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Impact of intensity and loss assessment following the great Wenchuan Earthquake

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Abstract: The great Wenchuan Earthquake occurred on May 12, 2008 in the Sichuan Province of China, and had a magnitude of 8.0. It is the most serious earthquake disaster in China since the great Tangshan Earthquake (M_s=7.8, July 28, 1976). According to official reports, there were 69,225 deaths, 379,640 injuries and 17,939 missing as of Aug. 11, 2008. The China Earthquake Administration quickly sent hundreds of experts to the field immediately after the event, to investigate the damage and assess the economic losses. This paper emphasizes the impact of seismic intensity and presents a preliminary loss assessment. A brief description of the geological features of the affected region is provided, followed by a summary of the earthquake damage. An isoseismal map is developed that shows that the high intensity region is distributed like a belt around the seimogenic fault, and that the epicentral intensity reached XI (Chinese Intensity Scale, similar to the Modified Mercalli Scale). The direct economic loss resulting from the earthquake is 692 billions RMB (about 100 billions US$).

Keywords: Wenchuan Earthquake; isoseismal map; earthquake intensity; earthquake damage; direct loss

1 Introduction

On May 12, 2008 at 14:28:01, a very large earthquake with a magnitude M_s=8.0 occurred in Wenchuan, in the Sichuan Province of China. The epicenter was located at 31.0°N, 103.4°E and the source depth was 14km. A large part of Sichuan and parts of the Gansu, Shaanxi, Chongqing, Yunnan, and Ningxia Provinces/Municipality/Autonomous Region, and even Vietnam, were affected.

This paper discusses the seismic intensity and presents a preliminary assessment of the losses caused by this earthquake. Some features of damage are summarized to gain a better understanding of the basis of the isoseismal map, and the geological features of the earthquake-affected area are briefly introduced. The isoseismal map of the earthquake is developed based on the field investigation of over 1,000 locations performed by hundreds of experts from the China Earthquake Administration. Casualties caused by the earthquake are briefly discussed. Direct economic loss resulting from this earthquake is assessed based on the damage investigation of hundreds of towns and/or villages.

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2 Geological features

Figure 1 shows the geographic features of the Sichuan Province and surrounding region, where more than half of the land is mountains and the rest is a basin that includes hilly land. These topographic features may affect the damage distribution in low intensity regions. Note that the epicenter (the origin of the fault rupture) and the seismogenic fault (Longmenshan fault) of this earthquake are located at the boundary between the mountains and the basin.

Figure 2 shows the seismogenic faults, the Longmenshan fault belt, and historical earthquake distribution. The Longmenshan fault belt consists of three parallel sub-faults: the front fault, the central fault and the back fault. In this earthquake, the central fault and part of the front fault ruptured. Ground rupture of these two faults (see in Fig.2) was discovered during the geological field survey, with the central fault having a length of about 200 km and the front having a length of about 50 km. For example, Fig.3 shows the strong dip thrust with a vertical component of 4.7 m at the ground surface. Extremely strong reverse thrust and right-lateral movement of the faults caused landslides and rockfalls over a large area, which had a significant effect on the shape of the most severely damaged region.

. Figure 4 shows the distribution of the aftershocks over a 300 km length. The trend of aftershock distributions seems to be the same as the fault, with a little expansion in the south.

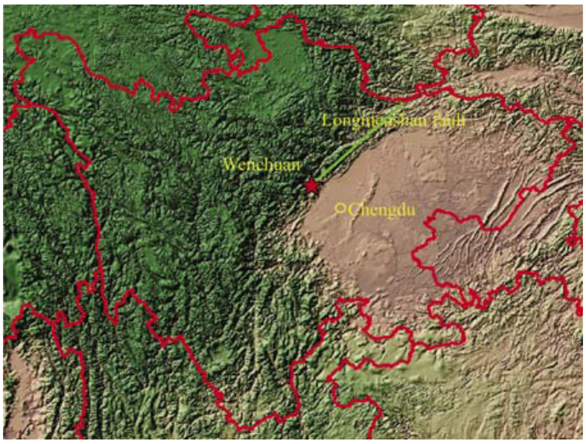

Fig. 1 Geographic features of Sichuan Province, China. The epicenter and fault located at the boundary between mountains and basin

