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THE WENCHUAN EARTHQUAKE OF MAY 12, 2008: FIELD OBSERVATIONS AND RECOMMENDATIONS FOR RECONSTRUCTION

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ABSTRACT :

The Wenchuan earthquake of May 12, 2008 hit a large area of Western Sichuan, China. This major earthquake had a moment magnitude of 7.9 M_W and a shallow focal depth (~19 km, USGS). The epicentre of the earthquake is located 80km WNW of Chengdu, an area with a population of more than 10million. The earthquake intensity is reported to have reached XI (in the Wenchuan area). 69,185 people died in the event, 374,174 people were injured and 5 million are reported to be homeless, (figures correct as of 27th June). Worldwide about twenty-five major earthquakes each with in excess of 50,000 deaths have been previously documented historically dating back to 893AD (including the 2004 Great Sumatran Earthquake and the Indian Ocean tsunami). The total economic loss is estimated at US$20.0billion. Following the event, the authors participated in the Earthquake Engineering Field Investigation Team (EEFIT, part of the UK Institution of Structural Engineers) field mission. The authors, a team of seismologists, earthquake engineering and geotechnical specialists, spent 7 days in the field surveying the damage to buildings, lifelines and observing geotechnical failures. This paper presents a summary of the team's observations and recommendation for preliminary to be considered during reconstruction.

KEYWORDS: China, Sichuan, Wenchuan earthquake, earthquake damage

1. INTRODUCTION

The United Kingdom Earthquake Engineering Field Investigation Team (EEFIT) carried out a reconnaissance mission to Sichuan, China following the Wenchuan earthquake, which occurred on the 12th May 2008. This major earthquake had a moment magnitude of 7.9 M_W and a shallow focal depth (~19 km, USGS). The epicentre of the earthquake is located 80km WNW of Chengdu, a city with a population of more than 10million (USGS). The earthquake intensity is reported to have reached XI (in the Wenchuan area). Over 69,000 people died in the event, over 374,000 people have been injured and 5 million are reported to be homeless. The total economic loss is estimated at US$20 billion. (figures correct as of 27th June, UNICEF).

The EEFIT team left for Chengdu, China on 11th July 2008 and spent seven days in the south of the disaster zone. One team member stayed a further 3 days, visiting locations in the north of disaster area. The aim of the team was to survey damage to buildings and infrastructure, investigate geotechnical failures and disseminate their observations to the international engineering community. The areas visited by the team are shown in Figure 1. Although two months had passed from the event, very little information had been made available to the international engineering community regarding the extent and type of damage incurred. Access to the affected area has been severely restricted to non-Chinese nationals not belonging to relief organisations, and EEFIT was amongst the first international teams to visit the sites. The team was composed of the paper authors, who are practicing engineers, academics, and one GIS specialist. The team was also given substantial local support by the Civil Engineering School of the South West Jiaotong University at Chengdu, China. This report gives a quick overview of the Team's observations of the performance of structures, infrastructure and geotechnical aspects. Recommendations are also made for the reconstruction and recovery from this event.

