, generally collapsed especially in the meizoseismic zone. In the surrounding area outside of earthquake zone, besides the buildings(construction works) collapsed individually, most of the damaged situations are shown as the walls are cracking, the buildings(construction works) are inclined, and some foundations present sinking or cracking etc. The parts of the buildings appeared collapsed individually. A lot of small-scale power station in the meizoseismic zone were collapsed or buried, suffered from earthquake secondary disasters such as landslide, debris flow, etc.

(a)

(b)

Photo 8.1.1 The building's steel truss roof of a power plant in Jiangyou completely collapsed and made two groups of generating sets to be destroyed.

Photo 8.1.2 The Jinyuzu Power Station in Deyang collapsed completely.

Photo 8.1.3 The mainly control building of 220kV substation of Anxian County was seriously damaged.

Photo 8.1.4 The Xiaogangjian Hydropower Station of Mianzhu City was buried.

(Photos8.1.5 - 8.1.7 are Offered by Chengdu Hydroelectric Investigation &Design Institute of SPC)

(a)

(b)

Photo 8.1.5 (a) The basic facilities of the Caopo Hydropower Station were destroyed due to the lanslide of the slopes; (b) The Taipingyi Hydropower Station was water overtopped because of the lanslides.

(a)

(b)

(c)

(d)

Photo 8.1.6 (a) Yingxiuwan Hydropower Station; (b) The open-close diesel engine of the sluice gate was destroyed; (c) The 2# gate was out of shape. (d) The 4# release sluice was obstructed due to deformation.

(a)

(b)

Photo 8.1.7 (a) The building of Yingxiuwan Hydropower Station was hit by rolling stone; (b) There are cracks in the Tongzhong Hydropower Station of Minjiang River.

8.2 The Destruction of the Transmission Tower

High voltage transmission tower is divided into straight tower, rain tower and so on, and is the key element of the electric network. The earthquake phenomenon of the tower is mainly as follows:

(1) The uphill landslide and fracture of the transmission tower lead its foundation to be buried and grounding grid exposed;

(2) The downhill landslide and fracture of the transmission tower;

(3) Landslide and subsidence of the foundation and its peripheral areas of the tower; fracture and collapse of the slope protection, fracture in the foundation of the backfill;

(4) The body of the tower was global deformed and toppled; the head of the tower was damaged, and out of shape, the tower material was out of shape by flying stone and even ruptured, the protect cap of the tower foot was out of shape by flying stone.

(5) The caused cavity and sinks made the foot of the tower to collapse

(6) The insulator inclined, moved or burst.

The main cause for this seismic damage is geological hazard. The damaged proportion of slope protection is

high. The overhead line and guy were buried by earthwork from the hill. The tower was inclined by the guy. Small amount of tower was inclined by the draw-off of the nearby tower, and the tower material was out of shape by flying stone.

In addition, because of landslide or cave-in, plenty of transmission towers had collapsed in this earthquake. For a typical example, No. 13 transmission tower with good strength is located at Sangjiang Road which belong to Guangyuan Electricity Bureau, the tower collapsed to the right in earthquake, and the tower itself distortied, but there were not stones falling down from the mountain. The reasons of collapse need to investigation in detail.

From districts that the damaged transmission towers was in, we can see that mountainous areas had been damaged badly, such as Yingxiu County, Anxian County, Beichuan County, Jiangyou County. These districts are close to fault zone of Longmen Mountains, and the seismic intensities are larger, so there are many secondary disaster, such as debris flow, mountain landslide and sand liquefaction. There are severe damage of transmission towers in plain districts.

Many reinforced concrete electrical poles were destroyed in heavy disaster areas, parts of them were destroyed by geological hazard, and another parts were destroyed by highly intense ground motion, In city zone, breakdown of constructions made the wire to break and resulted in collapse or break of lots of poles.

(a)

(b)

(c)

(d)

Photo 8.2.1 The high pressure transmission towers was destroyed by rolling stones or landslides.

(a)

(b)

Photo 8.2.2 The high pressure transmission towers was smashed by rolling stones. (a) The 123# tower of 500KV in Maotan line was smashed; (b) The footing of 23# tower in Hongxue line of Yingxiu Town was smashed.

(a)

(b)

Photo 8.2.3 The high pressure transmission towers was smashed by rolling stones. (a) The main material of Dleg of 79 # transmission tower of Zhoumao line was interrupted by the slungshots; (b) The 13 # transmission tower of Jiangsang line collapsed.

(a)

(b)

Photo 8.2.4 (a) The bottom of 14# tower of Tianjin line in Jinlong Lake area was destroyed in Wenchuan; (b) The 11# tower of Tianjin line was destroyed in Wenchuan Earthquake (Offered by Chengdu Hydropower Investigation & Design Institute, SPC).

Photo 8.2.5 The electric wires were destroyed because the buildings around collapsed (Mianyang).

