Damage in the 2008 China Earthquake

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ABSTRACT:
An earthquake measuring 7.9 Richter scale occurred in Wenchuan on 12 May 2008, some 92km west of Chengdu, Sichuan Province, China.
A field investigation was conducted in regions with Modified Mercalli intensity ranging from MMI VI to XI in order to study the damage pattern. As Australia has a low to moderate level of seismicity, this paper presents the failure characteristic of reinforced concrete buildings for intensity MMI VI to VIII, which dominated by 1) precast construction collapse, 2) unreinforced masonry damage, 3) soft storey building, 4) damage on façade system, 5) reinforced concrete quality and detailing, 6) pounding between two adjacent structures.

KEYWORDS:
Earthquake damage, earthquake reconnaissance, reinforced concrete, unreinforced masonry, soft storey structures.

1. INTRODUCTION

A 7.9 magnitude Wenchuan earthquake (named after its epicentre in Wenchuan County) jolted Sichuan Province of China on 12 May 2008. Over 69,000 people were reported to have died, around 374,171 injured, 18,340 people missing, more than 15 million people were evacuated and an estimated five million people left without housing. Table 1 [2] shows the scale of damage from the Wenchuan earthquake.

A collaborative team from Swinburne University of Technology, University of Melbourne, and University of Hong Kong investigated building structure damage. The places chosen were Chengdu (MMI VI-VII), Dujiangyan (MMI VII-IX), Mianyang (MMI VII-VIII) and Ying Xiu (MMI XI) as shown in Figure 1.

Table 1: Infrastructure damage [2]

1	Collapsed Buildings	US$5.36 million
2	Damaged Buildings	US$21 million
3	Pipes	5,000 km
4	Water tanks	839
5	Water treatment works	1,281

The aim of this paper is to classify the damage based on the building types, modes of failure, the distance from the epicentre and the corresponding available ground motion parameters. Moreover, a comparison between the Wenchuan Earthquake and the characteristics of design

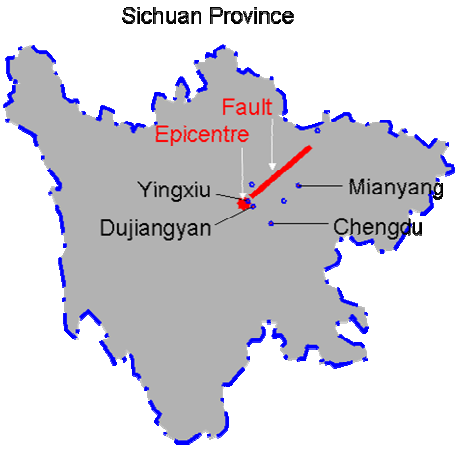


Figure 1. Map of Sichuan Province along with epicentre of earthquake and fault.

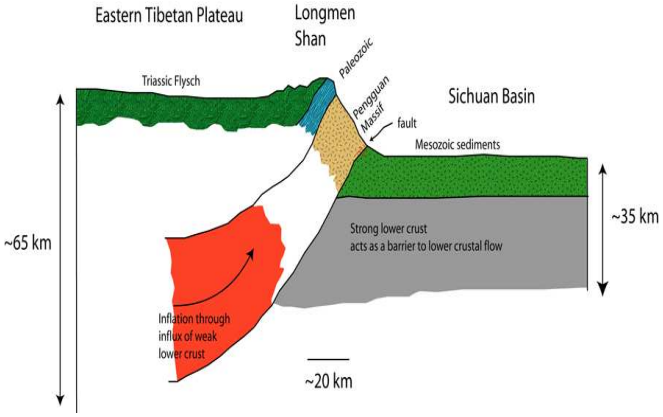


Figure 2. Movement of Eastern Tibetan Plateau against Sichuan Basin [6]

earthquakes in Australia is made to provide insight for the development of future design standards and for the assessment of existing buildings in Australia.

According to USGS (2008 [8]), the Wenchuan earthquake occurred as the result of motion on a northeast striking reverse fault or thrust fault on the north-western margin of the Sichuan Basin. The earthquake's epicentre and focal-mechanism are consistent with movement on the Longmenshan fault or a tectonically related fault. The earthquake reflects tectonic stresses resulting from the convergence of crustal material slowly moving from the high Tibetan Plateau, to the west, against strong crust underlying the Sichuan Basin and south-eastern China.

The colder and heavier oceanic lithosphere plate of the Sichuan Basin was subducted beneath the continental lithosphere plate of Tibetan plateau as shown in Figure 2 [6]. The resulting earthquake was quite shallow and hence the ground shaking more severe causing the massive damage reported and summarized in the form of a damage intensity plot shown in Figure 3 [8].