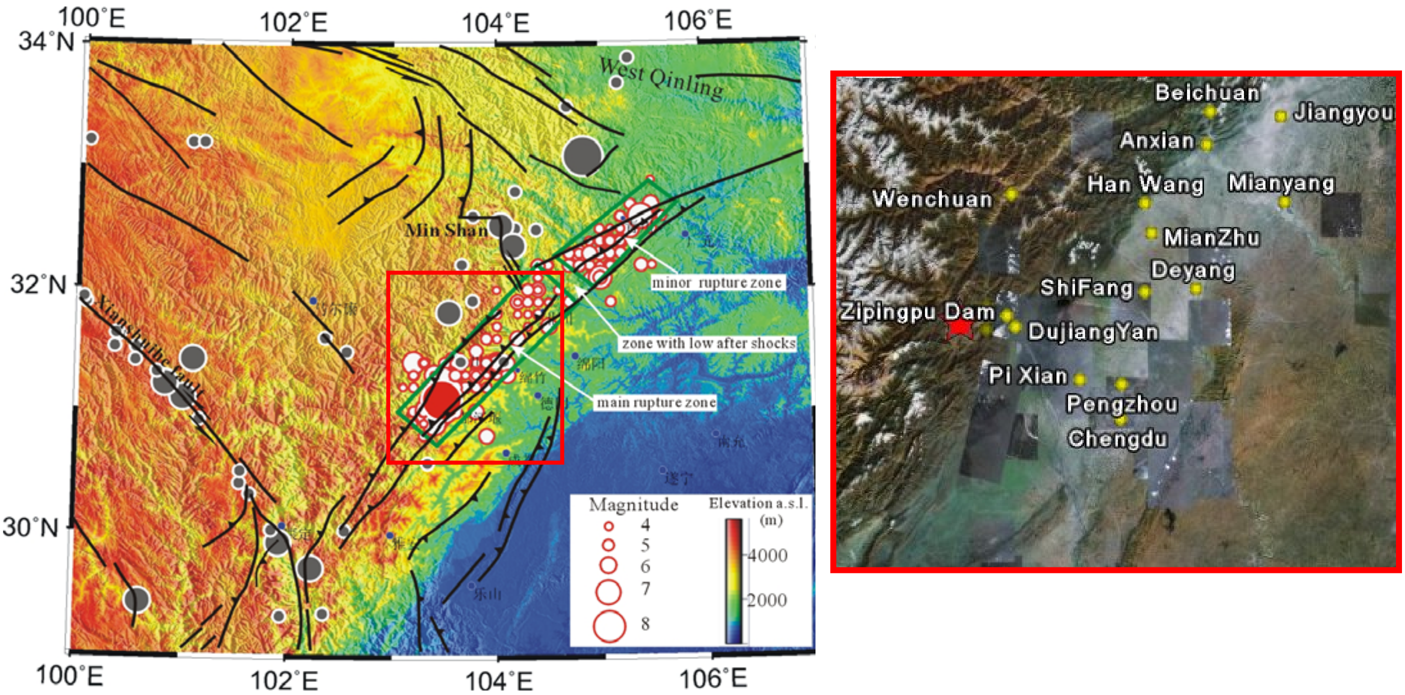

Figure 1: Map of the earthquake fault zone (left) and areas visited by the EEFIT Team (yellow dots, right) (GoogleEarth). The red dot indicates the epicentre location.

2. SEISMOLOGY AND STRONG GROUND MOTION

On May 12, 2008, at local time 14:28:04 (GMT 06:28), a major earthquake of magnitude 7.9 M_W, struck Wenchuan County, Sichuan Province, China with an epicenter at 30.986°N, 103.364°E. The earthquake is estimated to have caused a 250km rupture along faults which mark the boundary between the Longmen Shan mountains and the Sichuan Basin. The epicentral area of Wenchuan County and Chengdu were considered regions of moderate seismicity according to the 2001 Chinese code, with a Design Seismic Intensity of 7. The design basic peak ground acceleration (PGA) of 0.1g for 475 years return period and PGA of 0.22g for rare earthquakes are being assigned to the areas. The region had experienced large earthquakes previously, most notably a magnitude 7.3 event in 1933 about 50km north of the present rupture at a place called Diexi. The Sichuan Seismological Bureau has a "Digital Strong Ground Motion Network" installed in the Sichuan province, a total number of 211 strong ground motion stations were built in the entire province, included a network system to record the ground motion effects in terrain areas and the responses of dams during earthquakes. More than 60 strong ground motion stations were built in the Longmen Shan fault zone and its surrounding areas. During the Wenchuan earthquake, the Sichuan strong ground motion network obtained a large numbers of records, however for various reasons as reported by the Sichuan Seismological Bureau, majority of the strong ground motion data are still not officially published in the China Earthquake Data Centre. Based on the information provided by the China Earthquake Data Centre, the largest recorded PGA was 632.9cm/s^2 (0.63g) at Bajiao town station in Shifang city, which is about 109km to the epicentre and 30km perpendicular to the fault rupture. Such a level of ground motion is 3 to 6 times larger than the design PGA for buildings in the area. Thus it is not surprising that the earthquake caused a significant amount of damage.

3. GEOTECHNICAL ASPECTS

The observations en-route to many of the damaged towns revealed the abundance of landslides, slope failures and the performance of geotechnical structures such as retaining walls, anchored walls and other earth works. The landslides observed were largely rock falls, shallow rock and debris slides triggered by the strong ground shaking. Deep seated landslides involving failure through the rock mass also occurred but were less common. Secondary landslides were also triggered by the wet weather conditions following the mainshock event and by aftershocks. Figure 2a shows such a series of rock and debris slides on the very steep hillslopes near Ying Xiu. Figure 2b shows a deeper seated landslide. The rock types observed in the area varied from granite, sandstone to limestone (Densmore et al., 2007).

