Earthquake Damage Characteristics and Assessment of Lifeline Systems on May 12th, 2008, Sichuan Earthquake

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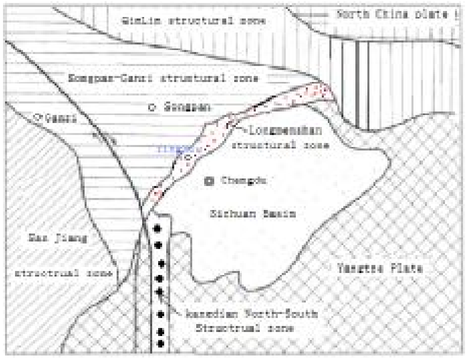
Abstract

On May 12, 2008, a devastating earthquake in Wenchuan County, Sichuan Province, China (latitudinal 31.00N, longitude 103.40E) invaded the most of the China, except North-eastern Provinces, and brought about near 90,000 deaths and about 700 billion dollars of direct economic losses. This earthquake impacted all lifelines in a huge area. This paper provides many records of observed damage to lifeline systems by site investigation. The seismic performances related to transportation, electric power, and water-supply in urban area and telecommunications systems were described in details in this paper. Occurring in a mountainous region, this earthquake severely damaged the transportation system and electric power because of strong earthquake motion, near the active faults, trigged landslides and debris, rock and soil collapses, and large ground deformation. Buried water-pipelines were mainly damaged due to the active faults, ground fissure and large ground subsidence. Dams and reservoirs in hydro-electric system and water-supply system were also damaged due to the strong earthquake motion, active fault, debris and landslide. Telecommunications system was damaged due to not only physical damages of equipments and buildings, but also the shortage of the electric powers. Some valuable measures for resisting strong earthquake motion, secondary earthquake-induced geological disaster and lessons learned for damage prevention and system recovery to lifeline system were also discussed in the end.

Keywords: Lifeline System, Earthquake Damage Characteristics, Seismic Performance Assessment, 8.0 Sichuan Earthquake

1 Introduction

The Sichuan Earthquake took place along the Longmenshan thrust active fault belt, formed by the Eastern Tibetan Plateau pushing against the Sichuan Basin causing an Ms 8.0 earthquake , which the epicenter located in north latitude 31.0° and east longitude 103.4, was 100 km north-west of Chengdu metropolitan(Fig.1). According to the site investigation, the rupture length trigged by this earthquake was about 300 km; three main faults broke the ground surface at many places with the maximum vertical offsets of up to 6.17 meters. This powerful earthquake killed over 90,000 people, toppling a great deal of buildings and almost all of lifeline system failure or malfunction in high seismic intensity near epicenter area. Almost the entire country except north-east of China felt this earthquake. The direct economic loss in this earthquake is 692.11 billion Yuan, which is 2.81 percent of China GDP in 2007[1]. The earthquake source depth is approximately 16~19 Km beneath the earth surface. There were three important faults trending southwest-northeast (SW-NE) running through the meizoseismal area, respectively named Maoxian-Wenchuan fault, Yingxiu-Beichuan fault and Guanxian-Anxian fault from west to east (Fig.2)[2,6]. The major seismic fault is Yingxiu-Beichuan fault (also called Central Fault), where a 300 km seismic ground rupture zones extend along this fault from west-south (SW) to north-east (NE). The ground ruptures show that this major seismic fault was a reverse-thrust fault with a 70° dips toward the west. The rupture velocity was up to 3.5km/s, horizontal and vertical displacements are 2.5~3.0 m and 3.0~5.0 m respectively. Ground motion in this earthquake may be characterized as high accelerations, large velocity pulse and a great number of geotechnical disasters. The nature of ground strong motion was related to the direction and mechanics of the fault rupture as well as landform and the path of the seismic wave to the site. Fig.2 clearly pointed out that the main shock and aftershock were concentrated to distribute along the central fault. Typical geological disasters were also found to distribute along this fault.



