Engineering Structures 31 (2009) 1707–1723

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Field investigation on the performance of building structures during the 12 May 2008 Wenchuan earthquake in China

Bin Zhao [a,*], Fabio Taucer [a], Tiziana Rossetto [b]

[a] ELSA Unit, Joint Research Centre, European Commission, 21027 Ispra (VA), Italy

[b] Department of Civil and Environmental Engineering, University College London, WC1E6BT London, UK

ARTICLE INFO

Article history:
Received 6 November 2008
Received in revised form
29 January 2009
Accepted 11 February 2009
Available online 27 March 2009

Keywords:
Wenchuan earthquake
Field investigation
Seismic performance
Building structure

ABSTRACT

A devastating earthquake struck the southwestern Chinese province of Sichuan on 12 May 2008, leaving 69,227 dead and 374,643 injured, with 17,923 people still missing five months after the main event. The epicentre of the earthquake was located in Wenchuan County, which triggered a fault rupture length of about 300 km, stretching northeast through Beichuan County and reaching Qingchuan County; many towns on both sides of the fault were severely damaged/destroyed, reaching an earthquake damage intensity of XI. This paper presents the findings of a post-earthquake reconnaissance field mission carried out by the Earthquake Engineering Field Investigation Team (The Institution of Structural Engineers, UK) and by the European Laboratory for Structural Assessment of the Joint Research Centre of the European Commission, through the description of the damage sustained by three of the towns that suffered the largest levels of devastation: Yingxiu Town of Wenchuan County, Beichuan Town of Beichuan County, and Hanwang Town of Shifang City. The work focuses on the description of building performance during and after the disaster, in particular of reinforced concrete frame, reinforced concrete confined masonry, unreinforced and unconfined masonry, industrial, local vernacular and historical buildings. The information and recommendations provided in this paper will be useful for future engineering applications in similar earthquake risk regions.

1. Introduction

On 12 May 2008, a devastating earthquake struck at 02:28 pm local time (06:28 UTC) the Sichuan Province of the People's Republic of China. The China Earthquake Administration [1] estimated the magnitude of the event as Ms 8.0, with a focal depth of 14 km; USGS [2] estimations gave a magnitude of Mw 7.9 and a focal depth of 19 km. The earthquake occurred in the north–south seismic belt of mainland China, along the Longmen Mountain fault zone which marks the boundary between the Longmen Mountains east of the Qinghai-Tibetan Plateau and the Sichuan Basin. The epicentre was located at 31.0 N and 103.4 E, approximately 3 km southwest of Yingxiu Town in Wenchuan County. The earthquake fault rupture started from the epicentre, stretching northeast for about 300 km [3], passing through Beichuan County and reaching Qingchuan County; most of the buildings and infrastructures located on both sides of the fault rupture line were seriously damaged/destroyed.

Fig. 1 shows the earthquake intensity distribution, based on the intensity map officially released by the China Earthquake Administration on 28 August 2008, following a long and detailed field survey [4]. The damage intensity reported in many of the most severely affected towns reached levels of X and XI, including Wenchuan County, Beichuan County, Mianzhu City, Shifang City, Qingchuan County, Mao County, An County, Dujiangyan City, Pingwu County and Pengzhou City, for a total area of approximately 26,000 km^2. The main event and its aftershocks resulted in 69,227 deaths and 374,643 injured, with 17,923 people still missing five months after the main event. At least 15 million people were evacuated from their homes, more than 5 million were reported to be homeless and the direct economic loss is estimated at RMB 845.1 billion (US$125.6 billion) [2,5].

China is a country that has been historically exposed to destructive earthquakes, with the last event of comparable disastrous proportions being the magnitude 7.9 Tangshan earthquake of 28 July 1976, where 255,000 people lost their lives [6]. According to historical records, the area affected by the Wenchuan earthquake had previously experienced a total of eight destructive earthquakes, all with magnitudes larger than seven, with the largest event being the magnitude 7.5 Diexi earthquake of 25 August 1933 in Mao County, killing more than 9300 people.

The scientific work on seismic design of structures started in China in the 1950s, which led in 1974 to the introduction by the Chinese Construction Committee of the first seismic design code

* Corresponding author. Tel.: +39 0332789247; fax: +39 0332789049.
E-mail address: dr.bin.zhao@gmail.com (B. Zhao).

0141-0296/$ – see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.engstruct.2009.02.039

Table 1
Locations and maximum PGAs of the recorded strong motions of the Wenchuan earthquake.

Observation station	Location	Direct distances (km)			Maximum PGAs (g)		
		Epicentre	Fault line	Surface rupture	E–W	N–S	Vertical
Wolong	Wenchuan County	19	19	23	0.98	0.67	0.97
Qingping	Mianzhu City	88	10	3	0.84	0.82	0.64
Bajiao	Shifang City	67	20	10	0.57	0.59	0.65
Zengjia	Guangyuan City	314	87	86	0.43	0.42	0.19

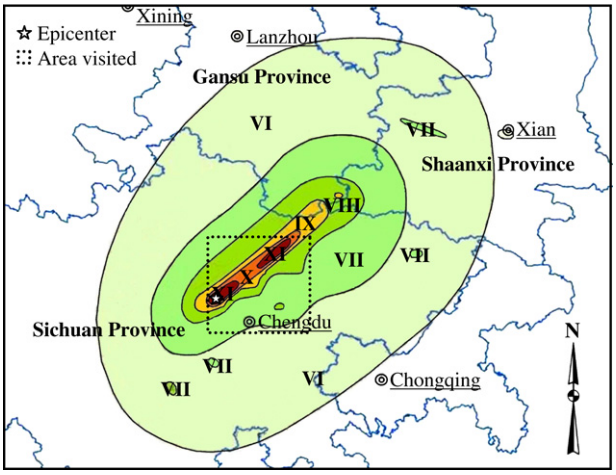

Fig. 1. Wenchuan earthquake intensity map and visited area (based on the intensity map from the China Earthquake Administration [4]).