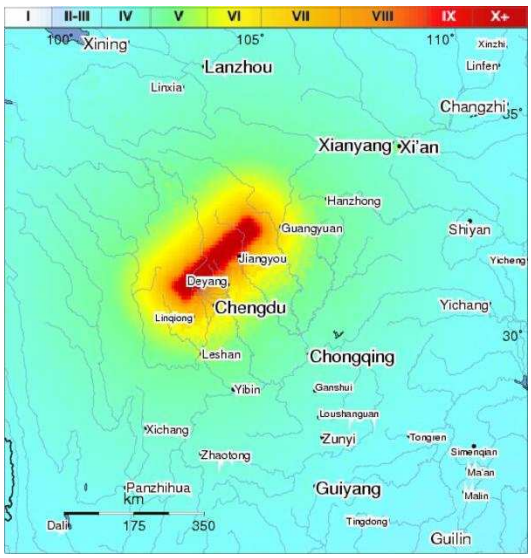


Figure 3. Wenchuan earthquake shaking intensity map [8]

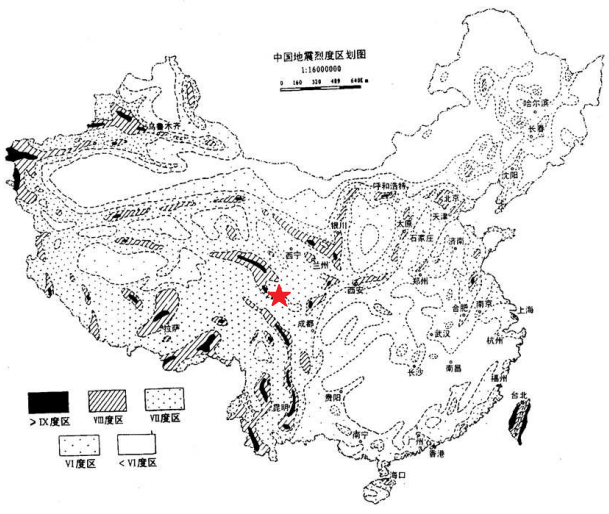


Figure 4. Chinese Seismic Intensity Zone, with location of Wenchuan earthquake epicentre [7]

2. SEISMIC PARAMETERS COMPARISON OF AUSTRALIAN SEISMICITY AND THE WENCHUAN EARTHQUAKE.

Australian earthquake is characterised by intraplate earthquakes associated with severe fault thrusting with magnitude typically no greater than Magnitude 7 with events of magnitude 5-6 more common [4,5]. The magnitude 7.9 Wenchuan earthquake subduction zone intraplate earthquake is very different in nature to Australian earthquakes. However at distance from the fault rupture, where the level of ground shaking (especially in terms of peak ground velocity or PGV and damage intensity measured on the Mercalli scale) is comparable with design level shaking in the Australian context. Many lessons can be learnt from studying the damage and non damage patterns, particularly since the Chinese building in the affected areas did not appear to have special seismic design detailing.

The Chinese Earthquake Code GB50011-2001 classifies the seismic regions of China into 12 zone of intensity. The code is applicable to buildings in intensity zones 6 to 9, whilst no seismic design is required in regions with intensity less than 6, and special design code required for intensity zones 10-12. The Wenchuan earthquake occurred in a region of design intensity 7.

The Australian Earthquake Loading Standard, AS1170.4-2007 [1] has a seismic hazard map in terms of a 'Z' coefficient (effective peak ground acceleration) for a 475 year return period. Values range from z=0.03–0.10 in the capital cities, with Canberra, Melbourne and Sydney characterized with z=0.08. The seismic coefficients can be approximately related to the PGV using the relationship that z=0.10 is equivalent to PGV=75 mm/s. Consequently the range of PGV values for design in Australia capital cities ranges from 25 mm/sec to 75 mm/sec on rock. Further, AS1170.4 provides guidance of converting the seismic coefficient to longer return periods, for example 1500 year return period is around 1.5 times greater than the design ground motion associated with 475 year return period. The PGV is approximately related to the Modified Mercalli Intensity (MMI) by the well known Newmark and Rosenblueth relationship [12]

$$\text{PGV (mm/sec)} = \tfrac{5}{7}\, 2^{\text{MMI}}$$

This relationship enables an approximate correlation between damage observed in Sichuan and design values in Australia, as shown in Table 2 for the cities of Chengdu, Mianyang, Dujiangyan and Ying Xiu. This intensity is determined according to the seismic intensity scale of China [10], which is similar to but not exactly the same as the MMI scale.
The seismicity of Chengdu is similar to a 500 year return period design earthquake on rock sites for major cities of Australia. Mianyang is similar to a 500 year return period design earthquake on soil sites. In contrast, Dujiangyan is similar to a 2500 year return period earthquake on deep soft soil site for Australia.

