THE WENCHUAN, CHINA EARTHQUAKE OF 12 MAY 2008

A PRELIMINARY FIELD REPORT BY EEFIT

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ABSTRACT:

The 12 May 2008 Wenchuan earthquake was a major earthquake with a magnitude of M_W 7.9, a shallow focal depth (~19 km, USGS) and a rupture length of 270km. The epicentre of the earthquake was located in Sichuan Province, 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). 69,185 people died in the event, over 374,000 people were injured and 5 million are reported to be homeless, (figures correct as of 27th June). 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 preliminary report presents a summary of the team's observations and provides some preliminary recommendations for consideration during the reconstruction of the region.

KEYWORDS:

China, Sichuan, Wenchuan Earthquake, earthquake damage

1. INTRODUCTION

This Preliminary Field Report describes the preliminary findings of the Earthquake Engineering Field Investigation Team (EEFIT) reconnaissance mission to Eastern Sichuan, China following the Wenchuan earthquake, which occurred on the 12th May 2008.

The 12 May 2008 event was a major earthquake with a moment magnitude of 7.9 M_W and a shallow focal depth (~19 km, USGS). The fault displace had a reverse mechanism with the fault dipping at approximately at 35° toward the northwest. The fault rupture is estimated to have been approximately 270km in length with maximum slip of 8m to 12m and more commonly 1m to 3m.

The epicentre of the earthquake was 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 near-source region). 69,185 people are reported to have died in the event, over 374,000 people have been injured and 5 million are reported to be homeless, (figures correct as of 27th June, UNICEF). Sichuan Province has a strong economy and the total economic loss is estimated at US$20 billion.

The EEFIT team left for Chengdu, China on 11th July 2008 and spent seven days in the southwest portion of the disaster region. One team member stayed a further 3 days, visiting locations in the central and northeast portions of disaster region. The aim of the team was to survey damage to buildings and infrastructure, investigate geotechnical aspects and disseminate their observations to the local and international engineering community. The areas visited by the team are shown in Figure 1.1. Although two months had passed since the event, very little information had been made available to the international engineering community regarding the extent and type of damage that had been 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 (the report authors) was composed of practicing engineers, academics, and an imagery and GIS specialist. The team was given substantial local support by the Civil Engineering School of the South West Jiaotong University at Chengdu, China.

This report gives an overview of the team's observations of the performance of structures, infrastructure and geotechnical aspects. Preliminary recommendations are also provided for consideration during the reconstruction and recovery from this event.

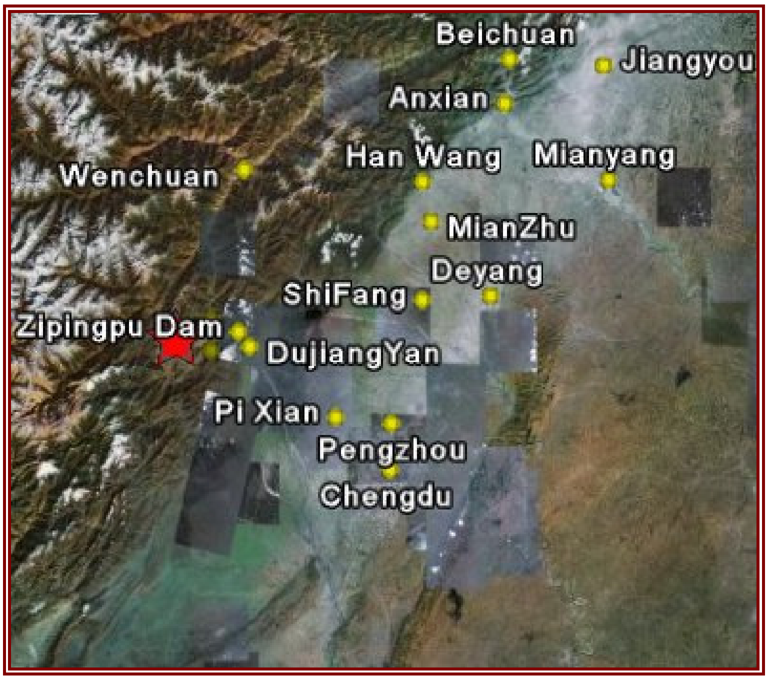

Figure 1.1 Map of the areas visited by the EEFIT Team (yellow dots). The red star indicates the epicentre location (GoogleEarth).

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 MW, struck the Wenchuan County (30.986°N, 103.364°E) in province of Sichuan. The earthquake is estimated to have caused a 240km rupture along faults which mark the boundary between the Longmen Shan mountains and the Sichuan Basin (see Figure 2.1).

The region has experienced large earthquakes previously, most notably a magnitude Mw = 7.3 event in 1933 about 50km north of the present rupture at Diexi (Densmore et al., 2007). The locations of other historical events in the region are shown on Figure 2.1.