8.3 The Destruction of the High Voltage Equipment

Most of the high voltage equipment suffered from serious damage in meizoseismal area, such as Beichuan County, Anxian County and Yingxiu Town (Intensity Ⅷ-Ⅺ). The seismic damage of the high voltage equipment is multiplicity: the voltage transformer was overturned and shifted, and the casing rupture and oil spilling phenomenon is general. The equipments with higher center of gravity, such as circuit breaker, disconnector, arrester and transformer bushing were damaged seriously, the post insulator displays the fracture at the root of porcelain insulator and oil spilling.

According to the information offered by Sichuan Province Utilities Electric Company, in the earthquake, for the Sichuan Province Utilities Electric Company (including the subordinate company) there were 116 of 110kV and the above voltage transformer damaged (Including a 110kV reactor and a 500kV reactor). Among them the number of the damaged 110kV voltage transformer is 84, accounts for 72.4% of the damaged total amount. The number of the damaged 220kV voltage transformer is 25, accounts for 21.6%. The number of the damaged 500kV voltage transformer is 7, accounts for 6%. The number of the damaged casing is 76, displacement of noumenon amounts to 33cm. The number of the damaged 110kV and the above current transformer add up to 163, 115 of 110kV and 48 of 220kV are among them. The number of the damaged 110kV and the above voltage transformer add up to 22, 5 of 110kV, 16 of 220kV and one of 500kV are among them. In 110kV and the above voltage transformer substation, the number of the dumping bus sections is 5, and the number of the breaking of the bus bar is 16. The number of the circuit breakers damaged in various degrees is 91.

Photo 8.3.1 The nearly completely collapsed equipments in 220KV Ertaishan Substation

(a)

(b)

Photo 8.3.2 (a) The main transformer was shifted, the casing was ruptured and oil was spilled in Chuanxindian, Shifang City; (b) The main control room collapsed in the substation in Anxian County

(a)

(b)

Photo 8.3.3 (a) The high voltage switchgear was broken in 6KV backup station of Yuanmenba Station (b) Voltage transformer in 110KV substation shifted seriously and oil spilled in Beichuan County

(a)

(b)

Photo 8.3.4 1# Main transformer of 500kV substation in Maoxian County was damaged; (a) C sleeve pipe broke out a fire and burnt; (b) porcelain bushing of B sleeve pipe burst and split

Photo 8.3.5 Damage to the High Pressure equipment of Caopo Power Plant

(a) (b)

Photo 8.3.6 (a) Ruptured and dropped circuit breaker in Yuanmenba Station; (b) A lot of hv electrical equipment were damaged seriously in Jiangyou Power Plant

(a) (b)

Photo 8.3.7 (a) Mother stands to unite switch B were ruptured from the root of No. 260 bus-link in the 220kV Yongxing substation, Mianyang; (b) Landslide calamity of the Yinxing Substation

9 EARTHQUAKE DAMAGE TO COMMUNICATION SYSTEM

The communication system plays an important role in disaster relief. After the earthquake, line jam is the most prominent problem. Fig. 9.1 is the statistics of talking frequency in Deyang. As the figure shows that the peak of trunk calling appeared from the afternoon on May 12 to zero o'clock on May 13, and in the morning and at 23:00 on May 13. The increased amplitude was about 200%. Percentage of successful connections is only 1/3 of peacetime.

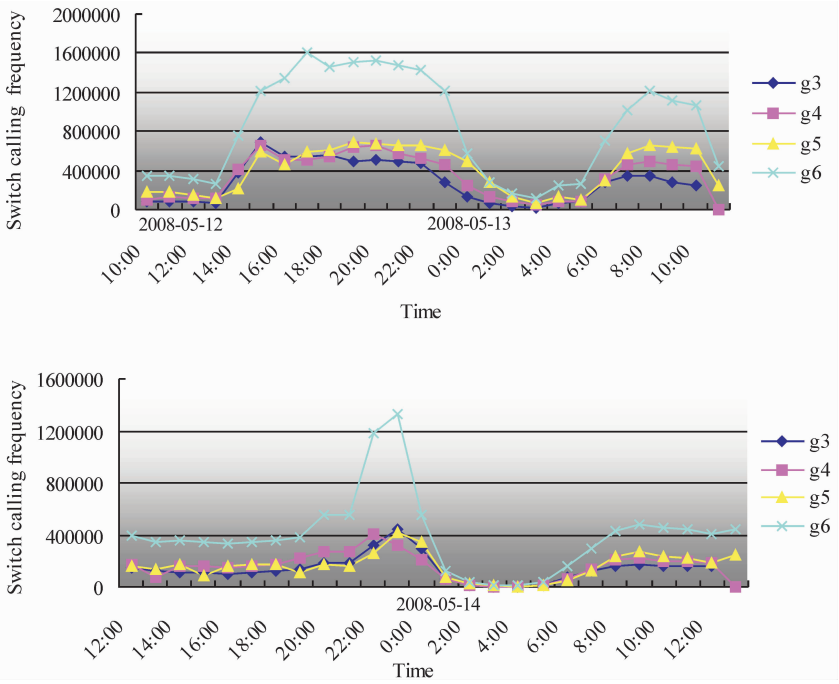


Fig. 9.1 The switch calling frequency of Deyang City after the earthquake.