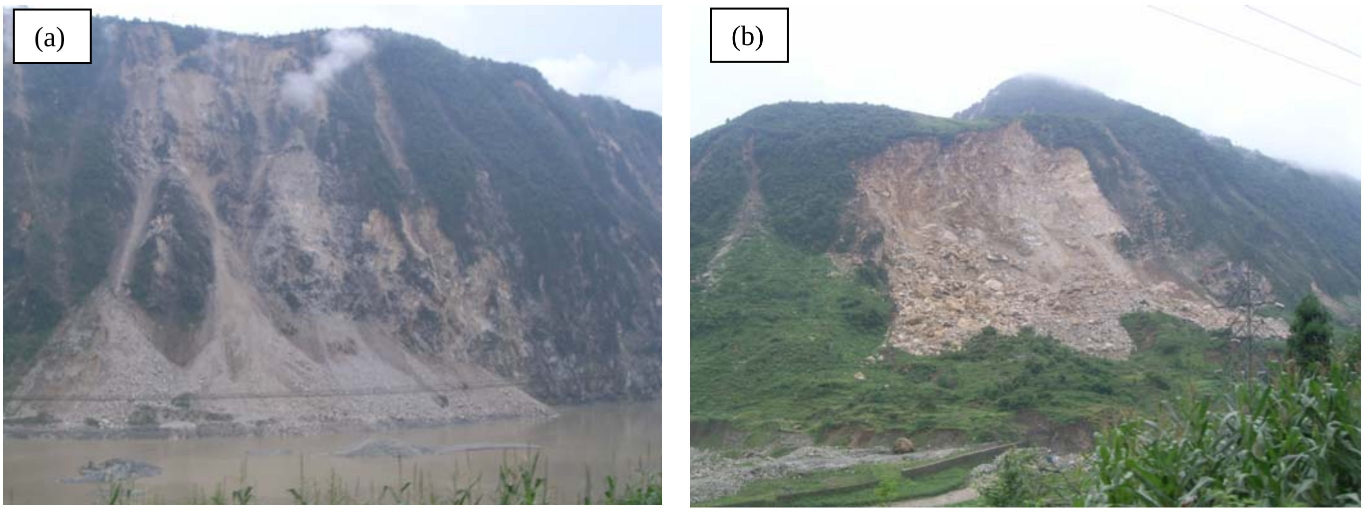

Figure 2: (a) shallow slip landslide involving the surficial soils (b) Deep slip landslide mobilizing the fractured rock basement Both hillsides were estimated to be 300m in height.

The mainshock landslides blocked routes to the towns and villages in the mountainous areas where help was needed after the earthquake. Secondary landslides continued to hinder the deployment of aid and reconstruction in the weeks and months after the mainshock. Along the route to Ying Xiu, the impact appears more pronounced closer to Ying Xiu as expected since this is closer to the fault rupture region (Figure 1). Landslides have also blocked rivers in several places especially in Beichuan county where they have formed landslide dammed lakes creating a flood risk to upstream as well as downstream areas. In many cases the authorities were able to remove the debris damming rivers by emergency earthworks but in some cases explosives, including rockets fired by the Chinese military, were successfully used to clear the debris and manage the flood risk.

Figure 3: (a) Collapsed section of stone facing gravity retaining wall near Ying Xiu (b) Displaced section of RC bored pile retaining wall stabilizing a pre-existing landslide to protect the road, near Ying Xu

A variety of earthworks types were observed, which were used to stabilize the cuttings made for the mountain roads. The earthwork types observed were rock anchoring systems, soil nail walls, gravity retaining walls, reinforced concrete flexural retaining walls and face protection systems using cement sand mix with possible grout injection. The geotechnical structures have largely performed well during the earthquake. Gravity retaining walls made of cemented stone blocks did not perform well at certain sections. The walls were constructed with breaks at about 15m and these sections collapsed often resulting in a shallow landslide of the retained soil. Figure 3(a) shows such a slide on a major route near Ying Xiu. The gravity retaining walls are susceptible to failure due to prolonged exposure to wet weather if the drainage holes were blocked. A buldged section of a gravity retaining wall was found near Ying Xiu, where it is likely to fail due to further wet weather or due to an aftershock. Reinforced concrete retaining walls have performed well from those observed during the survey. Figure 3(b) shows an RC bored pile retaining wall stabilizing a pre-existing landslide and only experienced a stable head displacement of about 15cm, hence the road was unaffected.