Table 2: Instrumental intensity, PGA, PGV and PGD for cities in China

Place	Dist. from the epicentre	Dist. From the fault	Intensity MMI	Z or PGA (g's) on rock sites	PGV from MMI (mm/s)	E-W	N-S	Z
Chengdu	80 km	80 km	VI-VII	0.06 – 0.12	45 - 91	110 gal 225 mm	90 gal 180 mm	55 gal 17 mm
Mianyang	145 km	60 km	VII - VIII	0.12 - 0.24	91 - 182	130 gal 225 mm	145 gal 115 mm	100 gal 5 mm
Dujiangyan	20 km	20 km	VII- IX	0.12 - 0.49	91 - 366	142 gal 700 mm	175 gal 500 mm	120 gal -70 mm
YingXiu	≈ 0 km	≈ 0 km	XI	1.46	1098	170 gal 1000 mm	205 gal 750 mm	155 gal -220 mm

The epicentre and damage area of Wenchuan earthquake was located in seismic zone VII as can be seen at Figure 4 [7]. But from the failure and collapse pattern, it seems that the earthquake intensity was much higher than what has been designed for that area. The ground motion intensity of Australia's most damaging earthquake, the Newcastle earthquake of 28 December 1989, is comparable to the intensity experienced in Chengdu and Mianyang from the Wenchuan earthquake.

3. DAMAGE TO REINFORCED CONCRETE BUILDINGS FROM THE WENCHUAN EARTHQUAKE

The collapse of buildings in the Wenchuan earthquake generally resulted from the combination of severe ground shaking, poor structural design, soft soil conditions and improper use of construction materials. It is clear that the buildings were not designed and built to resist severe earthquakes. Some examples of damage that occurred in Chengdu and Mianyang with intensity range MMI VI to MMI VIII are presented here for comparison with Australian conditions. The more severe damage intensity MMI VIII to MMI XI found in Dujiangyan and Ying Xiu are beyond the scope of this paper. However, some structural damage photos from Dujiangyan and Ying Xiu have been presented for comparison.

3.1. PRECAST CONSTRUCTION

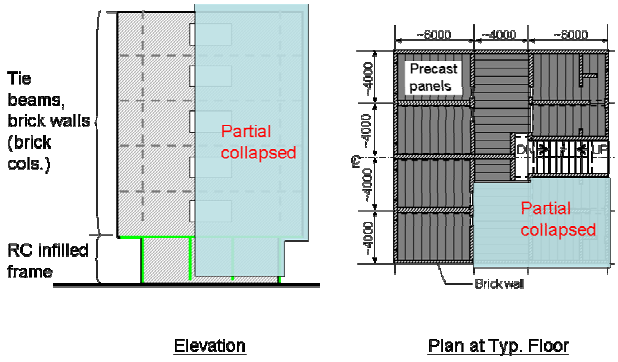


Figure 5. Schematic of precast slabs failure resulting in partial collapse of building

Damage appeared to be isolated to precast floor system which had not been properly connected to the vertical support elements, resulting in unseating of the slabs elements as shown in Figure 5 and 6. The slabs not only resist the gravity loads but provide overall structural stability through horizontal diaphragm action, hence failure of the slabs system will compromise the overall structural integrity of the building.

a) in Mianyang

b) in Dujiangyan.

Figure 6. Partial collapse of building with precast slabs floor

3.2. UNREINFORCED MASONRY

The common form of URM in the Sichuan region consisted of infill walls within reinforced concrete frame building, external building façades and separate chimney elements.
Within the cities of Chengdu and Mianyang, the main damage observed were the inplane cracking of infill walls as shown in Figure 7 and 8, the collapses of chimney and the sliding of unrestrained roof tiles as shown in Figure 9 and 10. The MMI scale explicitly reports chimney damage states with values of VI, VII and VIII associated with cracking, failure of weak chimney and widespread failure respectively.
Out of plane failure of external masonry façade wall was not observed in Chengdu or Mianyang. However, extreme failures were observed in the higher intensity regions of Dujiangyan and Ying Xiu, including the collapse of parapet walls at roof level.

Figure 7. Horizontal crack at the Sichuan University office in Chengdu.