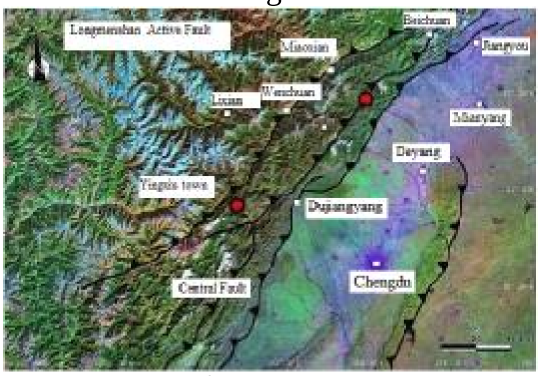


Fig.1. Geological tectonic map in Chengdu Basin   Fig.2. main faults in Wenchuan earthquake

According to the strong earthquake observation report of the Chinese Earthquake Administration(CAE), there were 1,160 main shock records and 3,000 aftershock records to be collected, the maximum horizontal peak ground acceleration is 957.8cm/s2 (gal), which was recorded in Wolong station, 19km from epicenter and 19km from the central fault. The maximum vertical peak ground acceleration is 948.1 cm/s2 (gal), which was also recorded in Wolong station [3].

This paper delineated the earthquake damage characteristics to lifeline system, and analyzed the relationship between lifeline systems and geological disasters in severe earthquake damage area. Three major parts are included in this paper: 1) earthquake damage characteristics of four main lifeline systems, such as the power system, transportations, water-supply and telecommunications system, and 2) relationship between important geotechnical disasters and major lifelines damage. 3) Lessons learned for damage prevention and system recovery to lifeline system.

2 Seismic Performance of Lifeline System in meizoseismal area

In this earthquake, lifeline systems are severely damaged. This paper presents seismic performance of four main lifeline systems, transportation, power-supply system, telecommunication system and water-supply system.

2.1 Transportation System

There are 19 expressways, 159 national and state highways, and 7,605 backloads to be damaged, which are 53,288 km long (Fig. 2). 5,560 bridges, and 110 tunnels are damaged in different degree, the total economic loss is up to 65.3 billions Yuan. In epicenter, all lifeline systems immediately lost their functions after earthquake; only few of them recovered emergency function one week later, most of them could provide limited services after three weeks. Geotechnical disasters were the major factors to damage these lifeline systems, where landslides caused damage to many highway and railway lines, and heavy rains following this earthquake and a large number of aftershocks made matters worse. Highway was mainly interrupted by rock collapse, landside and debris. Tunnels were damaged by active fault and falling rock. Inside of tunnel, the ground was lifted up and become uneven due to fault rupture; their entrances were covered by rock collapse or landside. Many miles of retaining structures were also damaged due to strong motion and slope failure.

(a) Tunnel entrance is covered by rock landslide (b, c) traffic is blocked by falling rocks

d) Failure of highway foundation (e) damaged railing track (f) carriage off the track

Fig.2. geotechnical disasters and transportation system

According to site investigation, 90 percent of traffic interruption in meizoseismal area was attributed to landslide, debris, falling rock and uneven foundation subsidence and ground rupture. Four highways to Yingxiu town are completely interrupted due to heavy landslides and debris. In Hongkou and Xiaoyudong, several bridges were damaged duo to large ground displacement or deformation related to fault motions. A railway system for coal transportation was found to be damaged due to foundation slope failure (Fig. 2, e, f).

Although most of bridge subsystem are intact or slight damaged, but some important bridges are also severely damaged in this earthquake because they were not adequately designed for earthquakes, resulting in the loss of many river crossings. (Table 1, 2), which made the emergency rescuing very difficult. The fault and near-fault strong motion, and geotechnical disaster trigged by fault motion were three of the important factors. The typical damaged bridges in details are shown in Fig.3.

Table 1: Bridge and its damaged index

Road Classification	Total number of bridges	Damaged index				Bridge in building (%)
		Intact /slight damage (%)	Medium damage (%)	Heavy damage (%)	Collapsed damage (%)	
Express ways	576	91.49	5.21	2.6	0.35	0.35
National highway	1081	78.71	11.01	8.78	1.48	0.56

Table 2: Bridge patterns and its damaged index

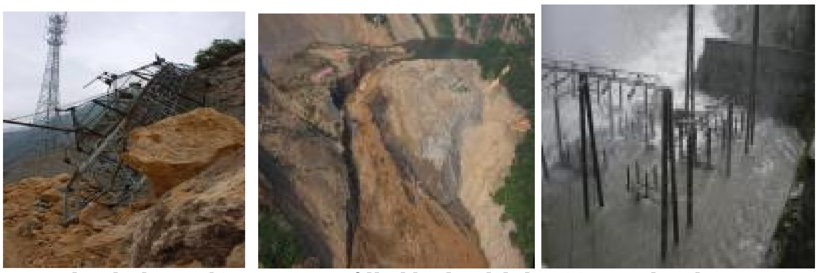
Bridge patterns	Total number of bridges	Damaged index			
		Intact /slight damage (%)	Medium damage (%)	Heavy damage (%)	Collapsed damage (%)
Simply beam bridge	1337	82.87	9.35	7.03	0.75
Arch bridge	286	87.75	7.00	4.20	1.05
Continuous beam concrete bridge	33	72.73	12.12	9.09	6.06
Continuous steel structure bridge	1	0	0	0	100

a) Jianjianghe Bridge　　b) Xiaoyudong Bridge　　c) Baihua Bridge

Fig.3. typical earthquake damaged bridges [7]