4. THE PERFORMANCE OF STRUCTURES AND INFRASTRUCTURE

4.1 Reinforced Concrete Buildings

Reinforced concrete moment resisting frames (RC MRF) are the predominant type of construction in the cities of Sichuan Province. The majority of these were observed to have a height between 4 to 6 storeys, with the ground floor being used for commercial purposes and the upper stories as residential units. Upper floors have clay brick infill, whereas concrete block masonry is sometimes used for ground floor infill. Most of the buildings observed were built after the 1980's, thus had some level of seismic design. The typical ground floor column dimensions for these mid-rise buildings were 400mm square and beam dimensions 400mm (depth) by 150mm (width). Construction materials and workmanship are good. Reinforcement varied but often consisted of 3 deformed longitudinal bars per column side with 25mm diameter at ground floor. Column ties were of 8mm diameter hoops with 90° anchorage hooks, and placed at relatively wide spacing of 200mm, thus not providing appropriate confinement.

Figure 4: Six-storey RC MRF in Yazhouyan housing development, Dujiangyan that is exhibiting a soft-storey failure mechanism at ground storey (detail of ground floor columns, right)

The performance of the mid-rise RC MRF varied substantially according to location. However, in any single location, no difference was observed between the performances of buildings built to different codes, due to the predominance of soft-storey type failure. For example, the Yazhouyan housing development in Dujiangyan composed of 27 buildings between 4 and 6 stories in height. Construction of these buildings began in 2006 and some were still under construction at the time of the earthquake. These structures are founded on very stiff soil with driven pile foundations of 300-400mm diameter and 900kN maximum axial capacity. Although designed to the most recent Chinese seismic code, about 70% of the structures had suffered some degree of damage with many suffering soft-storey failure at either the ground or first floor, mainly due to non-consideration of the added stiffness due to the presence of infill. Figure 4 shows a typical example where this type of failure was also precipitated by the presence of reinforcement bar splices in plastic hinge zones and inadequate confinement reinforcement. Overall, RC MRF performed well outside the immediate fault zone, and achieved life-saftey performance despite the fact that the reported felt PGA's are much larger than the design values for the area. In locations very near the fault zone, instead, they did not achieve life-safety performance.

4.2 Unreinforced Masonry Buildings (URM)

In Sichuan, unreinforced masonry construction is used for residential as well as commercial buildings. In towns these buildings are typically 1-2storey where the ground floor is used for commercial purposes and the upper floor for residential. There are some masonry structures built to 4-storeys or higher for commercial, residential and for schools. In the rural areas, masonry structures are largely residential and of single storey. The performance of masonry structures was seen to depend on their location with respect to the epicentre. The 1-2storey masonry structures in Dujiangyan generally performed well, probably because of terraced construction giving greater seismic resistance. Failures of this type of structures involved shear cracks running through the masonry bearing walls and damage to masonry columns. Figure 5(a) shows a 5-storey commercial structure appears to be using masonry bearing walls through confined masonry construction in Dujiangyan. The end bearing walls have experienced large diagonal shear cracks running through the RC beam and exposing a column section. Figure 5(b) shows a 5-storey masonry school building in Ying Xiu that has a collapsed ground floor and collapsed section of the building through all the floors. The masonry houses in rural areas performed badly, most houses having collapsed or suffered damage beyond repair.

Figure 5: (a) 5-storey confined masonry building in Dujiangyan with shear cracks on bearing walls, (b) 5-storey masonry school building in Ying Xiu partially collapsed

4.3 Vernacular Structures

Non-engineered wood-frame residential houses with masonry infill were observed in the poorer quarters of affected towns. These had masonry infill in the ground storey that consisted of smooth round stones laid with mortar made of mud mixed with cement. These dwellings were of one or two stories in height, the second storey often being clad with wood. The roofs of these buildings were also of timber, overlain with corrugated iron sheets and clay tiles. A variant of this type of buildings was unreinforced masonry dwellings made in the same manner as the aforementioned infills. Many of these were observed to perform badly, with the masonry walls (infill) collapsing out of plane.