9.1 Damage to Communication Building

(a)

(b)

Photo 9.1.1 (a) The top of a building in Mianzhu Mobile Communication was damaged and the wall was cracked; (b) The building of Dujiangyan Mobile Communication Station was damaged.

(a)

(b)

Photo 9.1.2 (a) The office building of Pengzhou Municipal Bureau of Radio and Television is a9-storey frame structure. It was built in 1989. Its height is 82m together with the launch tower on roof, the filled wall in frame cracked, lightning rod on roof droped, angle steel buckled and launch tower was broken; (b) The office building of Yingfeng Mobile Communication was damaged.

(a)

(b)

Photo 9.1.3 The building of Dujiangyan Base Station was damaged.

Photo 9.1.4 The building of Jianshi Town Shifang Base Station was damaged.

Photo 9.1.5 The building of Wudu Town Shifang Base Station was damaged

Photo 9.1.6 The communication tower of Mianchi Town Shifang Base Station was damaged by the rolling stones.

9.2 Damage to Communication Equipment

(a)

(b)

Photo 9.2.1 The mobile communication equipment of Dujiangyan was damaged

(a)

(b)

Photo 9.2.2 The mobile communication equipment of Dujiangyan was damaged because of the damaged building.

(a) (b)

Photo 9.2.3 (a) The mobile communication equipment of Dujiangyan was damaged because of the damaged building; (b) The wire stringing exfoliated

10 EARTHQUAKE DAMAGE TO WATER SUPPLY AND SEWER SYSTEM

The main damages of water supply and sewer system were those of pipelines. The pipelines were destroyed very seriously in the high intensity areas and the damages of pipelines were at large. The large underground deformation cacsed joint and valve shaft to be fractured. Some leaks were caused by collision of the heavy block from the collapsed buildings. And some iron pipes had been corroded and aged. For example, in Anxian County, among 39.6 kilometers long of the Φ63 ~Φ300 main pipeline, there were 100 places where the pipelines broke, among which iron pipe accounting for 70% and steel pipes 30%, and many damages were joint and valve shaft failures, and there also 700 places where the pipe damages were caused by collapsed buildings. Joint failures were the main damages of PE and PPR pipes.

(a) (b)

Photo 10.1 A joint of the iron pipe leaked (In Mianzhu City)

(a) (b)

Photo 10.2 The straight iron pipe was damaged and the water erupted

(a) Joint and conduct of the iron pipe

(b) Damage to the iron pipe

Photo 10.3 Damage to the iron pipe (In Mianzhu City)

(a) Damage to a joint of PE pipe

(b) Damage to a joint of iron pipe flange

Photo 10.4 Damage to a joint of PE pipe

(a)

(b)

Photo 10.5 Damage to a valve well

(a) Place of water intake

(b) Damage to elbow of the pipe

Photo 10.6 Damage to PVC pipe

(a)

(b)

Photo 10.7 (a) The water supply pipeline cracked and water was leaked; (b) A joint of the water supply pipe cracked and the water erupted through the ground in Guangyuan City

(a)

(b)

Photo 10.8 (a) Damage to a joint of cement pipe in Guangyuan City; (b) Damage to an iron pipe

(a) (b)

Photo 10.9 (a) The iron pipe was damaged and water erupted in Mianzhu City; (b) The straight iron pipe was damaged and water erupted in Shifang City

11 EARTHQUAKE DAMAGE TO GAS SYSTEM

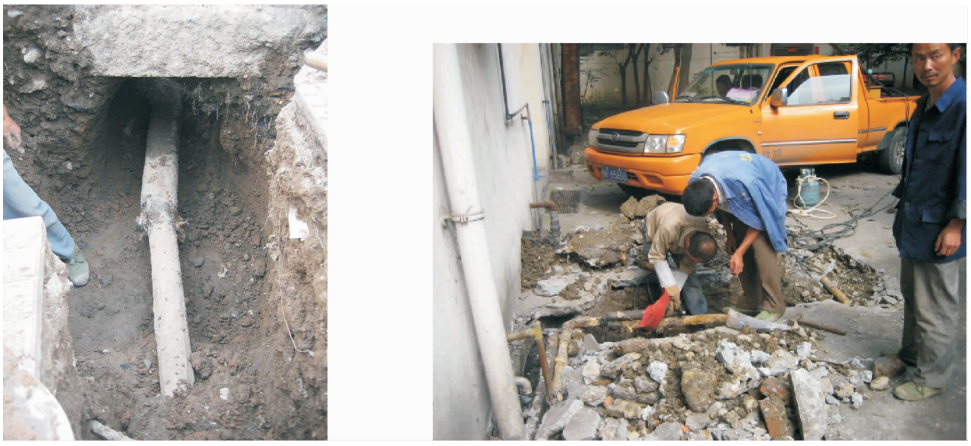
Gas pipelines are mostly the steel tubes and the tubes indoor are made of seamless steel tubes and aluminium plastic pipes. The main reasons of the damages of gas pipes were that the steel pipelines and craters were corroded for years and acted upon by external force. And PE tubes behaved well. Damages to the overground gas pipeline network were mainly caused by external force acting upon joint of steel pipes, which caused gas leakage, but there were no leakages of aluminium plastic pipes.