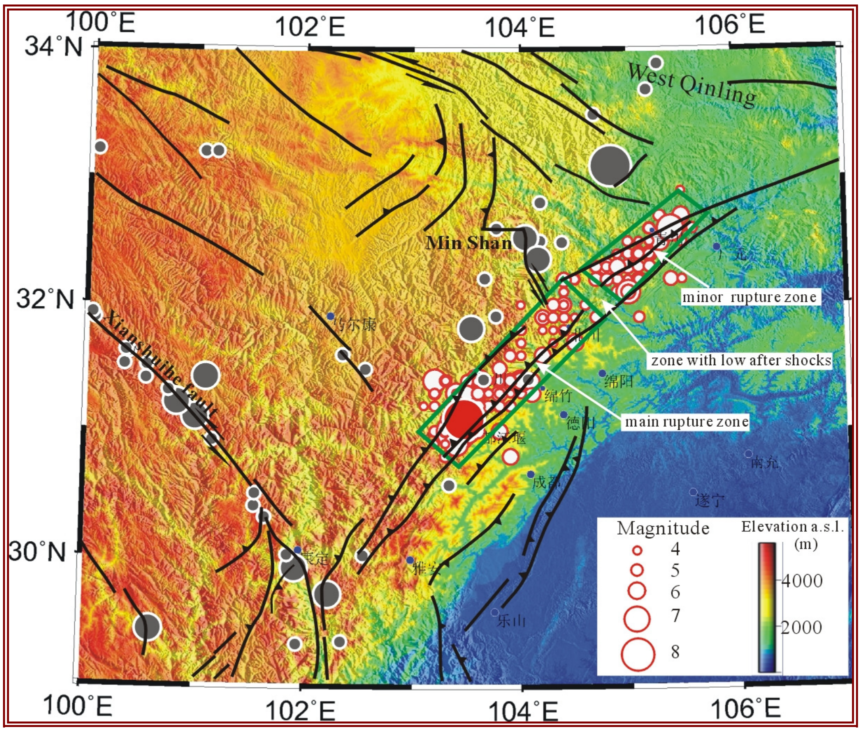

Figure 2.1 Map of the earthquake fault zone. The red dot indicates the mainshock epicentre location. Smaller red open circles indicate aftershocks. Solid grey circles indicate histrical earthquake epicentres. Solid black lines indicate mapped faults. (reference).

The Sichuan Seismological Bureau has a "Digital Strong Ground Motion Network" installed in the Sichuan province. A total of 211 strong ground motion stations were built in the entire province, including networks to record the ground motion effects in a range of terrain areas and the response of dams during earthquakes. More than 60 strong ground motion stations were built in the Longmen Shan fault zone and its surrounding area. It is reported that during the Wenchuan earthquake, the network obtained a large number of records. However, the vast majority of the strong ground motion records had not been made available to the international seismological community by the China Earthquake Data Centre at the time of reporting. Based on the limited information available, the largest recorded peak ground motion was the vertical component of 6.329 m/s2 (0.63g) at Bajiao town station in Shifang City, which is located about 30km perpendicular to the fault rupture. The horizontal components at this station were 5.489 m/s2 (0.55g) in the EW direction and 5.857 m/s2 (0.59g) in the NS direction.