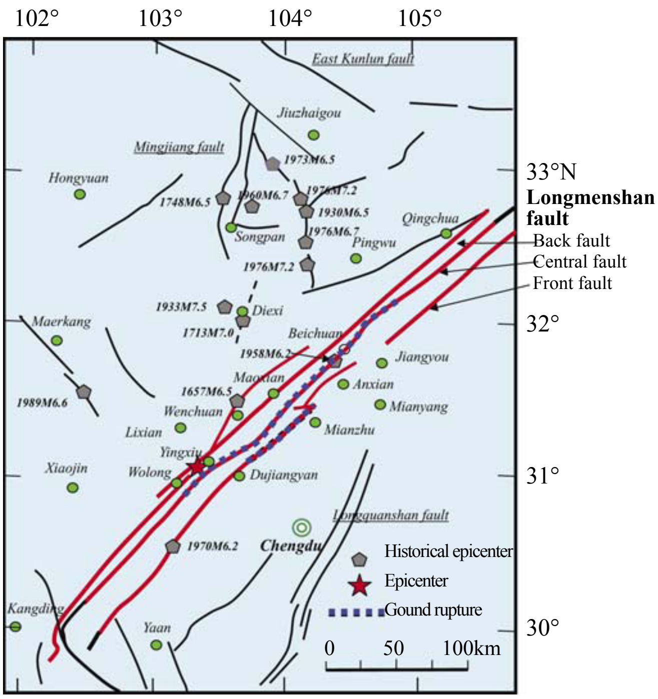

Fig. 2 Faults and historical earthquake distribution near the Longmenshan fault, and ground ruptures of seismogenic fault with a length of about 200 km for the central Longmenshan fault and 50 km for the front fault observed in the Wenchuan Earthquake

3 Earthquake damage

To achieve a better understanding of the basis of the isoseismal map and to perform a loss assessment following the great Wenchuan Earthquake, some features of the damage are summarized in this section.

(1) Fault dislocation induced building damage

Figure 5 shows buildings near the bank of the

Fig. 3 A big vertical dislocation of 4.7m in Hongkou Town, showing strong thrust movement of the Longmenshan fault

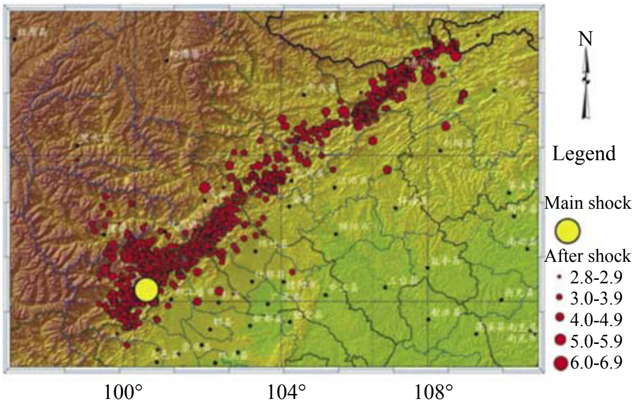

Fig. 4 Aftershock distribution of the Wenchuan Earthquake

Jianjiang River in Beichuan County town that were destroyed by the fault displacement.

(2) Severe geological disasters

Unlike the Tangshan and most other devastating earthquakes, the earthquake in Wenchuan resulted in massive geological disasters since it occurred in a mountainous area, which in turn caused geological hazards such as landslides and rockfalls, etc.

Figure 6 shows a large landslide that blocked a road and a destroyed building in the disaster area.

Figure 7 shows a huge landslide that buried an entire village, causing many casualties, and Figure 8 shows a landslide that damaged a railway, sealed a tunnel and caused a fire on an oil train.

Many buildings and bridges were damaged by large ground displacement that was induced by landslides and fault movements.

(3) Rockfalls occurred in many places, even in areas far from the epicenter, resulting in damage to building, houses and cars, in addition to many casualties (Fig.9).

(4) The earthquake devastated the economic corridor of Sichuan Province, including Mianyang, Deyang,

Fig. 5 Building collapse and river bank damage caused by fault dislocation in Beichuan County town

Fig. 6 Landslide buried road and building in Wenchuan County

Fig. 7 Landslide buried village and killed people in Beichuan County

Fig. 8 Landslide damaged railway, sealed tunnel and caused fire of oil train

Fig. 9 A big rolling rock killed 2 people and stopped at the front of a shop in Anxian Town

Fig. 10 Damaged factory building of Dongfang Steam Turbine Works in Hanwang Town

Guangyuan, and Dujiangyan cities, where many well-known businesses in China are located. Many large factories suffered severe damage (Fig.10) and had to relocate. Significant losses, including direct and indirect loss, resulted from damage to industrial buildings and equipments.

