Learning from Earthquakes

The Wenchuan, Sichuan Province, China, Earthquake of May 12, 2008

A team sponsored by the Earthquake Engineering Research Institute (EERI) and the Geo-Engineering Earthquake Reconnaissance (GEER) Association carried out a field investigation in conjunction with Chinese colleagues from August 3-11 to document effects of the May 12 earthquake. The EERI-GEER team was invited by Professor Zifa Wang, Director of the Institute of Engineering Mechanics-China Earthquake Administration (IEM-CEA). Professor Junwu Dai of the IEM-CEA accompanied the team during the field investigation.

Under the leadership of Marshall Lew of MACTEC Engineering and Consulting in Los Angeles, the team included experts in structural, lifelines, and geotechnical engineering as well as in disaster response and recovery. EERI team members were David Friedman and Dennis Lau of Forell/Elsesser Engineers, Inc.; Laurie Johnson, urban planning consultant, San Francisco; Tricia Wachtendorf of the Disaster Research Center at the University of Delaware, Newark; and Jian Zhao of the University of Wisconsin at Milwaukee. The GEER team consisted of David Frost of the Georgia Institute of Technology in Savannah; J. P. Bardet of the University of Southern California; and Tong Qiu of Clarkson University in Potsdam, New York. Observations of other investigators who visited the earthquake-affected region have also been incorporated in this report.

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Tectonic Setting

The M7.9 Wenchuan earthquake is the worst to strike China since the M7.8 Tangshan event of July 1976 that claimed an estimated 242,000 lives. The Wenchuan earthquake affected more than 100,000 square miles and about 30 million people, causing 69,226 deaths (as of August 21, 2008) and injuring almost 375,000 people. Almost 1.5 million people had to be relocated (Xinhua, 2008). The earthquake also destroyed more than 216,000 buildings in Sichuan Province, including approximately 6,900 school buildings that buried thousands of students and teachers.

The earthquake originated on the Longmenshan fault, a northeastern-striking thrust fault that ruptured for almost 300 kilometers (see Figure 1). The fault is the result of convergence of crust from the high Tibetan Plateau to the west, against the strong and stable crust block underlying the Sichuan Basin and southwest China to the east. On a continental scale, the seismicity of central and eastern Asia is a result of