2.2 Power-supply System

Power systems were damaged due to pulse velocity near fault, landslide and rock collapse. In Yinxiu town, a hydro-power station was buried by debris. There were many high-volt electric poles installed in slope to tilt down because of slope failures of foundations (Fig. 4, a). There are 470 hydropower stations to be affected in this earthquake, and parts of them completely lost their functions because of landslide and debris to be full of the entire reservoirs’ volumes or split and subsidence of dams (Fig. 4 b). Some Power transmission equipments were inundated and dam was overtopped because of barrier lakes formed by landslides, landslide or collapse (Fig. 4 c).



(a) electric-pole tilt down (b) reservoirs filled by landslides (c) inundated power equipments
Fig.4. Power supply system typical earthquake damage

2.3 Water-supply System

Two types of water-supply systems were run in this earthquake affected area. In the major cities, water was supplied by water factories that were owned by the government, but independently operated; this system often serves a large area and consisted of reservoirs and pipeline network system. In the countryside and remote areas, water sources were mostly spring water and the wells. The wells and spring water supply systems were either operated by townships or village governments, or by a group of homeowners, but without pipeline system. Water supply system was also severely damaged. 1,803 reservoirs were damaged in different levels, among them, 379 dams were severely damaged or in big dangerous (Fig.5). In meizoseismal area, the shortest duration of water-supply interruption lasted two days. In Dujiangyan city, 67km of 138km main pipeline with the diameter of 100 mm were damaged. In the Chengdu Metropolitan area, water facilities were damaged in many locations, but the water service in small townships and villages in the rural areas were more severely impacted by the earthquake. It was reported that a water shortage affecting about 690,000 people after the earthquake in the Chengdu metropolitan area.

Fig.5. damaged water supply system

The Chinese Earthquake Administration estimated that 18,000 miles of buried water pipelines were subjected to reasonably strong ground motions due to the PGA 0.10g or higher. About 14,000 miles of pipelines had restored water service after 20 days of the main earthquake. The out of service and extensive damage to buried pipes was mostly due to landslide, strong ground shaking, differential movement at bridge abutments, fault, housing collapse, lack of manpower and parts to perform repairs, and water treatment plants out of service due to structural damage and water pollution.

2.4 Telecommunication System

The telecommunication system was also damaged. In Sichuan, Gansu and Shanxi provinces, there were 3,897 telecommunication offices, 29,064 cell phone stations and 28765 km long line to be damaged. There were 142,078 telecommunication poles broken or collapsed due strong earthquake motion, landslide and debris. Telecommunication building, equips and apparatus was found to be damaged by falling rock and landslide in Yingxiu town (Fig.6). The backup systems for emergency response were buried by landslide, debris and collapsed building. The entire telecommunication systems including cable system, mobile system, and satellite systems, lost their performance at once when this earthquake took place. In Urban area of Beichuan, the telecommunication system was limitedly set up after its 25 hours break by satellite system. Normal network call volume typically increased immediately after earthquake that created the perception of telecommunication failure. In Deyang, the volume of daily busy hour calls increased 3 times its norm 500,000 calls. However, in both landline and cellular services, there were equipment building, tower and equipment failures in large cities as well as rural areas. Most of the cell site buildings were unreinforced masonry and the equipment was not anchored. Coupled with building and equipment failure was the long duration of power loss. The batteries in the cell sites usually lasted two to three hours. Cellular service disruption in some areas within the earthquake impacted region lasted more than 70 days. The mobile handsets depend on batteries to power the units. Usually these units when fully charged can last for a few days. With power outage in the earthquake impacted areas lasting as long as four the six weeks, even when the cell sites were repaired, he handsets did not function without power. In many communities, people with small gas power generators provided the people with free charging service. Landline service in large cities in the earthquake impacted region performed reasonably well with inter-city call disruption of about 2 to 3 days, while intra-city call disruption was in the order 4 to 5 hours due to call volume.