(5) Infrastructure suffered more severe damage in this earthquake than in any other historical earthquake in China. Many electric supply systems were damaged and make big troubles to the others, such as water supply, communication system, etc. The damage to roads and collapse of bridges interrupted or blocked emergency rescue and disaster relief operations.

4 Isoseismal map

Figure 11 shows the distribution of the surveyed towns and villages and the locations of geological disasters. The evaluation of the building damage given in this paper is based on about the same of the investigated locations shown in the figure.

Based on the field investigation and the China Seismic Intensity Scale (1999), which is similar to the Modified Mercalli Scale, the isoseismal map of the great Wenchuan Earthquake is developed and shown in Fig. 12.

This map shows the following:

(1) The epicentral intensity reached XI. There are two extremely impacted areas: one in Yingxiu Town of Wenchuan County and the other in Beichuan County Town, where most buildings totally collapsed or were severely damaged, and a large scale landslide occurred. Note that part of the building damage was caused by the resulting geological disaster combined with severe ground shaking.

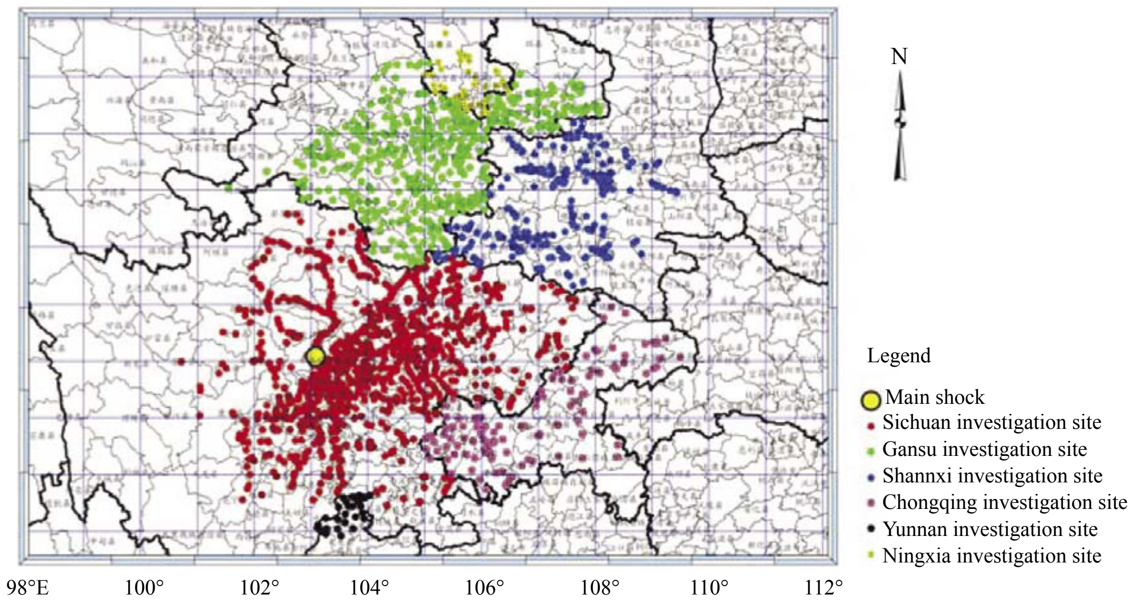

Fig.11 Field investigation location distribution during the Wenchuan Earthquake

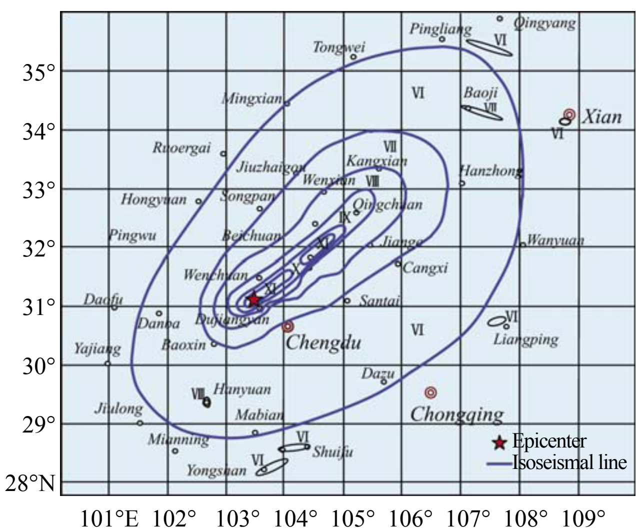

Fig. 12 Isoseismal map of the great Wenchuan Earthquake

(2) The area with intensity larger than IX is in a narrow belt around the seismogenic fault. In the southeast, the isoseismal curve expands towards the east due to the severe damage caused by the front fault movement.