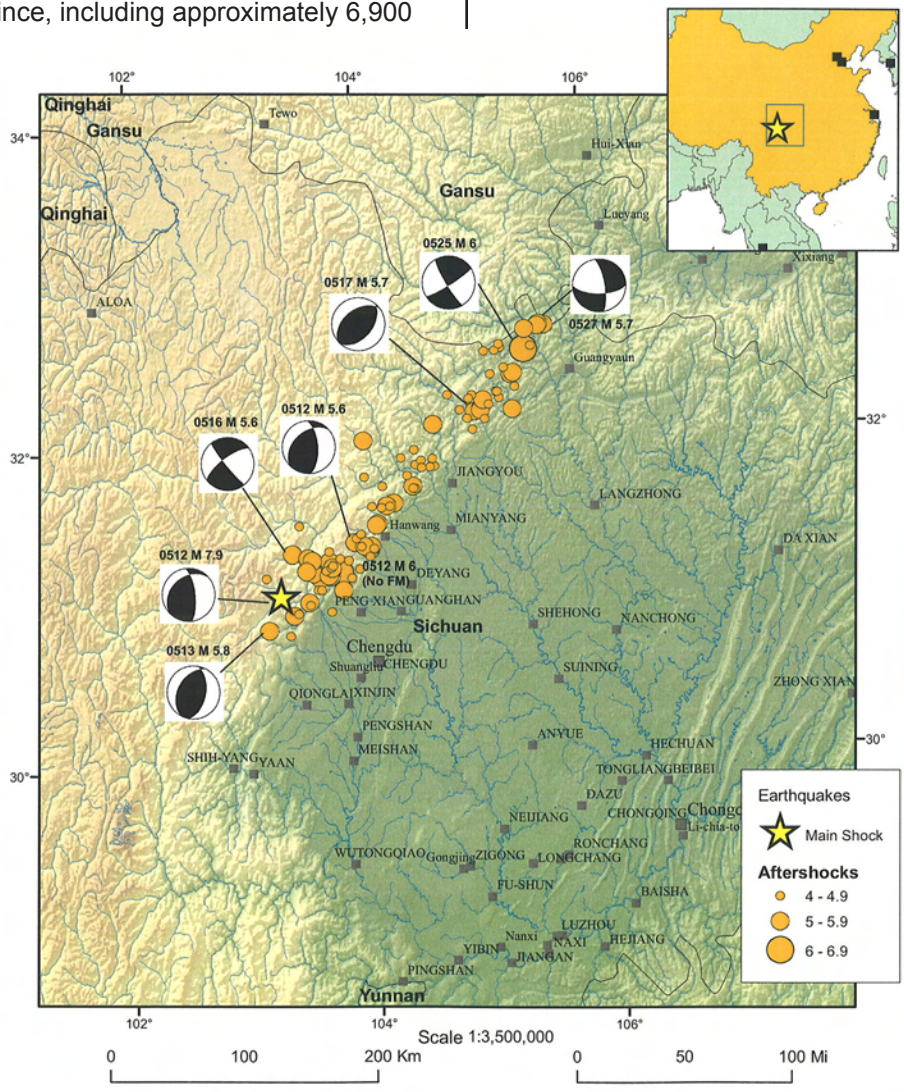

Figure 1: *Locations of Wenchuan earthquake May 12, 2008, mainshock and aftershocks through May 28, 2008 (U.S. Geological Survey, 2008).*

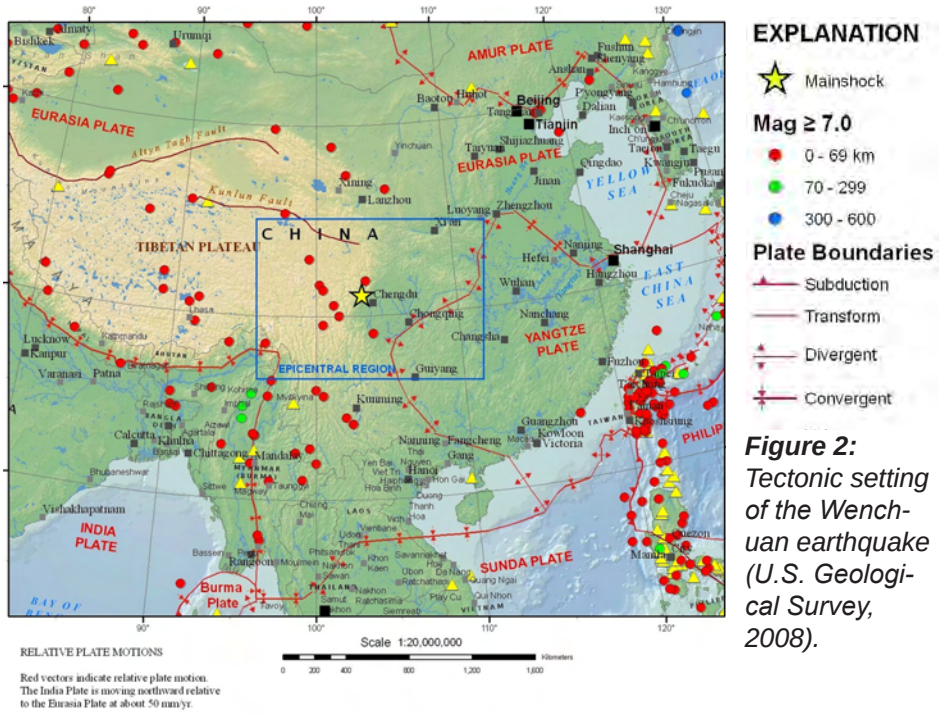

Figure 2: *Tectonic setting of the Wenchuan earthquake (U.S. Geological Survey, 2008).*

northward convergence of the Indian plate against the Eurasian plate. This convergence is broadly accommodated by uplift of the Asian highlands and by the motion of crustal material to the east, away from the uplifted Tibetan Plateau. Thus, India is moving northward into central Asia and pushing Tibet eastward, overriding the Sichuan basin. The tectonic setting is shown in Figure 2.

Previous earthquakes along the northwestern margin of the Sichuan Basin include a M7.3 earthquake in August 1933 that caused over 6,800 deaths, with another 2,500 people perishing subsequently in the failure of a "quake lake" dam created by an earthquake-induced landslide. The average recurrence interval of the Wenchuan earthquake has been estimated to be in the general range of 2,000 to 10,000 years by Burchfiel et al. (2008).

Because large earthquakes were rare before the May 12 event, basic design levels in the Sichuan region were established at Intensity VII (Modified Mercalli Scale). School buildings were considered Category C buildings, which is the same as regular buildings.

Ground Motions: Strong ground motion was measured at about 200 stations established by the China Earthquake Administration. The strong motion time histories have not yet been made available to the research community, though three recordings were shown to the EERI-GEER team. One record obtained at a distance of 22 km from the epicenter and 1.0 km from the fault had a peak ground acceleration (PGA) of around 957 gal and a duration of nearly 60 seconds. A recording made 88 km from the epicenter and 1.0 km from the fault had a PGA of 802 gal and shaking duration of 90 seconds. At 150 km from the epicenter and 75 km from the fault, a third recording showed a PGA of 550 gal and shaking of 150 seconds.