(a, b) Damaged unreinforced masonry and equipments (c) Satellite dish under the tower [C, 7]

Fig.6. damaged telecommunication system (About 2300 mobile stations were damaged)

The other lifeline systems, like medical rescuing and public security system, were also severely interrupted due to building severely damage, members' injured and killed, which the geotechnical disasters were one of the important factors, particularly in Yingxiu town & Beichuan urban area [8]

3 Earthquake Damage Characteristics & Seismic Performance of Lifeline System

It has been proven that the earthquake damage of lifeline systems was mainly contributed to the near-fault strong ground motion, active fault, trigged geotechnical disasters and interaction among lifeline systems.

3.1 Near-fault Strong Ground Motion

Based on the site investigation, typical damage characteristics to bridge were span collapsing, sliding between bearing and girder, shear key failure, damage of expansion joint, pounding of adjacent girders, and tilting and cracking of abutments. Almost all of the medium and severely damaged were near fault, where there are strong ground motion recorders. Table 3 illustrates two typical examples. It is obvious that the nearer the bridge located to the fault, the severer the bridge was damaged. This damage phenomenon is particularly obvious within 10 m in both side of fault. According to statistics of lifeline earthquake damage, this safety distance to the fault surface was about 300 meters.

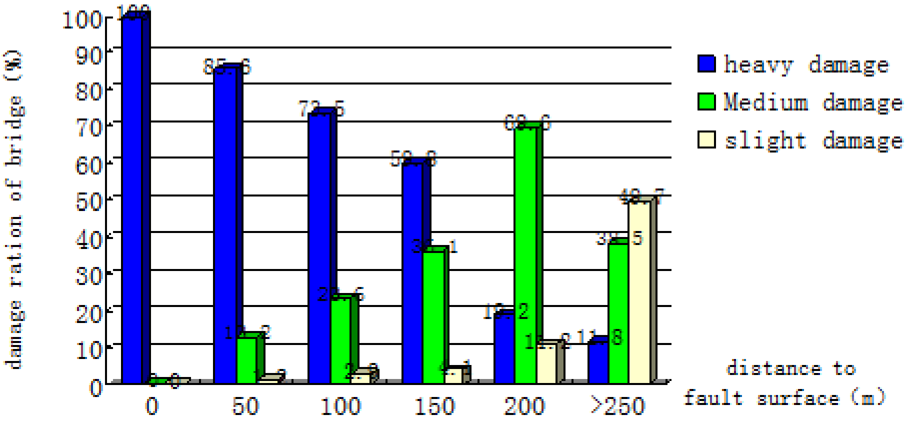


Fig. 7 the relationship of bridge damage to distance

Table 3: Near-fault strong ground motion recorders and bridge [3]

Name of bridge	Maximum ground acceleration /Gal			Distance from bridge to station/km	Name of Station
	Horizontal direction		Vertical direction		
	EW	NS			
Baihua Bridge (Bridge to epi. is 4.2 km, and to main fault is 0.6 km away)	956. 7236	652. 186	947. 1365	28	Wolong
	339. 7329	342. 3814	379. 5771	54. 6	Taoping, Li county
	581. 5923	556. 1694	633. 0923	51. 8	Bajiao, Shifang town
	120. 515	142. 2059	99. 1222	44. 8	Zoushishan, Pi county
	127. 6421	135. 108	82. 6923	47. 6	Yinpintai,Dayi county
Jianjianghe Bridge (Bridge to epi. is 121.8 km, and to one branch of main fault is 50 m away)	203. 4545	289. 5394	179. 9261	40. 6	Tashui, Anxian
	802. 713	824. 1283	622. 9108	43. 4	Qingping, Mianzhu
	458. 6844	511. 3325	198. 2779	28	Jiangyou town
	350. 1356	519. 4967	444. 331	15. 4	Hanzeng, Jiangyou
	278. 9646	297. 187	180. 4879	50. 4	Chonghua, Jiangyou

There were same damaged phenomena in all of the damaged bridges near fault: 1) the girder rotated in horizon, so, the protection to anti-falling of deck was damaged. The rotation direction was clockwise, in accordance with the fault rupture direction ((Fig.8, right-lateral strike fault). 2) The girder took place the snake-deformation in horizontal direction and waving of deck in vertical direction, which meant wave propagation effect (Fig.9 a). 3) Obvious pressure deformation in axial direction of these bridges, which meant pulse-like motion which exposed the structure to high input energy (Fig.9, b, c).