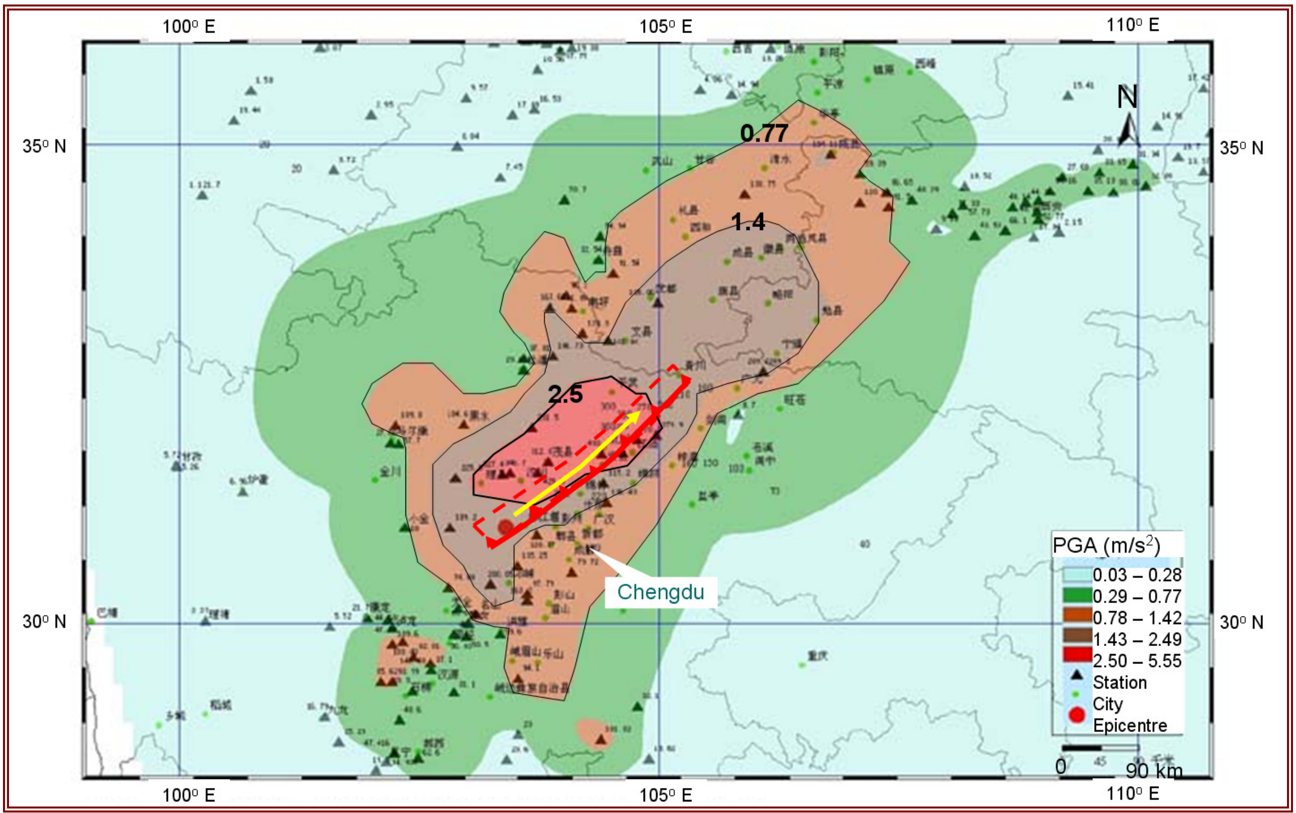

Figure 2.2 Distribution of peak horizontal ground motion - east-west component (China Earthquake Data Centre, 2008). Red rectangle indicates surface project of fault. Dip is to northwest. Yellow arrow indicates direction of rupture.

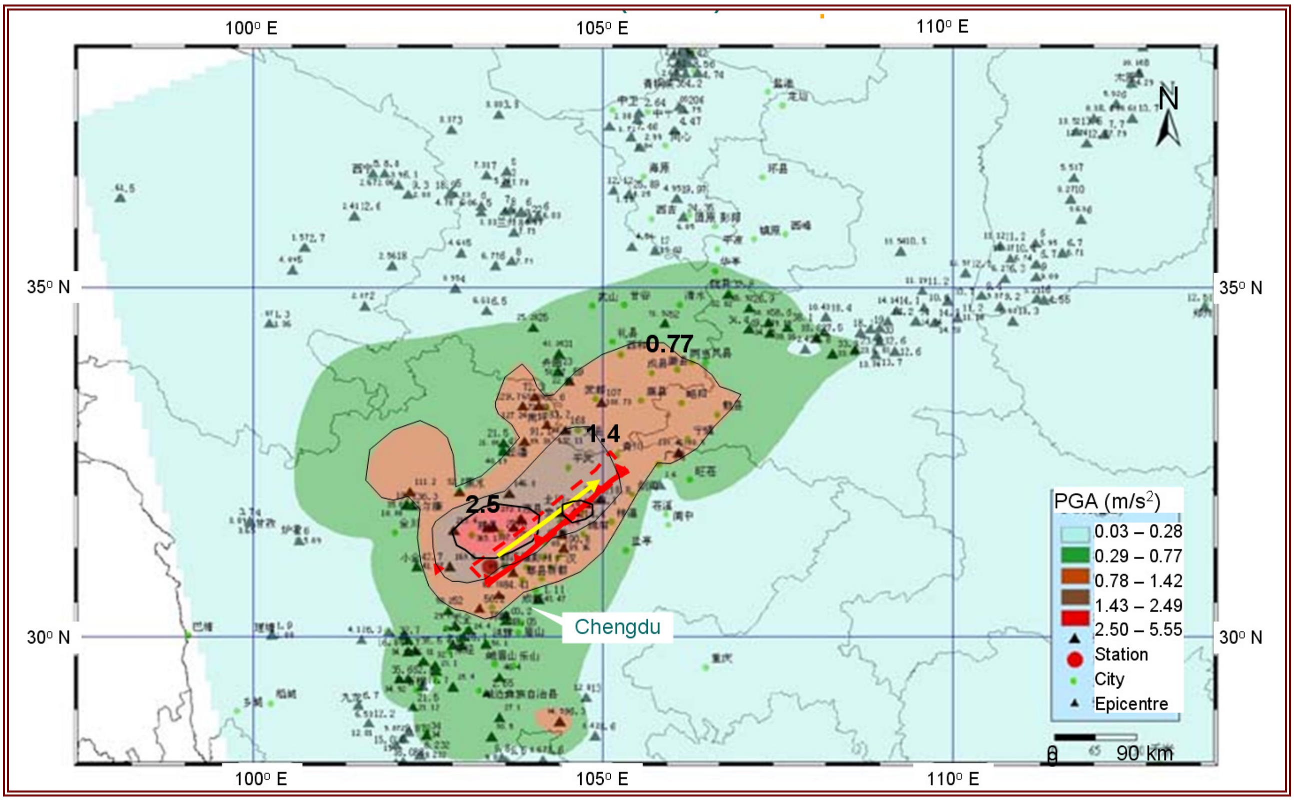

Figure 2.3 Distribution of peak vertical ground motion (China Earthquake Data Centre, 2008).

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 near-source region is mountainous with very steep slope angles.