(a) (b)

Photo 11.1 (a) A equalizing valve of gas pipe; (b) T-joint of PE gas pipe (Already repaired)

(a) (b)

Photo 11.2 (a) The building of the gas station damaged and smashed the pipeline in Dujiangyan City; (b) The building of the gas station damaged and smashed the equipments in Dujiangyan City.



(a) (b)

Photo 11.3 (a) Damage to joint of the steel pipe; (b) The intake gas pipe was damaged and being repaired.

Photo 11.4 The entering pipeline was crushed by falling objects from the damaged building

(a) (b)

Photo 11.5 Damage to the gas steel pipeline (a) Damage to the joint of main pipe; (b) Damage to straight pipe (Already repaired)

12 EARTHQUAKE DAMAGE TO INDUSTRIAL ENTERPRISES

The industrial and mining enterprises suffered largely in this earthquake, factory buildings collapsed, machinery, apparatus, products, etc were damaged too, the loss in stop production and yield reduction was enormous.

12.1 Damage to Workshops

(a) (b)

Photo 12.1.1 The top of the workshop gable partially collapsed

Single Storey Factory Buildings include reinforced concrete column, steel column, a few brick column, and many types of roof truss. The earthquake damages included crack and collapse of the cladding walls, crack and break of columns, collapse of the roof truss, etc.

(a) (b)

Photo 12.1.2 The gable of the old spherical tank workshop collapsed (Sichuan Lanxing Machinery Limited Company, Shifang City,).

(a) (b)

Photo 12.1.3 (a) Cladding wall of the workshop collapsed (Aba Aluminum Plant, in Xuankou Town); (b) Column of the workshop cracked or broke (Sichuan Lanxing Machinery Limited Company, Shifang City,).

(a) (b)

Photo 12.1.4 (a) A Workshop collapsed in Yingxiu Town (intensity, Ⅺ); (b) A reinforced roof truss collapsed at Yingfeng Industry Corpartion(In Shifang City)

(a) (b)

Photo 12.1.5 A workshop roof truss collapsed in Dongfang Turbine Factory

(a) (b)

Photo 12.1.6 (a) A workshop was destroyed in Dongfang Turbine Factory; (b) The roof boarding of the workshop fell down, the lading wall collapsed, and the roof truss collapsed in Yingfeng Industry Corpartion(In Shifang City)

(a) (b) (c) (d)

Photo 12.1.7 The roof truss and the roof boarding of single storey workshop with RC column collapsed in Hongda Group Phosphate Chemical Plant (In Shifang City).

(a) (b)

Photo 12.1.8 (a) A light warehouse with steel frame was basically intact in Hongda Group Phosphate Chemical Plant (In Shifang City); (b) The steel roof truss and the light roof boarding of the new spherical tank workshop were intact in Sichuan Lanxing Machinery Co (In Shifang City).

(a) (b)

Photo 12.1.9 (a) The main building and some other buildings in Dongfang Turbine Factory (In Hanwang Town were intact, intensity X); (b) Some workshops of the plant were Intact

12.2 Industrial Structures and Equipment

(a) (b)

Photo 12.2.1 (a) Workshops and equipments were destroyed in Hongda Chemical Plant (In Shifang City); (b) The reaction tower fell down in Hongda Chemical Plant.

(a) (b)

Photo 12.2.2 (a) The pier-supported pipeline broke in Hongda Group Phosphate Chemical Plant (In Shifang City); (b) The pier-supported pipeline fell down

(a) (b)

Photo 12.2.3 (a) The conveyor belt protector was intact in Huali Cement Plant (In Hongbai Town, intensity X); (b) Transfer station of the conveyor belt protector was damaged.

(a) (b)

Photo 12.2.4 (a) Cracks on the conveyor belt protector in Hongda Group Phosphate Chemical Plant; (b) Intact light conveyor belt protector in Pengzhou Mineral Region

(a) (b)

Photo 12.2.5 (a) The reaction tower fell down in Hongda Group Phosphate Chemical Plant (In Shifang City); (b) The steel reaction tower was partially intact.