(3) Intensity attenuates quickly from the mountains to the basin. It may be explained that in high intensity area geological disaster triggered by earthquake, such as large ground displacement, landslide, rockfalls, etc. caused severe damage. However, the damage is limited to a narrow belt. Damage to buildings would not be as severe if the geological disaster did not occur.

(4) It seems that in the north, the areas of intensity of IX, VIII and VII are larger than in the south. In fact, detailed analysis of the fault mechanism indicates that the rupture during the main shock started from the southwestern end of the fault and propagated toward the northeastern end.

(5) The area of intensity VI is broad, evaluated according to the damage to old countryside houses, which have very low seismic resistance. However, some abnormal attenuations of the damage to buildings and houses were observed in many places, which may be due to the complex local site conditions.

(6) A large area with abnormally high intensity is Hanyuan County, located more than 150 km away from the fault where the shaking intensity reached VIII, in contrast to the intensity VI of its surrounding area.

5 Casualties

According to an official report from the Chinese government, the great Wenchuan Earthquake caused 69,225 deaths and 379,640 injuries with 17,939 missing, as of Aug. 11, 2008. The central and local government provided 64.4 billion RMB for emergency disaster relief and received 59.3 billion RMB in donations. Figure 13 shows the distribution of casualties in Sichuan and its adjecent provinces that were severely impacted by the earthquake.

Collapse of buildings and houses was the major cause of casualties, particularly the collapse of public buildings, such as schools, hospitals, office buildings, shops, etc. For example, in Dujiangyan City, there were 990 deaths in schools and 345 in hospitals. The corresponding ratios to the 3,075 casualties in the city are 32.2% and 11.2%, respectively. This means that public buildings, especially schools, should be constructed to have sufficiently high seismic resistance. This is a significant finding for developing countries. In addition to the severe ground shaking and fault rupture, there are some other factors in the Wenchuan Earthquake that caused serious casualties, such as landslides that buried villages, and falling rocks that hit houses, cars and trucks (see Fig.14). Some of these disasters occurred far from the epicenter, where rockfalls were the main cause of casualties.

6 Economic losses

Building losses comprise the greatest portion of the total direct economic loss caused by earthquakes, and was about 60% for the Kobe earthquake and 70%-80% for Chinese mainland earthquakes in the past. Accordingly, building loss assessment is concerned mostly with the Standardization Administration of China, post-earthquake field works, Part 4: Assessment of airect loss (GB/T18208-2005). To carry out a loss assessment following the Wenchuan earthquake, the entire impacted region was divided into four subregions based on the isoseismal map. The damaged buildings in each subregion were classified into five grades, i.e., intact, slight, moderate and heavy damage, and collapse, by the Field Investigation Team of China Earthquake Administration (2008).

The direct economic loss of buildings for each subregion is evaluated by Eqs. (1).

$$L_{\mathrm{f}}^{i}(s)=\sum_{j=1}^{5} A_S\cdot\lambda_S(j)\cdot\eta_S(j)\cdot P_S \qquad (1)$$

where $L_f^i(S)$ — the direct loss of buildings of the s-th structure type in the i-th subregion, hereafter the superscript i is omitted, unless stated otherwise.