Geotechnical Effects

Surface Faulting: The surface rupture was about 270 km in length. The fault rupture cut through towns, villages, and roads. The fault movement was predominantly a reverse thrust in the southwestern portion of the rupture, becoming more strike-slip towards the northeast. At several locations, surface rupture with 3-4 m of vertical offset was observed; at other locations not visited by the team, vertical offsets as high

Figure 3: *Surface fault rupture with 2 m vertical displacement at Gaoyuan Village.*

Figure 4: *Surface fault rupture with 5 m vertical displacement at Shenxigou.*

Figure 5: *Surface rupture causing total collapse of buildings at Xiaoyudong.*

Figure 6: *Surface fault rupture contributed to failure of Gaoyuan Bridge; north abutment is to the left*

as 5.6 m were reported. Fault rupture at Gaoyuan Village, north of Dujiangyan, is shown in Figure 3. The fault rupture was reported by CEA to be as much as 5 m vertical and about 4.5 m vertical displacement (Figure 4). Fault rupture caused collapse of many structures that were constructed over the fault traces; as many of the buildings were of brick construction, total collapse was very common (Figure 5).

Surface faulting caused extensive damage to civil engineering systems due to the shallow epicenter and the length over which the ruptured faults propagated to the ground surface. In addition, significant variations in terrain elevation in many areas where the fault rupture reached the ground surface led to significant complimentary ruptures that produced more complex patterns of damage. These systems included buildings, roadways, bridges and utility lines. Generally, less damage was observed in structures on the footwall side of the fault than in similar structures on the hanging wall. Cases in which this pattern appeared not to hold true were typically resolved as being due to complimentary fault rupture, although rupture patterns were frequently difficult to discern due to large variations in elevation within short distances.

Fault rupture damaged and caused the collapse of several bridges, including the Xiaoyudong Bridge, the Baihua Bridge near Yingxiu, and the Gaoyuan Bridge (Figure 6), a two-lane traffic bridge with north and south abutments and three bents over a river. The thrust fault rupture went through the north (left) abutment of the bridge and caused the approach slab to be thrust over the first span of the bridge. In addition, part of the west wing wall of the abutment collapsed, along with some of the fill in the abutment. The movement was large enough that the second span became unseated at the center bent and fell to the ground below.

Landslides: Numerous earthquake induced landslides were observed as the team travelled through the mountainous terrain (Figure 7), an area that is historically known to be prone to landslides and debris flows. Evidence of historical events was abundant. Most of the new earthquake-induced slides were relatively shallow, involving predominantly surficial soils, although the lateral and vertical extents were significant. There was evidence that some of these failed progressively. More than 25 deeper and broader slides each mobilized more than 10 million cubic meters of slide material, according to reports. The team members

Figure 7: *Landslides along the Min River between Dujiangyan and Hongkou.*

Figure 8: *Longmenshan Town landslide.*

Figure 9: *Rainfall triggered secondary mudflow in Pengzhou.*

Figure 10: *Resort hotel damaged by rockslide in Shenxigou.*

visited the site of one of these large slides, the Longmenshan Town landslide, that buried a community of more than 20 families, resulting in 68 fatalities (Figure 8).

Large landslides along river valleys formed "quake-lakes," which subsequently threatened communities downstream. Thirty-four landslide-induced lakes have been reported, with Tangjiashan quake-lake being the largest one. The China People's Liberation Army deployed troops to cut channels through the slide to stop the rising water and reduce the risk of a catastrophic failure of the landslide dam. Many of the observed landslides occurred in slopes having abrupt local unevenness, suggesting that local topography had an effect on observed performance.

Mud Flows: Surficial soil and rock loosened by the strong ground shaking during the earthquake was prone to form mud flows and, in fact, heavy rainfall at the time of the site visit triggered secondary mudflows. One mud flow observed by the GEER/EERI team members (Figure 9) took place in Pengzhou during a heavy rainfall on the evening of August 7, 2008. The mud flow was reported to have lasted about 40 minutes and was accompanied by a loud "ground shaking" sound. At the time of the GEER/EERI team visit the following day, the mud flow had ceased, but the debris—which consisted of boulders up to 1.5 m in diameter, tree trunks up to 30 cm in diameter, and a sand/silt clay matrix with a very high moisture content—was still in a very fluid state with low bearing capacity, as evidenced by individuals sinking to their knees as they traversed it.

Lateral Spreading: Strong ground shaking from the earthquake also resulted in lateral spreading. Two slopes with earthquake-induced lateral movements were observed in Dujiangyan City. The first slope had a 50-meter long fissure several meters back from the edge of the slope. The open fissure was covered by plastic sheet to prevent surface water infiltration. The lateral movement of the slope was being monitored by several extensometers installed across the fissure. The second slope had a 100-meter long crack about 4-5 m from the edge of the 5-6 m high slope adjacent to a river. The fissure had a width of approximately 5 cm and a smaller vertical offset of 1-2 cm. In general, engineered slopes appeared to perform

Figure 11: *Large boulders blocking roadway.*

Figure 12: *Unreinforced brick bearing wall building.*

Figure 13: *Collapsed four-story Xuankou Middle School in Yinxiu.*

Figure 14: *Collapsed upper stories above reinforced ground floor storefronts.*

well without any signs of damage resulting from the earthquake.