(a) (b)

Photo 12.2.6 (a) The reaction tower fell down in Yingfeng Industry Corpartion (In Shifang City). (b) The fallen roof on a horizontal Liquid ammonia tank

(a) (b)

Photo 12.2.7 (a) Intact vertical sulfate tank in Yingfeng Industry Corpartion (In Shifang City,); (b) Horizontal liquid ammonia tank

(a) (b)

Photo 12.2.8 (a) The middle of a vertical hydrochloride tank buckled in Yingfeng Industry Corpartion; (In Shifang City,). (b) Details of that illustrated in (a)

(a) (b)

Photo 12.2.9 The upper part of a FRP Tank buckled. (a) appearing horizontal cracks of the tank in Yingfeng Industry Corpartion (In Shifang City). (b) Details of that illustrated in (a)

(a) (b)

Photo 12.2.10 (a) The upper part of a FRP Tank broke and fell down in Yingfeng Industry Corpartion (In Shifang City); (b) Intact horizontal steel tank

(a) (b)

Photo 12.2.11 (a) A FRP hydrochloride tank in Yingfeng Industry Corpartion (In Shifang City); (b) The upper part of some tanks was damaged and fell down

(a) (b)

(c) (d)

Photo 12.2.12 (a) A spherical tank in Yingfeng Industry Corpartion (In Shifang City); (b) Fixing bolt of the base was distorted; (c) The steel column of the base deviated, and the bolts fell off; (d) The draw-bar pulled out.

(a) (b)

Photo 12.2.13 The damage to equipments in Hongda Chemical Plant (In Chuanxindian Village, Shifang City, intensity X)

(a) (b)

Photo 12.2.14 The reaction tower fell down in Hongda Chemical Plant (In Chuanxindian Village, Shifang City, intensity X); (b) Damage to the support of a filter tank

(a) (b)

Photo 12.2.15 Damage to equipments (Sichuan Lanxing Machinery Limited Company, Shifang City,).

(a) (b)

Photo 12.2.16 Damage to equipments in the workshops

Photo 12.2.17 Damage to cars caused by collapsed buildings

13 EARTHQUAKE DAMAGE TO WATER CONSERVANCY SYSTEM

The main damages to water conservancy system were those of dams. A joint survey carried out by Ministry of Water Resources and some provinces, cities and counties, showed that the damaged reservoirs had a widespread distribution, and the damages of small-scale reservoirs were serious. The damaged reservoirs distributed in 8 provinces and municipalities, and the range was unprecedented. The basic situation of the damaged reservoirs in 8 provinces and municipalities are shown in Table 13.1.

Table 13.1 Basic situations of the damaged reservoirs

Order number	Name of province and municipality	Total num. of reser-voirs	Number of damaged reservo-irs	Proportion of the damaged to thetotal for each province (city) (%)	Proportion of the damaged to the total in 8 provinces (municipalities) (%)	Classification of dangerous situations		
						Dangerous situations of dam-break	High dangerous situations	Secondary high dangerous situations
1	Sichuan	6678	1996	29.89	74.87	69	310	1617
2	Chongqing	2824	352	12.46	13.20		2	350
3	Shaanxi	1036	126	12.16	4.73		17	109
4	Yunnan	5422	51	0.94	1.91		2	49
5	Gansu	297	81	27.27	3.04			81
6	Guizhou	2105	12	0.57	0.45			12
7	Hubei	5804	25	0.43	0.94			25
8	Hunan	11435	23	0.20	0.86			23
Total		35601	2666			69	331	2266

There were 1996 damaged reservoirs in Sichuan Province. The situations were divided into three kinds, namely dangerous situations of dam-break, high dangerous situations and secondary high dangerous situations, according to the degree of damage. For Type Ⅰ, dangerous situation of dam-break, the reservoir dams and major projects were overflowed, the through-going cracks appear on the dams, the dams upstream and downstream slide extensively, and these situations were possible for dam-break in short time; For Type Ⅱ, high dangerous situations, the situations of the reservoir dams and major projects were the same as those described above, which might affect the safeties of reservoir dams and major projects; For Type Ⅲ, secondary high dangerous situations, the damage to reservoir dams and major projects was not so serious as those mentioned above, which would not affect the operating safeties of major projects basically. Of the 1996 damaged reservoirs in Sichuan Province, there were 69 reservoirs of dangerous situations of dam-break, 310 reservoirs of high dangerous situations, 1617 reservoirs of secondary high dangerous situations and general dangerous situations.

Of 1996 earthquake-damaged reservoirs, dangerous situations included cracks on the dams (1425), collapse and settlement of dams (687), slide of dams (354), leaks of dams (428), damages of hoisting devices of dams? (161), other damages of releasing devices, spillway, office room of dams (422), and many kinds of dangerous situations appeared simultaneously in more than 50% of the reservoirs.