The landslides observed were predominantly shallow rock and debris slides and rock falls on very steep hillsides (45° to 75°) where the shallow soil and weathered rock overlying more competent rock had failed due to the ground shaking. Further landslides are interpreted to have been triggered on slopes near failure due to aftershocks and most commonly the wet weather conditions in the weeks and months following the event. Figure 3.1 shows typical shallow rock and debris slides observed near Ying Xiu. The rock type was interpreted to comprise jointed, limestone, and calcareous siltstones and sandstones. Several deeper landslides (10 to 30 m thick) were also observed where the slip surfaces occur within the fractured rock mass along pre-existing discontinuities. Landslides were observed in a wide range of rock types including sandstones, siltstones, granite and metamorphic rock such as shales and phillites.

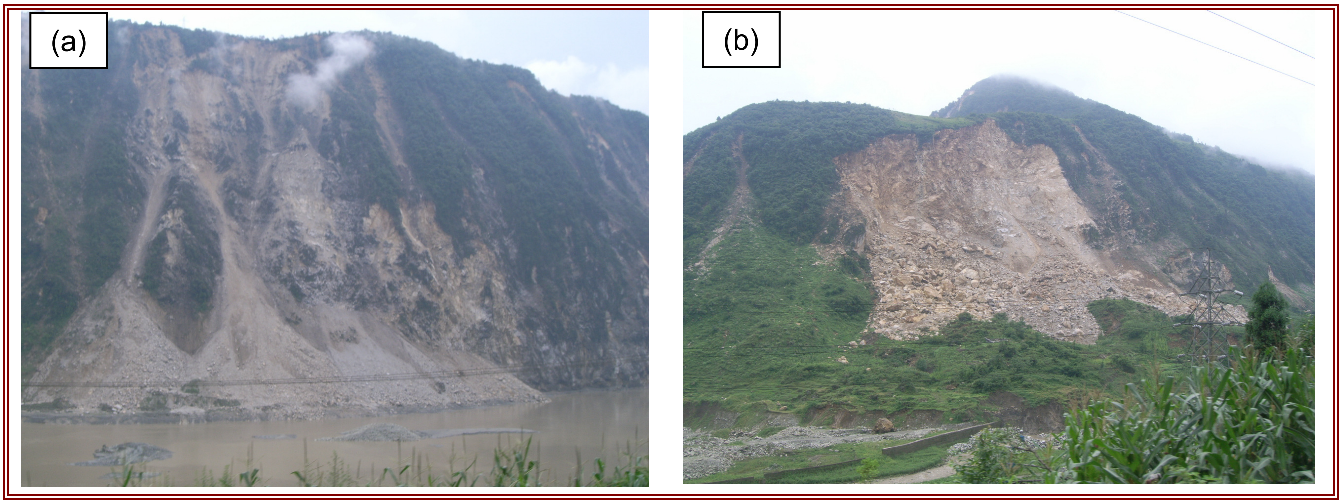

Figure 3.1 (a) Shallow slip landslide involving the surficial soils (b) Deep slip landslide mobilizing the fractured rock mass. Both hillsides are approximately 300m high.

The landslides blocked lifeline routes to the towns and villages in the mountainous areas where help was urgently needed after the earthquake. The slopes continued to be unstable during the weeks and months after the mainshock with many landslides occurring after 12 May 2008 causing further access problems and resulting in many additional fatalities.

Landslides debris blocked rivers in several places, especially in Wenchuan and Beichuan counties, and have formed earth dams and reservoirs creating a flood hazard to both the downstream as well as upstream areas. Many successful efforts were made by the authorities to either remove the earth dams, in some cases using explosives, to manage the release of the impounded water.

A variety of earth stabilisation types were observed that had been used to stabilize the cuttings and embankments made during construction of 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 very 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 centres and these sections collapsed often resulting in a shallow landslide of the retained soil. Figure 3.2(a) shows such a slide on a major route near Ying Xiu. The gravity retaining walls appeared to be vulnerable to failure due to the prolonged wet weather and susceptibility of the drainage holes to blockage. A bulging section of a gravity retaining wall was found near Ying Xiu. It was interpreted that the wall is likely to have a low factor of safety against failure due to current wet weather and likely high water pressure behind the wall or due to aftershock ground motion. Reinforced concrete retaining walls have performed well from those observed during the survey. Figure 3.2(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.