4.5 Industrial Buildings

The Sichuan Province is a growing region with several multi-national companies as well as local businesses having their manufacturing facilities set up around Chengdu. These manufacturing facilities, which are modern, built perhaps over the last 20years, appear to have suffered no damage or production losses as a result of the earthquake. This may be attributed to the distance from the epicentre, which is about 80-100km in the metropolitan area of Chengdu.

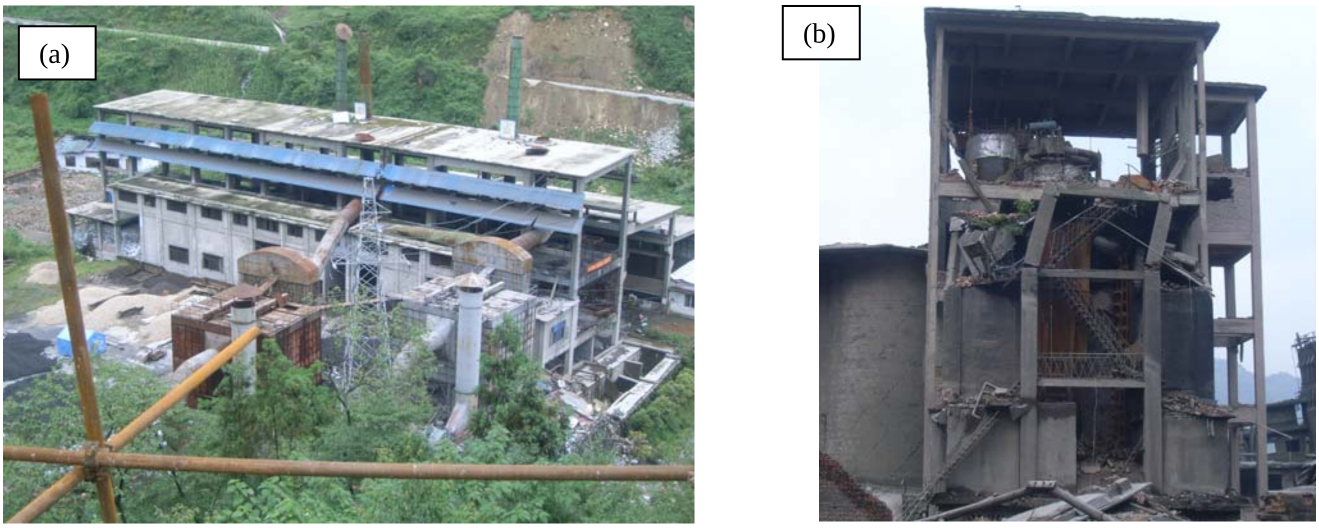

Figure 6: Damaged cement factories in (a) Ying Xiu and (b) Xiao Yu Dong

A few industrial facilities were visited in rural areas closer to the epicenter. These are of older construction than those observed in Chengdu and suffered substantial damage. Figure 6(a) shows a cement processing factory that was out of action following the earthquake. The building structure appears to be intact but there may have been damage to the equipment since the factory was not operational at the time of the survey. Figure 6(b) shows a cement manufacturing plant with damaged structures at several locations at the site. There were damages to masonry silos ranging from shear cracks to collapsed section of one silo. Factories such as these, sited in rural towns, were the main source of employment for local people, and also provided them with accommodation. Hence, the closure of these factories has a huge impact on the recovery of the local communities.

4.6 Infrastructure

Infrastructure damage observed was primarily due to a combination of ground surface rupture and strong ground shaking. Stretches of the roads and highways from Dujiangyan to Wenchuan were inspected and were seen to have been blocked by rock falls and landslides. At the time of the EEFIT field visit, some of the damage had been repaired, while an alternative temporary route had been constructed next to the severely damaged roads and bridges. The EEFIT team visited two dams during the field investigation. The Zipingpu dam was one of these, and located 10km east of the earthquake epicenter. The dam had recorded a maximum vertical settlement and horizontal displacement of 80cm and 30cm, respectively. Cracks of 2cm width and a few meters long were observed on the concrete facing. Deconstruction of the masonry facing on the opposite side of concrete facing was seen. At the time of earthquake, the stored water only reached one third of designed capacity. The discharge of the reservoir was ordered immediately after the main shock in order to minimize the potential risk to nearby towns and cities.