Rock Falls/Ejections: Numerous rock falls/ejections were observed throughout the mountainous terrain area. In a number of cases, these large rock blocks and boulders were up to several meters in size. Many of these large projectiles appear to have been ejected and landed in their current positions. The largest rock block observed during this trip was estimated to weigh more than 100 tons. These rock blocks/boulders blocked highways and railroads in a number of cases and damaged many buildings during the earthquake. Figures 10 and 11 show rock falls that closed roads and damaged structures.

Structures

Much of the development in the damaged region is located at the base of the steep-sided valleys; it is founded on the alluvial materials deposited by relatively fast-flowing rivers. The resulting matrix of predominantly boulders, cobbles, gravel, and sand is not prone to settlement or bearing capacity problems under the size or style of structures constructed in the region. Brick masonry is the predominant type of construction in Sichuan Province.

Three types of URM buildings were observed in the affected regions: (1) pure unreinforced masonry bearing wall buildings of 1-3 stories with timber and shingle roof structure; (2) reinforced concrete storefront on first story with 2-3 stories of pure URM bearing wall above; and (3) 3- to 7-story mixed brick-concrete system (unreinforced brick infill shear [and some bearing] wall buildings known in the Chinese building code as “restrained brick”). The URM bearing-wall buildings are frequently used for housing in the rural and mountainous areas, and the restrained brick buildings are found mostly in dense urban areas such as Dujiangyan and Chengdu. Concrete moment frame buildings are present, but are not as numerous as brick buildings in the regions most strongly affected by the earthquake. There are a few wood buildings, primarily limited to distant rural areas.

The unreinforced brick bearing-wall buildings typically had precast hollow core plank floors and roofs that bear on transverse brick walls and longitudinal perimeter walls with many openings. As would be expected, this type of building did not perform well in the earthquake, and there were many catastrophic collapses (see Figures 12 and 13). Reportedly, many of the older school buildings that collapsed were 3-4 story pure URM buildings without a reinforced first story. This building type was outlawed in the 1976 Chinese building code, but many can still be found in rural areas.

Storefronts were frequently formed using reinforced concrete frames; however, in many damaged structures the frame only supported the front half of the building with the back of the building supported by load bearing masonry walls. Figure 14 shows typical damage. The 1989 Chinese Building Code has very specific provisions for this building type.

Restrained brick buildings were typically long rectangular buildings three to seven stories tall with precast hollow core plank floors and roofs bearing on reinforced concrete beams spanning to reinforced concrete columns (see Figure 15). There is also a reinforced concrete perimeter ring beam. It was observed that beam stirrups and column ties were typically No. 3 undeformed bars with a fairly wide spacing of 12 inches or greater (Figure 16). There was no positive connection of floor planks to the bearing beams or perimeter ring beam, except by bearing and friction contact.

These buildings typically appeared to be stronger in the longitudinal direction than in the transverse direction because the ground floors typically had open storefronts. The performance of the building type varied greatly from “life safe” (with significant and perhaps unrepairable damage) to partial collapse and total collapse. There did seem to be evidence of directionality effects (strong forces in the direction of the building’s “weak axis”) as well as of orthogonal behavior (forces at a skewed angle to the principal building axes). This may have resulted

Figure 15: *Restrained brick building.*

in torsional behavior, but it's difficult to make engineering sense of this given the lack of real floor and roof rigid diaphragms. We observed many ground floor collapses even without soft-story storefront conditions. Other observations of the performance of this building type include: building "ends" with severe damage, perhaps coinciding with stairwell construction; "end of block" effects; and severe damage or partial collapse at zones of detailing or material defect. Defects include poor ductile detailing, insufficient concrete cover over reinforcing steel, improper size and shape of aggregate in concrete, quality of cement, and poor quality of brick.

Not as common in the Longmenshan Mountain region, concrete moment frame buildings appeared to perform much better than adjacent brick buildings; however, we did not have the opportunity to observe many of them. Although it was noted that some concrete moment frame buildings suffered from weak column/strong beam behavior, there were some buildings that performed remarkably well, even when in close proximity to the fault rupture, such as the newer building constructed in 2007 at the Bailuzhen Middle School (Figure 17) and the middle school in Tongji.