13.1 Zipingpu Dam

Zipingpu Dam lies in the upper reaches of the Minjiang River, Zipingpu Town that is 9km away northwest of Dujiangyan City, upper reaches of Dujiangyan Water conservancy Project which is world heritage, and a large A size water control project. Main buildings are designed to withstand floods of 1000 years recurrence period (flow rate of 3800m3/s). The check dam is a rock fill dam, and its design seismic intensity is 8. The dam is 156 meters

high, and the capacity of the reservoir is 1,112 million cubic meters (Photo 13.1.1). Hydropower station installed 4 power generators (190,000 kilowatts each) with total capacity of 760,000 kilowatts.

Zipingpu Dam lies in the area of intensity Ⅹ, and the local earthquake intensity was Ⅸ. During the quake, main body of the dam was basically intact, and the main damage was the displacement of the dam such as vertical settlements 73cm on the top of the dam, horizontal displacement 38cm, within the limits range. And other damages include that top of the dam cracked, the upper reaches protecting panel pressed and cracked, the downstream revetment cracked, and the building of elevator was cracked but not collapsed, workshops cracked. And slab stones of the revetment become flexible and shifted, which did not affect the normal work.

(a) (b)

Photo 13.1.1 The exterior view of Zipingpu Dam (a) Upstream face (b) Downstream face

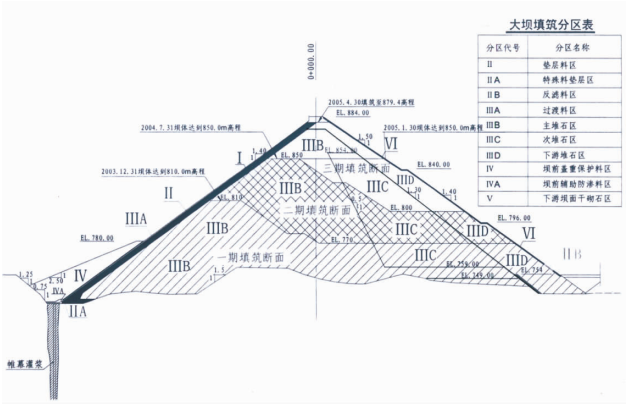


Fig. 13.1.1 The schematic diagram of filling rockfills of Zipingpu Dam (Offered by WenYanfeng)

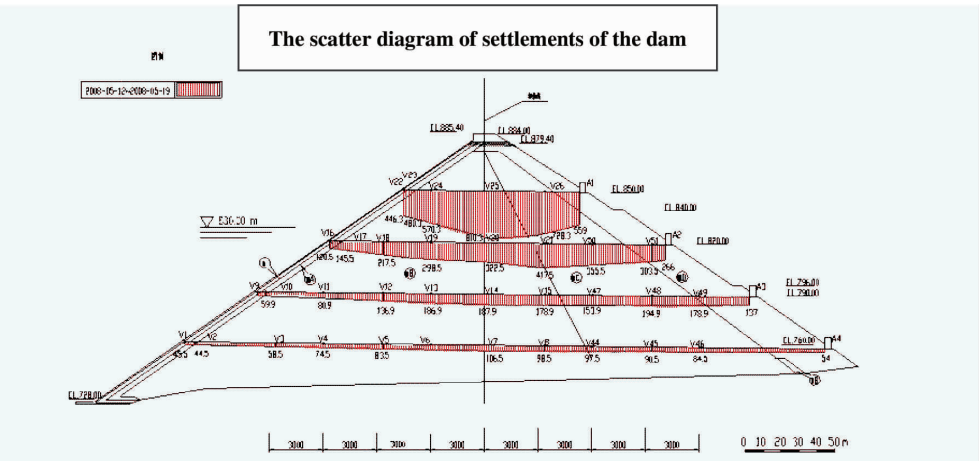


Fig. 13.1.2 The scatter diagram of settlements in the body of Zipingpu Dam (Offered by Lingao)

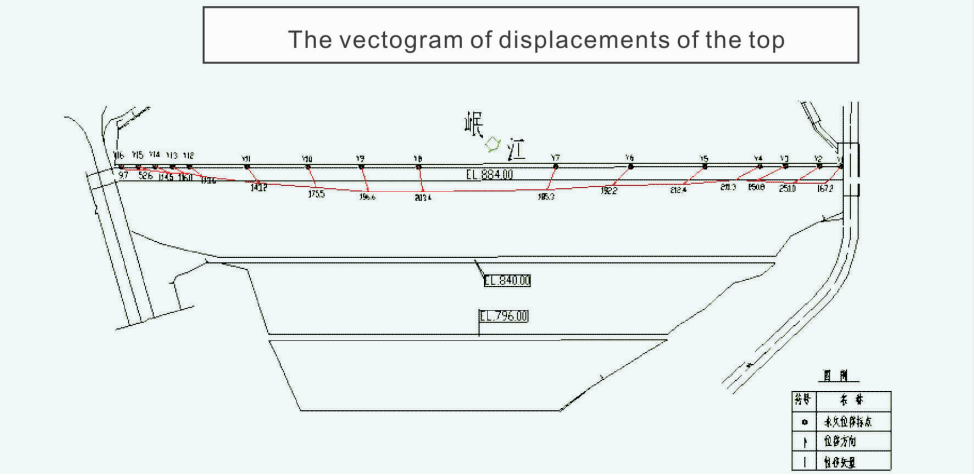


Fig. 13. 1. 3 The vectogram of displacements at the top of Zipingpu Dam (Offered by Lingao)