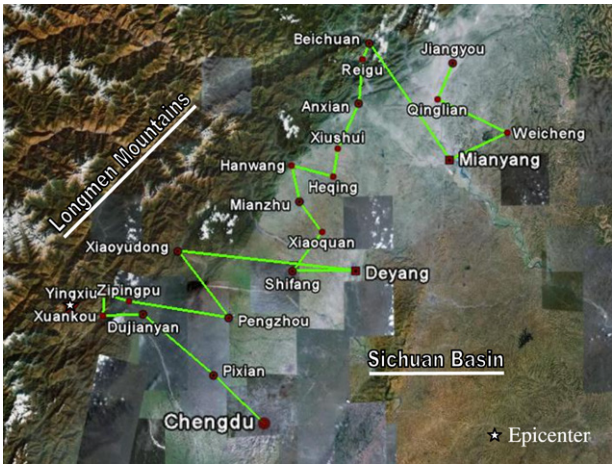

Fig. 2. Cities and Towns visited in the affected area (satellite image from GoogleEarth).

for buildings, known as TJ11-74. Four years later, in 1978, a revised version was issued as TJ11-78, to include the lessons learned from the Tangshan earthquake. In 1989 a new seismic code was introduced, known as the Chinese national standard GBJ11-89. The current Chinese seismic design code for buildings GB 50011-2001 was introduced in 2001. According to the seismic zone map of the current seismic design code GB 50011-2001 [7], the areas seriously affected by the Wenchuan earthquake were classified as zones of Intensity 7, with the towns of Mao County and Pinwu County having a basic design peak ground acceleration (PGA) of 0.15g and a plastic design PGA of 0.31g (corresponding to a rare event), and the towns of Wenchuan County, Dujiangyan City, Beichuan County, An County, Li County, Mianzhu City, Shifang City, Pengzhou City and Qingchuan County having a basic design PGA of 0.1g and a plastic design PGA of 0.22g.

The Wenchan earthquake is estimated to have induced PGAs ranging from 0.34g to 1.24g in the epicentral region [2], while the actual recorded Maximum PGA is on the order of 0.98g [8,9]. The locations, as well as the distances from the epicentre, fault line and surface rapture, of the four main earthquake observation stations, Wolong, Qingping, Bajiao and Zengjia station, in the earthquake area and their recorded maximum PGA values in E–W, N–S and Vertical directions are listed in Table 1. The Wolong station is the closest to the epicentre, at a distance of 19 km, Qingping, and Bajiao stations are close to the mid-point of the fault line, while Zengjia station is near the northeast end of the fault line. The PGAs of the Wenchuan Earthquake are several times larger than those predicted by the Chinese code, in addition, the predominant periods of the recorded ground motions are distributed between 0.1 s and 0.5 s [9], which are consistent with the main periods of low masonry and reinforced concrete buildings in the area. Both aspects are cited among the causes of the heavy damage, large number of casualties and high economic loss associated with this earthquake.

Through a joint activity of the Earthquake Engineering Field Investigation Team (EEFIT) of the Institution of Structural Engineers (UK) and of the European Laboratory for Structural Assessment of the Joint Research Centre of the European Commission, a post-earthquake field reconnaissance mission [10,11] was carried out in the affected area; the itinerary of the team included the visit to 22 towns and cities, starting at Chengdu City and ending at Jiangyou City (Fig. 2). Based on the findings of the field investigation, the seismic performance of buildings in the area affected by the main earthquake event and its aftershocks is summarised by selecting a set of three of the towns that suffered the highest levels of damage, all located in mountain areas close to the earthquake rupture fault line. The damage to cities located farther away from the fault rupture line, such as Chengdu, Deyang, Mianyang and Guangyuan, is not described in the present work, as building structures there suffered relatively slight or no damage, due to their better design and construction quality, as well as to the attenuation of the seismic ground motions.

Following the description of the damage sustained at the selected three towns, the seismic performance of the different building types found in the affected area is described: reinforced concrete frame, reinforced concrete confined masonry, unreinforced and unconfined masonry, industrial, local vernacular and historical buildings. The reinforced concrete shear wall constructions are not presented, as they are rare in the affected area and no associated damage was observed during the field investigation.

2. Damage overview of three selected towns near the fault rupture line

In the following, an overview of the damage sustained by Yingxiu Town of Wenchuan County, Beichuan Town of Beichuan County, and Hanwang Town of Shifang City is described. These towns were selected as they were almost fully destroyed during the main earthquake event, with buildings and infrastructures suffering full or partial collapse with structural damage beyond repair. Moreover, all these towns received extensive coverage by the news media after the earthquake and were chosen by the Chinese Government as exhibition sites for establishing