Figure 8. Diagonal shear crack of one of the buildings in Mianyang.

Figure 9. A building in Chengdu with roof tile sliding.

Figure 10. Many old buildings at Sichuan University in Chengdu suffered from roof tile damage.

3.3 SOFT STOREY BUILDING

A Soft storey is characterized by one storey of the building being much weaker and more flexible than the adjoining stories. Consequently deformation and damage are concentrated at this level with the column that must resist the gravity loading also being forced to deform laterally. Subsequent failure of the column results in a soft storey collapse, which is one of the most common failures from severe earthquake ground shaking. Poor concrete quality and poor seismic detailing will further limit the drift capacity of columns and encourage soft storey

collapse. In the Chengdu and Mianyang region, no soft storey buildings were observed to have collapsed, whilst in Dujiangyan and Ying Xiu many buildings were significantly damaged with drifts up to 7.5% measured whilst other soft storey building collapsed as shown in Figure 11 to 16.

Figure 11. Soft first storey of 6-storeys building in Dujiangyan with drift about 7.5%

Figure 12. Plastic hinge failure at all first-storey columns of Figure 11.

Figure 13. Formation of plastic hinges at both ends of the columns shown in Figure 12.

Figure 14. Building in Ying Xiu collapsed because of soft storey mechanism on one direction and short column on other directions.

Figure 15. First storey of 5-storeys building in Ying Xiu has totally collapsed.

Figure 16. Soft storey damage of second storey with drift about 5.6% in Dujiangyan

3.4. FAÇADE ELEMENTS.

Some local inplane façade damage caused by excessive drift was observed at Qingyang district in Chengdu and in Mianyang as shown in Figure 17. Meanwhile for the higher intensity shaking in Dujiangyan and Ying Xiu the moderate façade damage was more widespread.

Figure 17. Façade element damage of building in Mianyang.

3.5 REINFORCED CONCRETE QUALITY AND DETAILING

Figure 18. Column shear failure at one of building in Mianyang.

Figure 19. One of building in Mianyang suffered from beam-column joint failure

Figure 20. Poor beam-joint connection

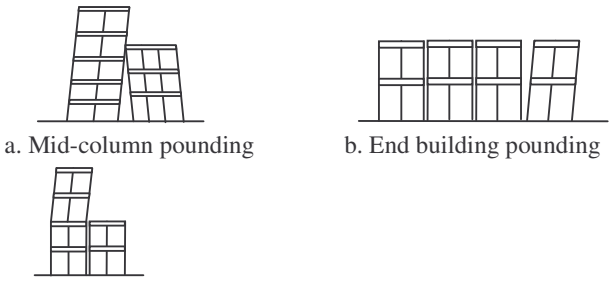
Figure 21. Bad gradation of aggregates.

Many buildings in Sichuan had inadequate construction quality including insufficient reinforcement, poor detailing and poor quality concrete as shown in Figure 18 to 21. Some of the poor detailing included lack of reinforcement in the beam column joint, lack of transverse ties in the beam and column and lack of an embedment length for reinforcement anchorage. Closely spaced transverse reinforcement in the form of closed ties with 135^{o} hooks provides concrete confinement, buckling restraint of longitudinal reinforcement and additional shear capacity, which improve the non linear performance.

3.6. POUNDING BETWEEN TWO ADJACENT STRUCTURES

Figure 22. Pounding between two different building in Dujiangyan

In Chengdu, particularly in the market areas, many buildings greater than 3-storeys were located very close or adjacent to each other resulting in pounding and some damage. The more severe structural pounding damages were observed in Dujiangyan and Mianyang as shown in Figure 22. The typical pounding damage occurred in the investigated area are shown schematically in Figure 23 [3].



a. Mid-column pounding

b. End building pounding

c. Taller adjacent Building Pounding

Figure 23. Typical of pounding damage in Sichuan province

CONCLUSIONS

The 12 May 2008 Wenchuan earthquake caused massive damage with over 69,000 people killed, and 374,171 injured.
From the observation of the Wenchuan earthquake impact on structures, the following conclusions can be reached.

- Damage to building at distance from the Wenchuan earthquake have significant relevance for Australian building subject to the design ultimate limit state earthquake.
- Unreinforced masonries are the most common type of low rise buildings in both countries.
- The most common damage pattern found due to Wenchuan earthquake for the intensity range VI to VIII were associated with of masonry walls.
- Both inadequate concrete quality and poor reinforcement detailing contributed to the significant damage and collapse of many buildings in the Wenchuan earthquake.

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