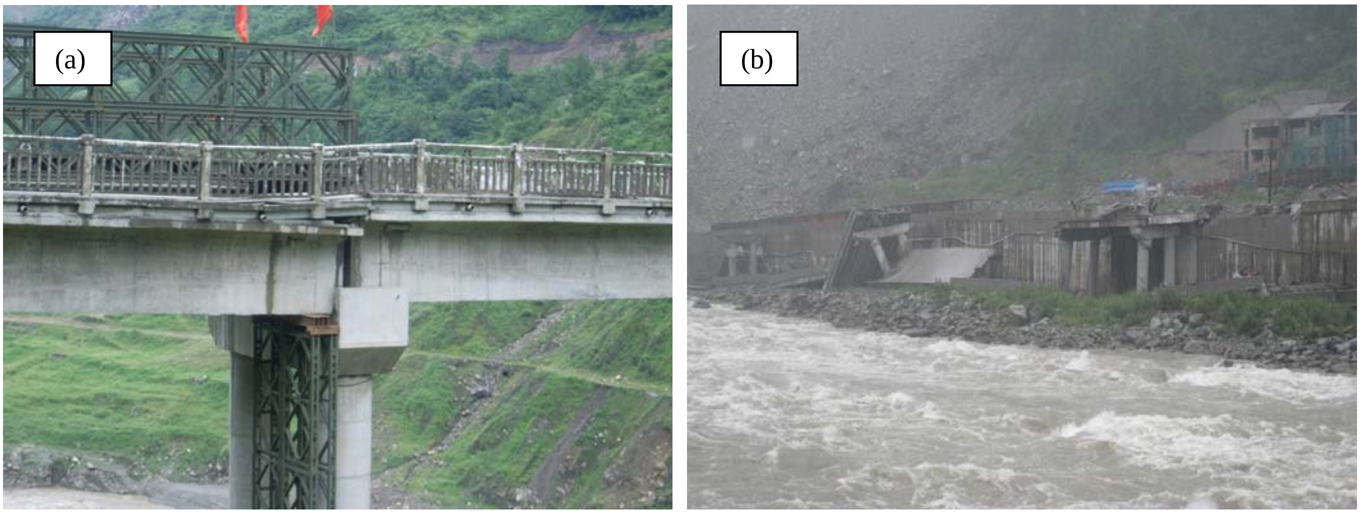

Figure 7: Damaged Bridges (a) Longitudinal displacement of simply supported beam at Shoujiang Bridge (b) Collapsed bridge along Mingjiang River in Ying Xiu Town

The EEFIT team inspected about 10 bridges along the road between Dujiangyan City to Ying Xiu town. Most of the bridges are damaged due to horizontal accelerations during the earthquake and were associated to one of the following patterns (see Figure 7):

a) Loss of support in the superstore in the longitudinal direction
b) Damage of parapets in the transverse direction, resulting from pounding of the superstructure after sliding with respect to the pier in transverse direction
c) Damage due to rotation of the deck on the horizontal plane, due to differential ground settlements or to differences in the stiffness of piers and abutment
d) Damage due to rock fall, landslides and loss of support of the bridge piers on the foundation

6. RECOMMENDATIONS FOR RECONSTRUCTION

The Wenchuan earthquake was a large event with very high ground motions being recorded in the near-source region, much larger than the design ground motion stipulated by the 2001 Chinese Seismic Code for the area. However, Western Sichuan has sustained several large earthquakes in the last century, which would suggest that a higher ground motion design values might be appropriate for Sichuan. We understand that a revision of the seismic zonation for the region is already in progress.

Damage and loss of life was caused by a range of seismic hazards, in particular the impact of ground shaking on buildings and infrastructure, but also landslides and flooding. A multi-hazard approach should be considered within a risk management framework during the reconstruction planning.

From observation of the performance of reinforced concrete moment resisting frames it is clear that soft ground-storey modes of failure were a problem. These resulted from uneven distribution of infill walls between the ground and upper stories of structures. This has been seen as a major problem in many past earthquakes around the world, and provisions should be taken to guide the placement of infill in seismically designed structures to avoid occurrence of stiffness irregularities. Furthermore, more stringent detailing criteria for the curtailment of reinforcement bars in column ends needs to be enforced.

A full set of recommendations for the different types of construction can be found in the EEFIT Report on the Wenchuan Earthquake, downloadable from www.eefit.org.uk

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