Dams: Southwest China is rich in hydropower. There are more than 7,000 dams in Sichuan Province, about 70% of which were built in the 1950s and 1960s. According to a survey by the Chinese Ministry of Water Resources on May 25, 2008, there were 2380 dams under emergency situation due to earthquake-induced damage, though 96% of them are considered small (reservoir volume less than 5 million cubic meters). In Sichuan Province alone, 69 dams were reported to be in danger of failing. No damage was reported at the Three Gorges Dam that was located approximately 600 km east of the epicenter.

While the GEER team was unable to make detailed observations at any of the dam sites, limited scrutiny of the Zipingpu Dam area, located 17 km east of the epicenter, revealed some of the type of distress. The Zipingpu Dam is a 156-m-high rockfill dam with a total reservoir volume of approximately 1.1 billion cubic meters of water. The reservoir was drained in the days following the earthquake due to safety concerns. High peak accelerations were reported at the crest of the dam. The crest is reported to have settled about 0.7 m. Small lateral displacements on the order of 10 cm were observed at the top of the parapet wall. The concrete slab at the crest of the dam settled approximately 5 cm with respect to the access road. One hundred fishermen were reported to have been killed by 10-m-high waves in Zipingpu reservoir after the earthquake, although this fact was not independently verified by the team members. These seiche waves may have resulted from the combined effects of landslides entering into the reservoir and earthquake shaking.

Lifelines

Water: There are mainly two types of water supply systems in Sichuan Province. In the major cities, water is supplied by water works companies, which are typically government-owned but independently operated. In the countryside and remote areas, water sources are mostly spring water and wells. The wells and spring water collection systems are operated by townships, village governments, or groups of homeowners. Water used for drinking is always boiled (before and after earthquakes), even water in the cities, due to the uncertain sanitary condition of the distribution systems.

In the Chengdu Metropolitan area, water facilities were damaged in many locations, but water service in small rural townships and villages was severely damaged. It was reported that a water shortage affected about 690,000 people after the earthquake in the area (which has a population of over 10 million).

Approximately 30,000 km of the pipelines were subjected to reasonably strong ground motions (about PGA 0.10g or higher) and, as of 20 days after the earthquake, about 22,000 km of pipeline had service restored. Pumping plant building structures (presumed URMs) appeared to be heavily damaged; however, the pumps were typically still functional. Crews installed steel pipe bollards to protect the pumps from the falling debris of the surrounding structures. According to reports, Chengdu Waterworks had

Figure 16: *Steel reinforcing and pebble aggregate used in column of restrained brick building.*

Figure 17: *Xuankou Middle School building in Bailuzhen with fault rupture in foreground.*

installed 6,500 meters of temporary piping by June 14 for distributing water to center locations of the temporary housing or tent encampments.

Evidence of pipeline damage included broken cast iron and PVC water mains. Initial estimates that consider ground shaking, landslide, fault offset, and liquefaction suggest more than 2,000 damaged buried water pipes requiring repair. The various building collapses would have caused many damaged service laterals. From our observation, at least some of the elevated cast-in-place concrete water tanks performed well and remained functional (leak tight). However, some of the water towers (assumed unreinforced masonry) sustained heavy damage, ranging from outright collapse to severe damage (large x-cracks in the supporting structures).

The headquarters of the Chengdu Waterworks sustained some damage, and the control room was temporarily relocated from the fifth floor to the ground floor on May 20 in response to the cracked walls and the aftershocks. The control room was returned to the original location on June 20.

The water works companies and the military provided water to central locations and temporary housing locations, such as disaster control centers and tent encampments. Temporary water treatment facilities were installed near the temporary housing to supply water to the distribution centers. Waterworks companies also distributed water disinfection pills throughout the towns and villages in the remote areas.

Two days after the earthquake, a rumor of water contamination due to a chemical explosion from a chemical factory at the water intake spread rapidly throughout Chengdu City. The company received more than 1,900 phone calls on that day (compared to 200 calls on normal days). Despite the company's denial, the rumor caused the city's residents to start storing water at home with pots and pans. The water system pressure suddenly dropped to a dangerously low level. In order to avoid damage due to negative pressure from the heavy water usage, the water system was shut down for a short period. The water agencies and the city government had to start a public campaign with all available means, including cell phone text messaging, to clear the rumor. The water pressure returned to normal in the afternoon.

Electric Power: The earthquake interrupted the power system in most of the disaster area. Chengdu was the only city with no power outage. In general, the outage ranged from 10 to 20 days, with remote areas experiencing the longest outages due to the difficulty of access to repair the damage.

Electric power generation plants, hydro and coal fire, sustained damage and remained out of service for 60 days after the earthquake. Many substations in the remote towns such as Yingxiu, Wenchuan, and Beichuan were extensively damaged. The distribution and transmission systems were damaged by landslides and rock falls (Figure 18). Damage to pole-mounted transformers was also observed.