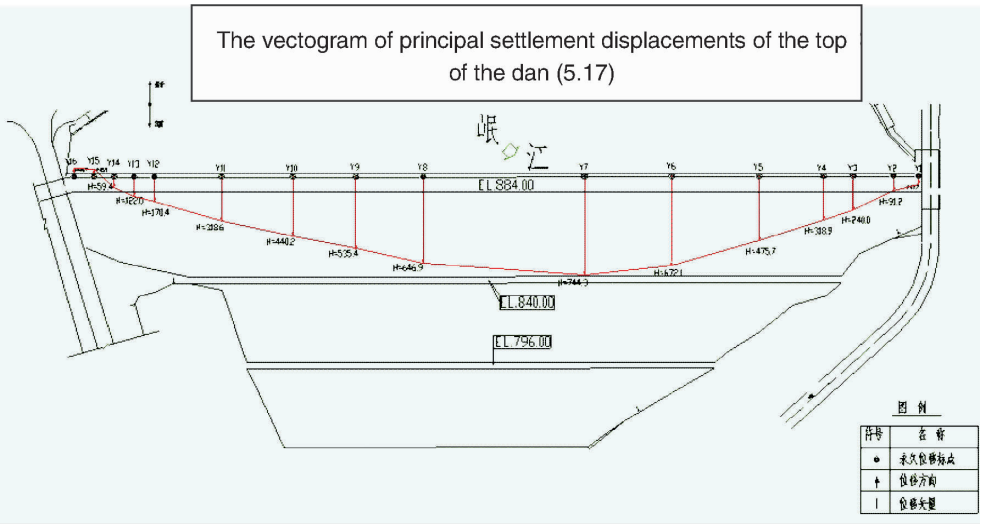


Fig. 13. 1. 4 The scatter diagram of settlements at the top of Zipingpu Dam (Offered by Lingao)

Photo 13. 1. 2 Intact workshops and spillway of Zipingpu Dam

(a) (b)

Photo 13.1.3 (a) The top of Zipingpu Dam cracked and the guardrails collapsed. (b) The building of gate lifting devices cracked but not collapsed. (Offered by WenYanfeng)

13.2 Shapai Arch Dam

Shaipai Arch Reservoir lies in Minjiang River tributary in Wenchuan County, earthquake intensity X, from magnitude8.0 earthquake epicenter about 30km, and Longmenshan back fault about 8km and the dam is the arch dam of reinforced concrete. After the quake, the steel diversion pipes outside were smashed by the rolling stones, the arch dam and the two sides dam abutment resisting force body was intact, the whole stability of slope of the bank near the dam was well-behaved, and the current situation of the dam is safe.

(a) (b)

Photo 13.2.1 Intact Shapai Arch Dam (Intensity X); (a) Upstream face; (b) Buildings on the port of water storage and intake. (offered by Chengdu Hydroelectric Investigation & Design Institute of China Hydropower Consulting Group)

(a) (b)

Photo 13.2.2 (a) Stability of the bank slope of Shapai Arch Dam; (b) The elevator hall cracked. (Offered by Chengdu Hydroelectric Investigation & Design Institute of China Hydropower Consulting Group)

Photo 13.2.3 Shapai Reinforced Concrete Arch Dam (Offered by Chengdu Hydroelectric Investigation & Design Institute of China Hydropower Consulting Group)

13.3 Damage to Earth Dam

The damages were mainly the longitudinal cracks on the top of the dams, sometimes prolonging the whole dam, there was transverse cracks individually, and serious one partially collapsed. In addition, spillway tunnel and wall protection of the slope cracked.

(a) (b)

Photo 13.3.1 Body of Jiguang Dam in Zhongjiang County (a) Longitudinal cracks (b) Transverse cracks

(a) (b)

Photo 13.3.2 (a) Longitudinal cracks on the newly built earth dam in Fenggu Town, Mianyang City; (b) Transverse cracks on the earth dam of Changdaogou Reservoir in Mianyang City.

(a)

(b)

Photo 13.3.3 (a) Longitudinal cracks on the earth dam of Dasongshu Reservoir; (b) Longitudinal cracks on the earth dam of Bailin Reservoir in Hanwang Town, Mianzhu City.