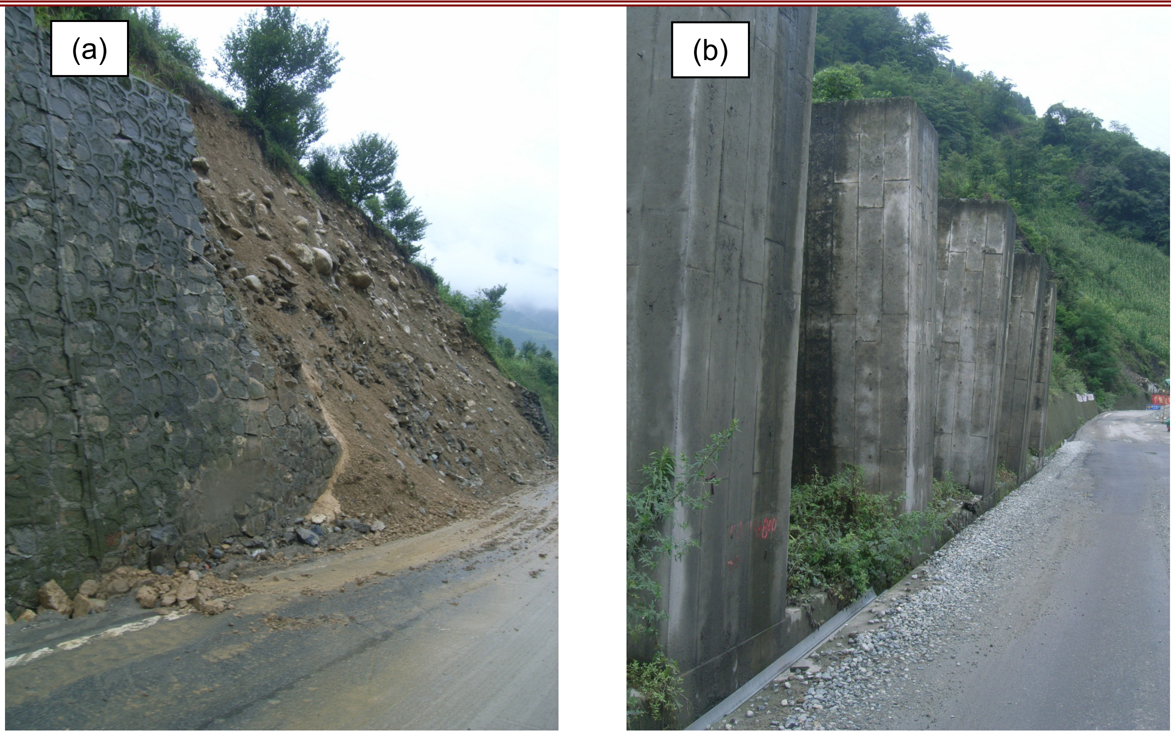

Figure 2.2 (a) Collapsed section of stone gravity retaining wall near Ying Xiu (b) Displaced section of RC bored pile retaining wall stabilizing a pre-existing landslide to protect the road, near Ying Xu.

4. THE PERFORMANCE OF STRUCTURES

The Wenchuan earthquake was a major event with very large ground motions recorded, much larger than the design ground motions stipulated by the 2001 Chinese Seismic Code. The area of Wenchuan County and Chengdu were considered regions of moderate seismicity according to the 2001 Chinese code, with a Design Intensity of 7. The design basic ground acceleration of 0.1g for 475 years return period and of 0.22g for rare earthquakes are assigned to the areas. In the near-source region the recorded level of ground motion (0.4 to 0.6g) is 3 to 5 times larger than the basic design level for buildings in the area. Therefore it is not surprising that the earthquake caused a significant amount of damage to buildings in the near-source region. In Chengdu, where the recorded level of ground motion was very similar to the design basic acceleration level then buildings appeared to performed very well.

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.

The performance of the mid-rise RC MRF varied substantially according to location. No difference was observed between the performances of buildings built to different codes, due to the predominance of soft-storey type failure even in those designed to the most recent code. 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 4.1 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 and achieved life-saftey performance despite the fact that the reported ground motions are much larger than the design values for the area. Part of this good performance is however attributed to the fact that construction of these buildings in China is as terraces. Multiple residences are built attached to each other and often act as a single structure with greater seismic resistance.

Figure 3.1 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).

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 4.2(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 4.2(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 4.2 (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.

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.

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.

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 4.3(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 4.3(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.

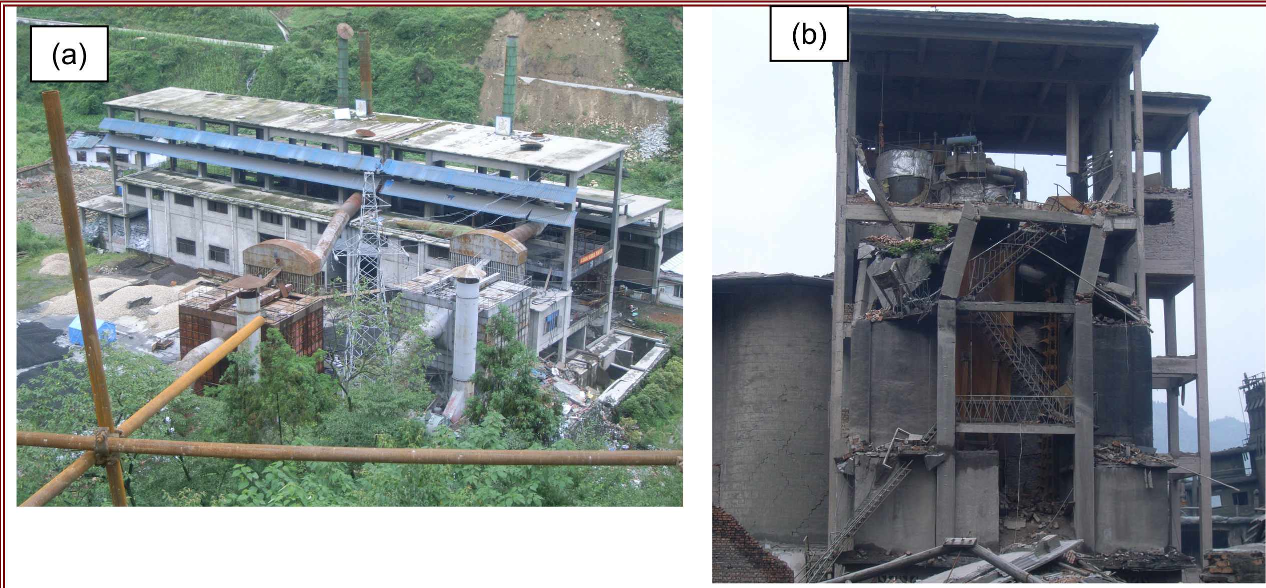

Figure 4.3 Damaged cement factories in (a) Ying Xiu and (b) Xiao Yu Dong.