Telecommunications: The earthquake interrupted both landline and wireless services in three ways: damage to equipment (Figure 19), the distribution system, and electric power outages. In Hongkou, when the ASCE/TCLEE team was there 60 days after the earthquake, one of the wireless service providers was still out of service.

In the mountain areas, people rely on wireless service as their primary means of telecommunication. With prolonged electric power outage, the cell sites not damaged by the earthquake ran out of reserve power within 2-3 hours. Landslides damaged many wired connections between cell sites, resulting in failed incoming and outgoing calls within the cell. An additional problem was that the cellular phones ran out of power. Some merchants provided recharging services using a small power generator.

Repairing damage was extremely difficult due to major landslides and rock falls preventing access to the

Figure 18: *Power pole damaged by rocks along the road leading to Hongkou.*

Figure 19: *A damaged cell site at Hongkou.*

damaged sites. Service providers were able to bring in material and personnel for repairs only after the military cleared access to remote towns. Unfortunately, we did not get access to any telecommunication service providers' facility to obtain information on overall system performance.

Transportation Systems

Approximately 30,000 miles of roads and railways, 3,000 bridges, 100 tunnels, and many miles of retaining structures were damaged by the earthquake. Losses to the transportation sector exceed US$10 billion. On the day of the earthquake, 31 passenger trains and 149 cargo trains were stranded on lines linking Chengdu with the rest of the country. There were many landslides, bridge collapses, and other damage along rail tracks, and 34 railway stations on the Baoji-Chengdu Railway lost power. A cargo train on this railway caught fire in a tunnel near Huixian County in Gansu Province as the tunnel collapsed.

The Railways Ministry dispatched rescue teams and sent repair teams to check railway facilities in the region. All trains running in the damaged area were ordered to halt in open areas, and passenger trains heading for quake-hit areas were ordered to turn back. By midnight on the day of the earthquake, a number of trains from Chengdu heading for Kunming, Wuchang, and Nanchang had resumed running, although about 10,000 passengers were still stranded at the Chengdu Railway Station.

Major highways and expressways in Sichuan were closed, according to the Ministry of Transport. Transport along the expressway linking Chengdu to Mianyang was halted. The roads linking Wenchuan to the city of Dujiangyan were damaged, blocking disaster relief teams. Landslides also struck several highways in neighboring Shaanxi Province, but the national highway linking it with Sichuan Province remained in operation. The Ministry of Transport was immediately engaged in repairing damaged roads to ensure that the quake-hit areas had access to goods for disaster relief. The ministry asked neighboring provinces to repair roads going into Sichuan.

Many of the bridges in the Longmenshan region have bridge spans that are simply supported at the ends (see Figure 6). A single span of one of the approaches to the tall Minjiang Bridge over the Zipingpu Reservoir became unseated and fell into the lake, as shown in Figure 20. There were numerous other reports that bridges with simply supported spans were unseated and collapsed (Figure 21). It was not uncommon to see improvised systems constructed to temporarily contend with the impact of the bridge collapse on community life. Engineers of new replacement bridges will want to consider higher seismic input as well as larger displacements. Existing bridges should be retrofitted to prevent unseating in future earthquakes; retrofit strategies used in California and the United States may be applicable.

Reports indicate that the lateral design for earthquake forces of bridges may not be sufficient given the ground motions of this earthquake. Some bridges had damaged shear keys at the abutments and ben caps when the strongest ground motions were in the transverse direction. The Baihua Bridge had damage to the transverse beams between the piers as well as flexural distress near the base of some of the bent piers.

Chengdu Shuangliu International Airport was temporarily closed, affecting 169 inbound and 108 outbound flights. Some facilities were damaged, and the control tower and regional radar control were evacu-

ated. The airport reopened on the evening of May 12, offering limited service as a staging area for relief operations. All airports in Sichuan were reopened by the end of the day.

After the earthquake, an enormous effort was made to repair roads and railroads as quickly as possible. Fourteen days after the earthquake, all roads into Chengdu were repaired. By June 14, roads to 248 out of 254 towns in the damaged area were repaired. Railways took a little longer, since they needed a smoother alignment and electric power for their operation. Repairs will continue for many months and years.

Emergency Response

The response to the massive earthquake was quick and decisive. Although no country is prepared for a natural disaster of this scale, the central China government rapidly mobilized 130,000 soldiers of the People's Liberation Army (PLA) to provide search and rescue, restore access, and maintain order. Other Chinese provinces and major cities sent personnel, equipment, and resources to supplement the PLA and local forces. In addition, many private individuals and groups from all over China went to Sichuan Province to offer aid and support. Foreign aid and personnel were also accepted by China, unlike during the 1976 Tangshan earthquake. There was some confusion on coordination and overlapping of responsibilities, but the response is considered well done by many.