A_S — the total area of the s-th structure type

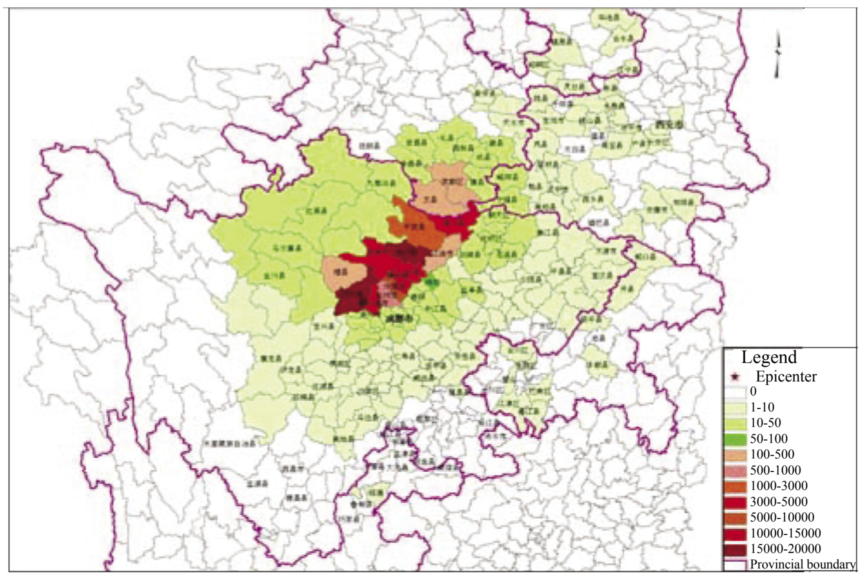

Fig. 13 Death distribution in the great Wenchuan Earthquake

Fig. 14 Rolling rocks hit houses, cars, and buses, killed people

$\lambda_S(j)$— the damage ratio of the j-th damage grade in the s-th structure type, defined as the ratio of the damage grade j in the damaged area to the total area of the s-th structure type

$\eta_S(j)$ — the loss ratio of the j-th damage grade in the s-th structure type,

P_S — replacement price in unit area of the s-th structure type

Summing up the losses of all types of buildings in all subregions yields the total direct loss of buildings in an earthquake:

$$L_{\mathrm{T}} = \sum_{i=1}^{M} \sum_{s=1}^{N} L_f^i(s) \quad (2)$$

where L_{T} is the total losses of buildings, N is the number of the structure types in each subregion and M is the number of the investigated subregions involved in the loss assessment; in this case N= M=4.

The loss ratio is defined as the ratio of the repair cost to the replacement cost depending on the damage grade. The damage grade can be selected from Table 1, which was generated from the results of an investigation of building construction in China.

Another important factor is the damage ratio, which is defined as the ratio of the area of the damaged building in an area to the total area of buildings in that area for a given building type. In fact, the damage ratio is an element of the vulnerability matrix. Each structure type has its own damage matrix. Before an earthquake occurs, this matrix is generated from seismic response analysis or damage data from past earthquakes. After an actual earthquake, the matrix can be developed by field investigation. Sample inspection is regularly performed in affected regions, since it is impossible to inspect all buildings during a short time period. In order to ensure that the sampled buildings represent the extent of the actual damage when taking subjective sampling, the samples must be carefully selected. Enough sample villages should be investigated and these sample villages should be distributed as uniformly as possible in countryside. In a city many blocks are then selected as samples, and at least 10%-20% of the total buildings should be investigated.

The assessment of indoor property losses can be performed in the same way as described above, by replacing the "structure" with "property" in Eqs. (1) and (2) and all related notations.

The same idea can be applied to assess direct losses to lifeline systems and other facilities, but there is no unified standard to classify damage grade, loss ratio, or damage matrix. Usually, losses to lifeline systems and large enterprises are assessed on an individual basis.

The results of the assessed direct economic losses caused by the earthquake are presented in Table 2, and the direct economic loss (100 million RMB) of the affected Provinces/Autonomous. Regions and ratios (%) to the provincial or country GDP are given in Table 3.

Table 1 Loss ratios of damaged building of different damage grade %

Building type	Intact	Slight	Moderate	Heavy	Destroyed
RC frame and masonry	0-5	6-10	11-40	41-80	81-100
Mill building	0-4	5-8	9 -35	36-70	71-100
Traditional residence	0-4	5-8	9 -30	31-60	61-100

7 Concluding remarks

Based on the China Earthquake Administration's field investigations conducted at over 1,000 locations, an isoseismal map of the great Wenchuan Earthquake is developed in this paper. Casualties caused by the earthquake are briefly discussed. Direct economic losses resulting from this earthquake are assessed by using data obtained from the field investigation. The following features are observed:

(1) The isoseismal map shows that the area with intensity greater than IX forms a belt along the seismogenic fault. Its complexity is due to the building damage caused by the strong ground motions near the fault and ground failure, including fault dislocations and landslides, etc.