5. THE PERFORMANCE OF INFRASTRUCTURE

Infrastructure damage observed was primarily due to a combination of strong ground shaking and earthquake induced landslides and less commonly to fault rupture. Stretches of the roads and highways from Dujiangyan to Wenchuan blocked by rock falls and landslides. At the time of the EEFIT field visit, some of the damage to infrastructure had been temporarily repaired, with alternative temporary routes constructed next to the severely damaged roads and bridges.

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 Figures 5.1 and 5.2):

(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

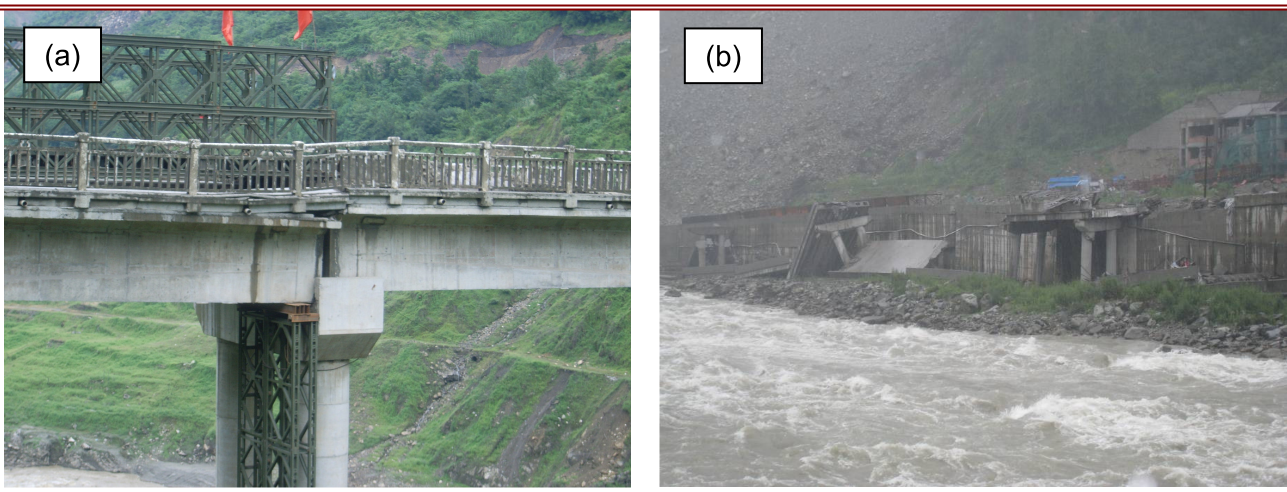

Figure 5.1 Damaged bridges (a) Longitudinal displacement of simply supported beam at Shoujiang Bridge (b) Collapsed bridge viaducts along Mingjiang River in Ying Xiu Town.

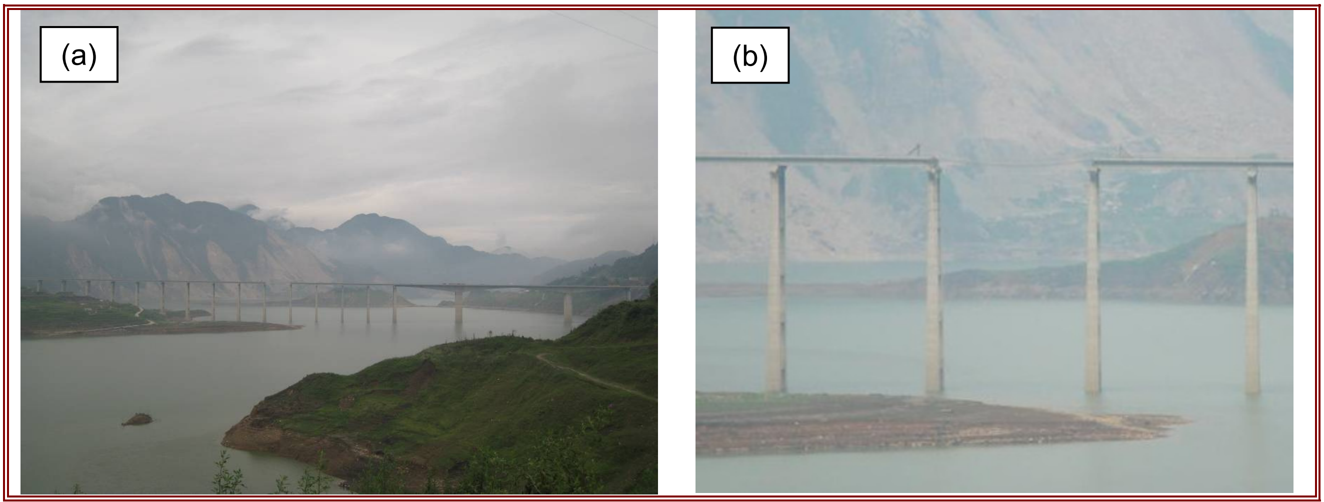

Figure 5.2 Damaged bridges (a) shows Minjiang Bridge crossing the Zipingpu reservoir where one span is unseated. (b) view of missing span.