Fig. 8. Mingjiang Bridge in Yingxiu town (clockwise rotation)

Fig.9. Jianjianhe bridge in Beichuan City(a,b) and Gaoyuan bridge in Hongkou town (c)

3. 2 Trigged Geotechnical Disaster

A great number of Geotechnical disasters were trigged in this earthquake. According to the report of China Earthquake Administration (CEA), there were about 20,000 landslides in this earthquake.[4] The largest landslide was Daguangbao landslide[5], which was 0.75~1.1 billion m3 (2,800 m long,1,700 to 2,200m wide, and 200m in average thickness, and 690 m in maximum thickness). The transportation system was interrupted by landslide, debris and collapsed rock and soil, and barried lakes, which were formed by these geotechnical disasters. In Yingxiu town and Beichuan city, most of buildings were severely damaged by landslides, collapsed rock and soil; equipments and apparatuses belonging to lifeline systems were buried and damaged due to these trigged geotechnical disasters too. During the procedure of rescuing and post-earthquake rehabilitation, the transportation system was interrupted by landslides, debris, and collapsing rock and soil, it is these geotechnical disasters that made the emergency response difficult. Until two months after earthquake, the frequency of landslide and debris was still higher than that of earthquake invading ago. A great number of geotechnical disasters, particular landslide, debris and collapsed rock and soil were the most important factor to bring such a terrible destructive disaster. At present, details slope failure mechanism and risk zonation were still going on along the main fault zone.

3. 3 Interaction among Lifeline Systems

Another outstanding damage characteristic of lifeline systems in this earthquake was interactions among lifeline systems. For example, malfunction of water-supply and telecommunication system in Dujiangyan city(XI) was mainly induced by damage and failure of power system. Most of the damaged element in water-supply system were repaired after 24 hours, but the water-supply completely lost its performance for 49 hours due to shortage of electric-supply, and telecommunication system only recovered its 50 percent of full function after 5 days although most of facilities in this system were intact, its backup system of power system worked only 5 hours every day before the power system recovery. Because of transportation interruption, the equipment and apparatus, energy and rescuing team could not be distributed to the demanders in time. In Hangwan town, a new temporary pipeline system for water-supply had to be built up by use of gravitation flow theory because the power system was cut off, and this pipeline system kept its service for two months until the electric power was recovered 50 percent.

4 lessons learned for damage prevention and system recovery to lifeline system

Lifeline system damage was the key factor to have little rescuing powers and materials to be sent to some heavy earthquake damage area within the golden 72 hours. The lessons learned from Sichuan earthquake on the performance of the lifeline system include the following:

- Lifeline system should be considered to resist geological disasters, particular in mountainous area. In this earthquake, there was significant damage to lifeline system where they cross zones subject to landslide and active fault zone. For example, repairs to pipelines at landslide and fault zones generally require installing entire lengths of new pipe. Transportations and water utilities should prepare suitable geology maps that identify lifeline system that traverse zones subject to landslide and fault rupture. Lifeline system should avoid traversing high landslide risk zones and active fault if possible.
- The facilities and all structures related to lifeline system should have designed to reasonable seismic standards, like building, bridge, tanks, tower and dam, etc. Unreinforced masonry infill walls did not perform well and were not acceptable, but most of engineered reinforced concrete structures performed well in this earthquake.
- Non-engineered unreinforced masonry structures performed poorly, with a large number of collapses.
- Dislocations of a large number of people from their houses due to structural damage leads to a large effort to establish temporary housing centers and supporting temporary lifeline systems. Temporary lifeline systems consisted initially of power system, truck and subsequently with above ground pipes and line tec. Performance of the temporary lifeline system should need to be monitored.
- A secured telecommunication and transportation system were very important in cities as well as rural communities. The service providers should initiate a plan of actions to reduce repeated disruption and economic losses. Dispersed network redundancy in the rural areas would be an excellent option to prevent communities from total telecommunication and transportation isolation. The service providers and governments should do their best to upgrade telecommunication and transportation network components, such as bridge, tunnel, equipment building, towers, transmission and distribution network, equipment anchorage, backup power generators, increase backup battery duration, and concentration.

5 Conclusions

In this earthquake, it has been proven again that the geotechnical disasters including these earthquake faults are the biggest hazard and risk to lifeline systems. So, the aseismic design for lifeline systems can’t focus on only improving anti-seismic abilities of their components under strong seismic wave propagation, but also reliable selection of building environments. Due to interaction among lifeline systems, network conception and its optimization should be emphasized on design of the lifeline systems.

Acknowledges

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