China's 50-member State Council, chaired by Premier Wen Jiabao, quickly established an Earthquake Rescue and Relief Headquarters that has provided most of the principles and priorities for restoring the livelihoods and physical environment of the 51 counties (cities and districts) in the 132,596 km^2 affected region and its 20 million residents. Three-month targets were established, heavily emphasizing the needs of survivors, as were an ambitious and comprehensive set of three-year goals to ensure that every family has a house, every household has employment, every person has social and medical care, and the infrastructure, economy, and environment are all improved.

Nongovernmental organizations, community groups, and volunteers—often referred to as civil society—played a significant role in the response, particularly during the early days after the disaster. Many of the initial search and rescue efforts were undertaken by family members, neighbors, and other local groups before formal assistance could arrive. For example, in the town of Yingxiu, three-quarters of the population were killed, and landslides made roads to the town impassable, so local citizens had to perform search and rescue operations before government help arrived.

In addition to these search and rescue efforts, a large number of civil society participants converged from unaffected areas to provide assistance. For example, Chengdu taxi drivers drove to nearby Dujiangyuan when they heard about the many people who did not have means to leave that area. Skilled personnel, including counselors and nurses, came from other provinces, and local doctors even trekked through rough terrain to reach more remote villages. Groups of foreigners based in Chengdu rallied together to provide assistance. Such convergence is typical following disaster events; however, many people we spoke with described this heightened level of nongovernmental involvement as unusual within the Chinese political and cultural context. We were told that all relief supplies were supposed to be directed to the Red Cross of China or the Ministry of Civil Affairs, but the first 10 days saw a number of alternative relief distribution strategies employed.

Given that land and mobile phone coverage was disrupted in the damaged areas, the media played a major role in disseminating information about need, and their reports drove

Figure 20: *Minjiang Bridge crossing over Zipingpu Reservoir with one missing span.*

Figure 21: *After this bridge collapsed, people rigged up ropes and pulleys to get supplies over a river.*

the direction of many volunteer efforts. We were told that in the early days of the response and recovery, towns with intense media attention received many donations, while other towns lacked supplies. Many private companies wanted to donate to the reconstruction of schools, an issue that received considerable attention given the loss of so many school children. Alliances of nongovernmental organizations also served a very important role in the initial activities, in terms of both credentialing and needs identification.

As relief and, later, recovery efforts became possible, the role of many of the civil society groups became smaller. Several people we spoke with indicated that such groups had limited capacity to undertake larger relief and recovery tasks. Others pointed to re-established government resistance to their involvement—particularly on sensitive issues such as those surrounding school collapses or land rights. Resistance was also attributed to concern on the part of local government officials not wanting to lose control of operations. It was not uncommon, we were told, for relief assistance from informal groups to be politely refused by village officials or survivors themselves, regardless of whether or not the groups were locally, nationally, or internationally based. Government concern over possible improper financial expenditures on the part of some informal groups was yet another issue raised in some of our conversations.

Some organizations continue to have a strong presence, particularly when they fill gaps in assistance provision for special needs. One such previously established organization was Half the Sky, which during routine periods provides services for China's orphaned children. Half the Sky maintained a presence within the temporary resettlement camps to provide daycare, art and play therapy, counseling, and a safe space within which children could play.

Temporary Housing

With the authority to redirect government land and the people residing there, and to control commercial production of materials, the government was able to establish an impressive number of temporary camps around the province quickly. We visited one camp that was home to 12,000 people (see Figure 22). Construction started on May 19, and the camp opened ten days later. Each unit within the camp housed 3-4 people. Furniture was provided through donations. While family members were assigned to the same unit, neighbors or even those families from within the same village were not necessarily housed nearby, as units were selected on a first-come, first-served basis. Camps had hospitals, pharmacies, and schools.

While facilities were partially staffed with camp residents who had worked at similar facilities that had been destroyed in the earthquake, other paid and volunteer staff were redirected from other areas. Food in the camp we visited had been free until just over a month after the disaster, but then residents were required to purchase their food from shops inside or outside the camp. While allowances were provided to victims, we were told that the government assistance program would cease at the end of the summer. Camps provided training programs and job searches for residents, and some residents took or created jobs within the camp itself. For example, some worked in the training sessions, others in sanitation roles, and still others opened up laundry, hair salon, and grocery businesses (see Figure 23). Many of the temporary housing encampments include temporary school facilities, such as the elementary school in Yingxiu shown in Figure 24.

We talked to some survivors who preferred not to take up residence in the resettlement camps. They were staying in much smaller tent camps or near the foundations of their former homes (see Figure 25). These people indicated that they had opted not to stay at the shelters because of their need to take care of crops, the distance between the camps and their original property, the additional costs associated with residing at the camps (for some food items and propane for cooking), and their deep sense of attachment to place and community.