Damage to tunnels was also observed (Figure 5.3). Damage and obstruction of tunnel portals was caused by landslides. Damage to sprayed concrete tunnel linings including; longitudinal and circumferential cracking at axis knee and invert level level, bulging of the invert, spalling of concrete from the crown.

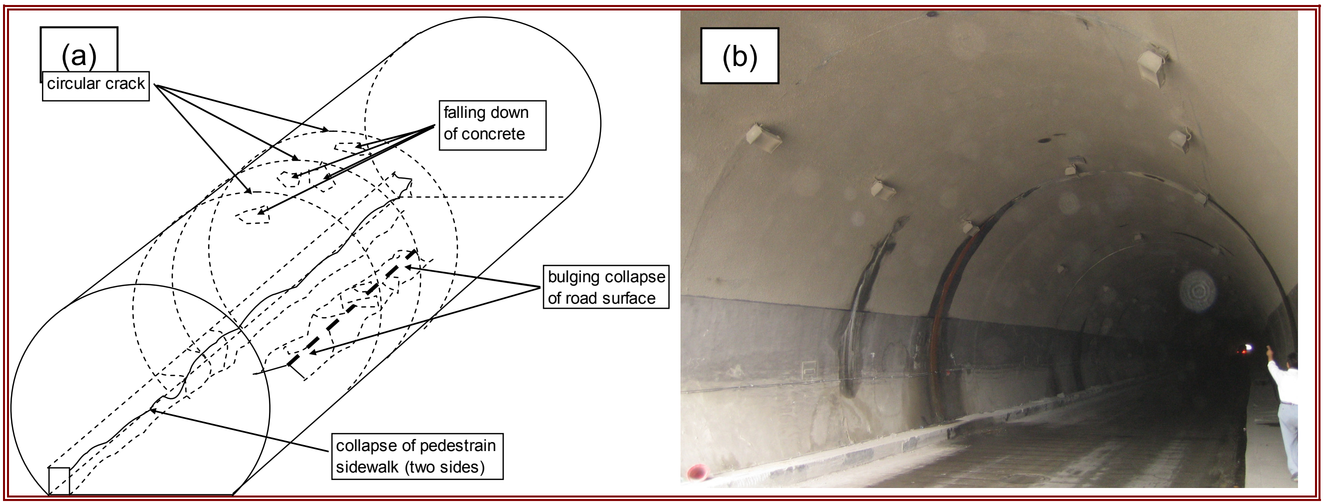

Figure 5.3 Damage to Friendship Tunnel (Youyi Tunnel) (a) Location and types of damage including bulging of the invert, spalling from the roof, longitudinal cracks at the axis and knee and cracks and b) circumferential cracks in sprayed concrete lining.

The team visited two dams during the field investigation (Figure 5.4). The Zipingpu dam is located 10km east of the earthquake epicenter. The dam had recorded a maximum vertical settlement and horizontal displacement of 800mm and 300mm, respectively. Differential settlement of the crest could be observed. Cracks of 20mm width and a few meters long were observed on the concrete facing on the upstream side of the dam. Spalling and slight bulging of the masonry facing on the downstream side of the dam was observed in minor areas toward the crest. 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.

Damage was also observed at the Dam at the Fish Mouth of the Dujiangyan Irrigation Project. The beam supporting the gates was observed to be laterally offset by approximately 100mm in the downstream direction. Longitudinal cracks were observe in the Fish Mouth diversion embankment.

