The Effectiveness of Chinese Seismic Design Codes on the Protection of Masonry Buildings against the Great Wenchuan Earthquake

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Abstract
The Great Wenchuan Earthquake that occurred on 12 May 2008 caused the widespread collapse of buildings, particularly masonry structures. On 29 June 2008, a post-earthquake field investigation team made up of earthquake engineering researchers from The university of Hong Kong, The University of Melbourne, and The Swinburne University of Technology reached the earthquake-affected areas and collected data and information with the aim of improving the understanding of the causes of building damage and collapses. This paper describes the observations from the field investigation and the findings from examination of the Chinese seismic design codes. The effectiveness and shortcomings of the Chinese seismic design codes in the design of seismic resistant masonry buildings is discussed. The misconception about the use of the ductility design approach for the design of low-rise buildings to resist rare earthquake loads is briefly mentioned.

Keywords: Wenchuan Earthquake, Masonry, Seismic intensity, Structural integrity, Ductility design, Strength design

Introduction
On 12 May 2008 at 02:28pm (local time), a magnitude (Ms) 8.0 earthquake occurred in the Sichuan province in southwestern China. The epicentre of the earthquake was 30.1°N 103.4°E in Wenchuan County, 90 km northwest of Chengdu, the capital of Sichuan, and 1545 km southwest of Beijing. The earthquake occurred at a depth of 14 km. Figure 1 shows the location of the earthquake in the Sichuan Province and the nearby affected cities. According to figures from the China Academy of Sciences, the earthquake caused 69,207 deaths and injured 374,216, and 18,164 people were still missing. The majority of the deaths and injures were in the cities of Chengdu, Mianyang, and Deyang. More than 216,000 buildings collapsed, including 6898 schools, and countless buildings were damaged to different extents. The total direct economic loss of the earthquake was estimated to be over RMB $525 billion.

Confined masonry structures, which represent a unique structural system in China, consist of tie-columns, reinforced concrete (RC) beams, and precast concrete hollow floor planks in the upper floors and RC infill frames on the bottom floor. About 70 % of residential buildings in China are made of confined masonry. In the Wenchuan earthquake, numerous confined masonry buildings failed and caused a large number of casualties. In Dujiangyan, about 51 % and 18 % of masonry buildings without and with earthquake resistant designs, respectively, collapsed or were seriously damaged (China Earthquake Administration, 2008). Thus, there is an urgent need to investigate the effectiveness of the Chinese seismic design code GB50011-2001 (National Standard of PRC, 2005), which deals with the protection of confined masonry buildings against rare earthquakes.

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Figure 1. Location of the epicentre and major affected cities

Figure 2. A typical construction detail of confined masonry structures.

Typical construction method of confined masonry structures

In China, confined masonry structures are widely used in the construction of low-rise residential buildings. Various types of brickwork, such as fired clay bricks, fired clay perforated bricks, and small hollow concrete blocks, are commonly used in building construction. We found that most of the collapsed buildings were constructed from fired clay bricks. According to the Chinese design code GB50011-2001 (National Standard of PRC 2005), masonry brickwork is required to be restrained by cast in-situ RC ring-beams and tie-columns. The minimum sizes of the tie-columns and beams are 240 mm×180 mm and 120 mm×180 mm (b×d), respectively. The beams and columns are required to be reinforced by only four longitudinal mild steel bars (f_y = 210 MPa) with diameters of 12 mm. The concrete used should have a cube strength of at least 20 MPa. Because the small section of the columns often impedes the

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