Figure 22: *This temporary camp housed 12,000 people.*

Figure 23: *Some camp residents opened up laundry, hair salon, and grocery businesses.*

Figure 24: *Temporary elementary school in Yingxiu.*

Figure 25: *Temporary tent home established near ruins of former home.*

Some survivors had rebuilt their homes with scavenged or reclaimed material; others had simply cleared the debris and created a living space outside near the foundation (Figure 26).

Some businesses had reopened in buildings of questionable structural integrity that had been rudimentarily repaired. Several of these business owners indicated that they completed the repairs themselves, noting that their damage was not severe enough to be a priority of the government. We repeatedly saw individuals taking the initiative to move forward in their own recovery efforts. At the same time, some (although not all) of the rebuilt structures appeared to be of the same hazardous type that had put them at risk during the quake.

Recovery

The State Council took swift legislative action to establish a multi-governmental management framework for the recovery effort. The "Wenchuan Earthquake Disaster Recovery and Reconstruction Act" (passed into law on June 4, 2008) provides the legal basis for various departments and government entities, both inside and outside the quake-hit region, to assist with recovery and reconstruction. The act specifies guiding principles for damage assessment, temporary housing, reconstruction planning, financing, implementation, and management. A special team on reconstruction planning was established to act on the planning principles, and the team has made dozens of trips to the disaster-affected region to speak with local officials and residents. A general reconstruction plan was developed for the three affected provinces, as were ten specific plans covering urban systems, rural development, urban-rural housing, infrastructure, public service facilities, productivity distribution and industrial restructuring, market service system, disaster prevention and mitigation, ecological rehabilitation, and land utilization.

These, in turn, were incorporated into a comprehensive reconstruction plan released for public review on August 12. The "State Overall Planning for Post-Wenchuan Earthquake Restoration and Reconstruction" groups the 51 disaster-affected counties into 3 categories—areas suitable for reconstruction, areas suitable for appropriate reconstruction, and ecological reconstruction areas (with future growth limitations)—and sets the rebuilding and funding guidelines for each. The National Development and Reform Commission, China's lead agency for urban plan development, is currently soliciting feedback on the plan through outreach workshops with international experts, and setting up special websites for comments at the NDRC, People's Net and China Net.

A central element of China's post-disaster management framework is a pairing of affected with unaffected regions to help provide the resources and funds for recovery and

Figure 26: *Some homeowners cleared the debris and adapted a living space outside near the foundation.*

reconstruction. The disaster-stricken areas of Sichuan, Gansu and Shaanxi provinces were divided into 24 districts and matched with 24 localities across China. For example, the town of Dujiangyan (within the administrative boundaries of the city of Chengdu) is sponsored by Shanghai. Similarly, Yingxiu's sponsor is Guangzhou, Pengzhou's is Fujian, Mianzhu's is Jiangsu, and Anxian's is Beijing. Each sponsoring locality has been given work tasks, funding and resource assignments, as well as timeframes for their completion. Their contributions include provision of human resources, "in kind" support from planning institutes and other agencies within the sponsor region, provision of temporary housing units, and donations and financial support. Banners acknowledging the work of sponsor locations are visible across the disaster-affected region.

As of August 25, the State Council reports that nearly 1.5 million disaster-affected people have been relocated; about 180,000 have been organized to work outside the disaster zone and about 678,000 people have found jobs in their hometowns (Xinhua, 2008). About 92% of the 139,000 damaged business outlets had been reopened. Almost 663,000 temporary houses have been constructed and another 2,500 were being installed. Nearly all of the 53,295 km of roads damaged by the earthquake had been restored.

Sponsoring localities have been major suppliers of the temporary housing, and planning institutes from sponsoring localities have volunteered to plan the temporary housing encampments, following the design principles laid out by the central government in the Wenchuan Earthquake Disaster Recovery and Reconstruction Act. The processes for determining the number of units needed and the site selections are unclear. Local officials described site selections being determined based upon the availability of water, electricity, and access, but were less certain about environmental and hazard considerations. Some very large encampments were observed in river floodplains and at the base of steep slopes.

Recovery will be a great challenge, even with China's strong economy. According to Watts (2008), the reconstruction is estimated to have a cost of about 1 trillion yuan (US$147 billion). This amount is equivalent to one-fifth of the entire tax revenue of China for a single year. This will include providing new homes for 3.9 million refugees, replacing schools, and creating jobs for 1 million people.

Rebuilding the infrastructure of the mountain areas will be a challenge with the geologic and climatic conditions, not to mention continuing seismic activity. One of the most pressing challenges is to ensure higher seismic standards and construction quality in the rebuilding. The reconstruction plan calls for higher earthquake-resistance levels of infrastructure construction in the quake-hit regions, especially for schools and hospitals. In rural areas, reconstruction planners recommend that technicians advise residents on safe rebuilding, but many villagers are moving ahead and reconstructing with a variety of traditional and recycled materials, particularly reclaimed bricks.

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