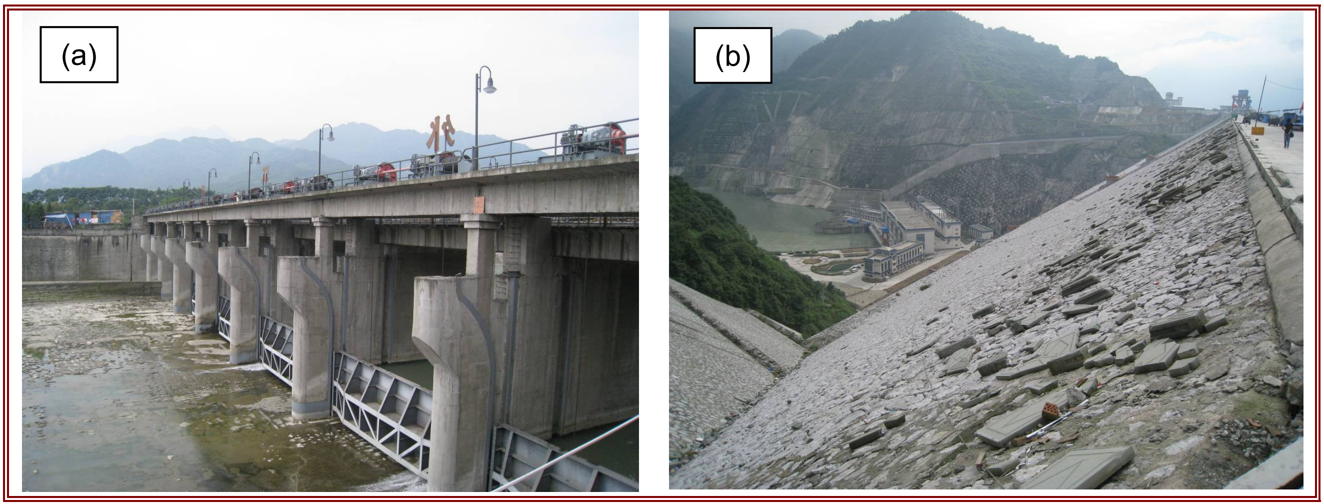

Figure 5.4 Damage to Dams (a) View of dam at Dujiangyan Irrigation Project Fish Mouth where the beam that supported the dam gates experienced a 100mm lateral displacement in the downstream direction, and b) View of downstream side of Zipingpu Damage where cracking, slight bulging and differential settlement was visible at the crest (the loose slabs visible on the surface are from the collapse of a light-weight pedestrian foorpath barrier along the crest of the dam).

6. SATELLITE IMAGERY AND DIGITAL IMAGERY DAMAGE ASSESSMENTS

EEFIT is collaborating with EPICentre (University Collage London), MCEER, EERI and ImageCAT Inc in the development of a Virtual Disaster Viewer (VDV). The VDV is a web-based tool which uses pre- and post-disaster, high resolution satellite imagery, in addition to field based GPS tracked, digital still and video imagery. The tool is being developed to allow a broad range of researches access to imagery and field information for scientific collaboration. The initial areas of research are intended to involve assessment of damage to buildings and infrastructure and the assessment of the distribution and impact of landslides.

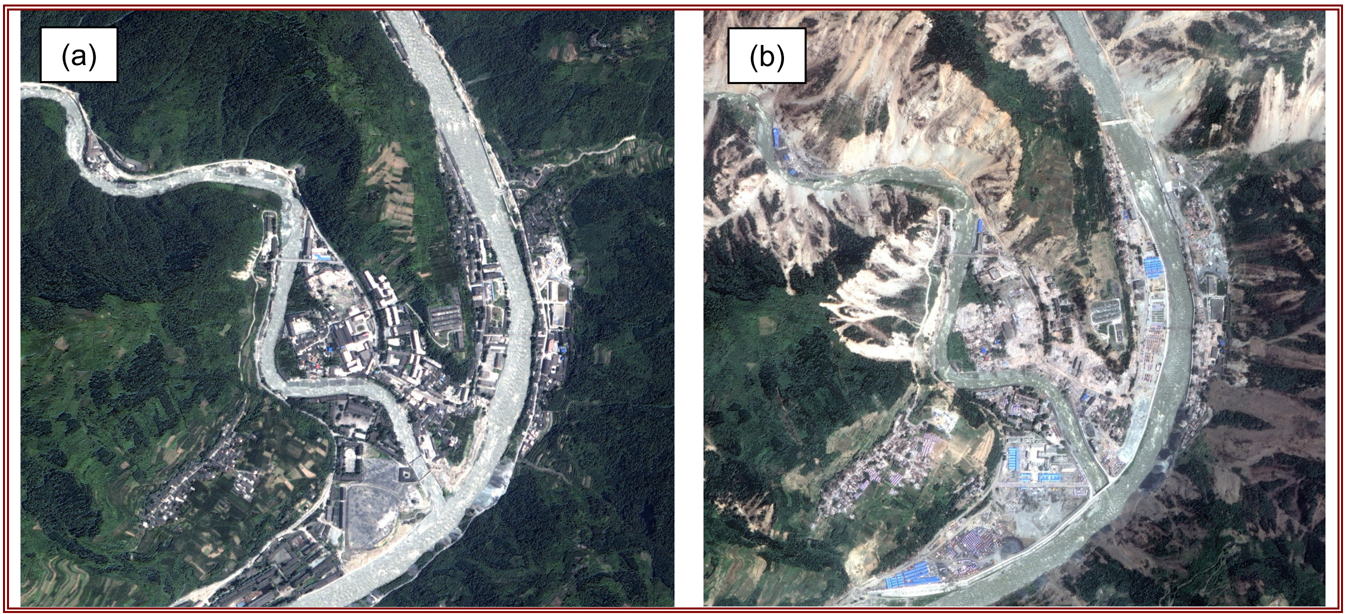

Figure 6.1 Satellite imagery view of Ying Xiu a) pre-earthquake b) post earthquake. The high density of landslides in the post-earthquake image can be clearly seen. (Quickbied Image distributed by Digital Globe)

7. RECOMMENDATIONS FOR RECONSTRUCTION

The Wenchuan earthquake was a major event with very high peak ground accelerations recorded in the near-source region. The ground motions were larger than the design values stipulated by the 2001 Chinese Seismic Code zonation map. It is understood that a revision of the zonation map is on-going and is to be issued in the near future. It is recommended that the zonation map account for ground motion from fault sources and near-fault effects.

Loss of life in the Wenchuan earthquake was associated with two main seismic hazards ground motion forces on buildings and other structures and earthquake induced landslides. Secondary effects such as the formation and failure of landslide dammed lakes and post-mainshock landslides triggered by aftershocks and rainfall on slopes near-failure.

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 need 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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