(a)

(b)

Photo 13.3.4 Longitudinal cracks on the earth dam of Fengshou Reservoir in Anxian County; (b) Landslide and collapse occurred aftershock, and was damaged seriously.

(a)

(b)

Photo 13.3.5 (a) Damaged roof of spillway tunnel of Wenjiajiao Reservoir in Cangxi County; (b) Leakage through dam foundations

14 EARTHQUAKE DAMAGE TO ANCIENT BUILDINGS

According to the statistics of Administrative department of cultural relic, during this great earthquake, 83 key cultural relic protection units in country-level, 174 units in province-level, 803 units in city and town level in all Sichuan Province were damaged. 19 key cultural relic protection units in country-level, 11 units in province-level and the ancient buildings of a famous town with historical culture under provincial protections in Gansu Province suffered the losses of different degrees. 29 key cultural relic protection Unit in country-level, 17 units in province-level were damaged in different degrees in Shaanxi Province. 13 key cultural relic protection unit in country-level, 19 units in province-level and 2 famous towns with historical culture were damaged in different degrees in Chongqing Municipality.

(a) Before the quake (b) After the quake

Photo 14.1 Main hall of Pengzhou Linbao Seminarium, a key cultural relic protection units in country-level. (Offered by Gao Dalun)

(a) Before the quake (b) After the quake

Photo 14.2 Classrooms of Pengzhou Linbao Seminarium, a key cultural relic protection units in country-level. (Offered by Gao Dalun)

(a) Before the quake (b) After the quake

Photo 14.3 Church of Pengzhou Linbao Seminarium, a key cultural relic protection units in country-level. (Offered by Gao Dalun)

Photo 14.4 Damaged Church of Pengzhou Linbao Seminarium, Key Cultural Relic units under State Protections. (Offered by Gao Dalun)

(a)

(b)

Photo 14.5 Damaged ancient building, a world cultural heritage, in Dujiangyan City.
(a) Damaged Erwang Temple; (b) Damaged temple in Dujiangyan. (Offered by Gao Dalun)

(a) Before the quake

(b) After the quake

Photo 14.6 Ziku Pagoda, a world cultural heritage in Dujiangyan City (Offered by Gao Dalun)

Photo 14.7 Damaged Bao'en Temple, a key cultural relic protection units in country-level in Pingwu County. (Offered by Gao Dalun)

(a) Before the quake (b) Douzhen Hall after the quake

Photo 14.8 Yunyan Temple, a key cultural relic protection units in country-level in Jiangyou City (Offered by Gao Dalun)

(a) Wall of Sutra Library shattered (b) Dongyue Hall after the quake

Photo 14.9 Yunyan Temple, a key cultural relic protection units in country-level in Jiangyou City (Offered by Gao Dalun)

(a) Before the quake (b) After the quake

Photo 14.10 Wenxing Pagoda, a key cultural relic protection units in country-level in Anxian County. (Offered by Gao Dalun)

(a) Before the quake (b) After the quake

Photo 14.11 Bi Pagoda, a key cultural relic protection units in country-level in Yanting County. (Offered by Gao Dalun)

(a) (b)

Photo 14.12 (a) Laiyan Pagoda broke in Guangyuan City; (b) Kuiguang Pagoda cracked in Dujiangyan City.

15 EARTHQUAKE DAMAGE TO WATER TOWERS AND CHIMNEYS

(a) (b)

Photo 15.1 (a) A crack on the water tower (Hongda Chemical Plant, Chuanxindian, Shifang, intensity X); (b) A annular crack on the bottom of the water tower (Yinghua, Shifang, intensity IX)

(a) (b)

Photo 15.2 (a) The top of water tower fell off (Anxian County, intensity VIII); (b) Intact reinforced concrete frame of a water tower (Shifang City).

(a) (b)

Photo 15.3 (a) Intact high water tower (Shifang cement plant); (b) The water tower was intact, but buildings around were damaged (Hanwang Town, intensity X).

(a) (b)

Photo 15.4 (a) A brick chimney in Shifang Cement Plant broke; (b) A chimney was dislocated and the top fell off in Shifang City.

(a) (b)

Photo 15.5 (a) A brick chimney in Shifang Cement Plant broke and cracked; (b) A brick chimney broke and tilted in Yangxian County, Hanzhong, Shaanxi.

16 OTHER EARTHQUAKE DAMAGE

Photo 16.1 A belfry was damaged in Hanwang Town, Mianzhu.

(a) (b)

Photo 16.2 Destroyed Jian-nan-chun spirit factory in Mianzhu City;
(a) Workshop was damaged; (b) Crocks were broken

(a) (b)

Photo 16.3 A big rolling rock stopped in front of a shop in Anxian County.

(a) (b)

Photo 16.4 Cars were smashed by rolling rocks in Beichuan County.

Photo 16.5 Cars were smashed by rolling rocks on the road.

(a) (b)

(c) (d)

Photo 16.6 Cars were smashed by collapsed buildings