Table 2 Summary of direct economic loss (unit: 100 million RMB, about 15 million US$)

Series	Loss item	Sichuan	Gansu	Shannxi	Chongqing	Yunnan	Ningxia	Total
1	Countryside houses	1,624.23	230.54	145.27	38.96	12.40	0.83	2,126.90
	City buildings	74.67				----	-----	
	Indoor property	307.52	16.92	1.05	0.05	0.03	-----	325.57
	Outdoor property	37.94	0.53	1.04	----	-----	-----	39.51
	Sum	**2,044.36**	**247.99**	**147.36**	**39.01**	**12.43**	**0.83**	**2,491.98**
2	Road system	580.00	56.58	11.17	0.70	1.59	----	650.04
	Railway system	194.85	----	-----	-----	-----	------	194.85
	Aviation	1.87	----	-----	-----	-----	----	1.87
	Communication	59.09	5.67	3.86	0.31	0.04	------	68.97
	Electric supply	86.13	16.05	3.37	0.98	0.09	----	106.62
	Broadcast	19.85	2.04	0.62	0.12	0.04	----	22.67
	Municipal system	168.05	8.08	1.22	0.73	0.20	------	178.28
	Dam and irrigation system	248.35	14.63	6.82	6.08	0.69	----	276.57
	Sum	**1,358.19**	**103.06**	**27.06**	**8.92**	**2.64**	------	**1,499.86**
3	Medical system	73.75	7.62	3.37	0.48	0.07		85.29
	Education system	209.67	35.19	15.23	2.57	0.49	----	263.14
	Forestry	210.05	13.30	6.65	----	-----	------	230.00
	Livestock	123.71	6.64	2.95	0.60	0.12	----	134.01
	Agriculture	168.20	1.50	1.95	0.10	0.33	------	172.08
	Fishing	14.40	0.31	0.36	0.35	0.10	----	15.52
	Reclaim	4.98	----	-----	----	-----	-----	4.98
	Agricultural machine	42.78	0.43	0.41	0.12	-----	-----	43.73
	Tourist trade	233.19	1.81	0.90	0.23	0.41	----	236.54
	Environment protection	16.32	1.13	0.75	0.07	0.13	------	18.40
	Cultural system	41.67	1.00	1.35	1.10	0.11	----	45.23
	Stock system	0.74	----	-----	-----	-----	------	0.74
	Grain system	49.00	----	-----	-----	-----	----	49.00
	Enterprises	1,223.40	22.70	19.80	0.67	-----	------	1,266.57
	Other public	362.89	0.12	0.01	0.01	0.00	---	363.03
	Sum	**2,774.74**	**91.76**	**53.72**	**6.30**	**1.75**	------	**2,928.27**
	Total	**6,177.29**	**442.80**	**228.14**	**54.23**	**16.82**	**0.83**	**6,920.11**

Table 3 Direct economic loss (100 million RMB) and ratio (%) to provincial or country GDP

Province/Autonomous Region	Loss	GDP	Ratio (Loss/Provincial GDP)	Ratio (Loss/Country GDP)
Sichuan	6,177.29	10,505.3	58.80	2.51
Gansu	442.8	2,699.2	16.40	0.18
Shaanxi	228.14	5,369.85	4.25	0.09
Chongqing	54.23	4,111.82	1.32	0.02
Yunnan	16.82	4,721.77	0.36	0.007
Ningxia	0.83	834.16	0.10	0.0003
Country		246,000	-----	2.81

(2) Intensity attenuates significantly from intensity XI to VIII in the boundary area between the mountains and the basin. It appears that the total area of intensity VIII and VII in the north is larger than in the south.

(3) Many casualties were caused by the collapse of buildings and houses. Designing these structures to be more seismically resistant is still the most important way to mitigate earthquake disasters. Public buildings, such as schools, hospitals and large shops, should be built to have sufficient seismic resistance to prevent collapse in a large earthquake. From a technical point of view, protecting these buildings from collapse can be achieved. In fact, it was observed that some well-designed and constructed buildings performed satisfactorily and did not collapse, even in areas of intensity as high as X.

(4) The estimated direct loss in this event is as high as 692 billion RMB (about 100 billion US$), which is about 2.81% of the GDP of China. The losses caused by the damage to buildings, infrastructure and other enterprises consists of about 36%, 22% and 18%, respectively, of the total direct economic loss.

(5) The economic loss assessment in this paper is restricted to direct economic loss. The assessment of indirect economic loss is very difficult and is not presented in this paper. It is expected that indirect economic loss will be comparable at least to or even larger than the direct economic loss.

Note that some of the most severely impacted regions are primarily composed of small and moderate cities, towns, and villages. The direct economic losses would be much higher if larger cities such as Chengdu were subjected to a greater intensity of ground shaking.

China will continue its substantial economic development, with the knowledge that it is impossible to predict earthquakes in the near future. By building new structures with life safety in mind, and minimizing the economic losses by ensuring quality in the design and construction phase, it is hoped that future disasters of this magnitude can be minimized. Meanwhile, it is needed to increase the seismic fortification target levels as continued progress is made.

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