Earthq Eng & Eng Vib (2009) 8:275-285 **DOI**: 10.1007/s11803-009-9064-x

Lessons in bridge damage learned from the Wenchuan earthquake

W. Phillip Yen[1†], Genda Chen[2‡], Mark Yashinski[3§], Youssef Hashash[4‡], Curtis Holub[5*], Wang Kehai[6§] and GuoXiaodong[7§]

1. *Turner-Fairbank Highway Research Center of Federal Highway Administration (FWHA)*
2. *Center for Transportation Infrastructure and Safety (CTIS), a National University Transportation Center at Missouri University of Science and Technology*
3. *California Department of Transportation Representing the Earthquake Engineering Research Institute (EERI)*
4. *University of Illinois at Urbana Champaign and Representing Geo-Engineering Earthquake Reconnaissance (GEER)*
5. *Mid-America Earthquake Center (MAE), University of Illinois at Urbana Champaign*
6. *Research Institute of Highway, the Ministry of Communication of China*
7. *Sichuan Province Highway Planning, Survey, Design, and Research Institute, China*

Abstract: A strong earthquake occurred in Wenchuan County, Sichuan Province, China, on May 12, 2008. Shortly after the earthquake, the Turner-Fairbank Highway Research Center of the Federal Highway Administration, in partnership with the Research Institute of Highways, the Ministry of Communication of China, led a reconnaissance team to conduct a post-earthquake bridge performance investigation of the transportation system in the earthquake affected areas. The U.S. transportation system reconnaissance team visited the area during July 20–24, 2008. This paper presents the findings and lessons learned by the team.

Keywords: earthquake engineering; bridge engineering; post earthquake investigation

1 Introduction

A team of five U.S. engineers led by Dr. Phillip W. Yen was invited to study bridge damage from the *M* 7.9 (*M* 8.0 according to the China Earthquake Administration, CEA) Wenchuan earthquake of May 12, 2008. The team was invited by the Ministry of Communication of China and hosted by the Sichuan Province Highway Planning, Survey, Design, and Research Institute.

The reconnaissance team visited the earthquake stricken areas during July 20–24, 2008. Figure 1 shows the location of the bridge structures investigated.

2 Observed damage to bridges

Although many bridges were inspected, only the three most severely damaged and/or collapsed bridges are discussed in this paper due to space limitations. More discussions of the performance of other bridges will be including in forthcoming papers.

2.1 Bridges in Nanba Town (Nanba Bridge)

Three bridges crossed near Nanba Town as shown in Fig. 2. The west structure was a concrete and masonry three-span arch bridge built in the 1970 s. The old arch bridge completely collapsed during the earthquake as shown in Fig. 3. Immediately downstream of the arch bridge was a 10-span river crossing (on a 10° skew) that was under construction during the earthquake, as shown in Fig. 4. Each 6 m long span was simply supported on two-column bents and seat-type abutments with 560 mm seats. As shown in Fig. 5, each span consisted of eight precast box girders with a cross section of 1067 mm by 1520 mm. Each girder was supported on two 200 mm round elastomeric bearings at each end. The girders were in place but the concrete deck had not yet been poured at the time of the earthquake, as seen from Fig. 5.

As shown in Figs. 4 and 5, most of the box girders of the new bridge dropped into the river and the two-column bents were distorted. The end box girders were transversely displaced by approximately 760 mm. The deck had not yet been poured, there was no transverse

Correspondence to: W. Phillip Yen, Seismic Research Program Manager, Turner-Fairbank Highway Research Center of Federal Highway Administration (FHWA), Office of Infrastructure R & D, Bridge Design & Hazard Mitigation T-111, 6300 Georgetown Pike, McLean, VA 22101
E-mail: wenhueiyen@hotmail.com
†Seismic Research Program Manager; ‡Professor; §Senior Engineer; *PhD Candidate
Supported by: Turner-Fairbank Highway Research Center of Federal Highway Administration
Received April 29, 2009; **Accepted** May 16, 2009

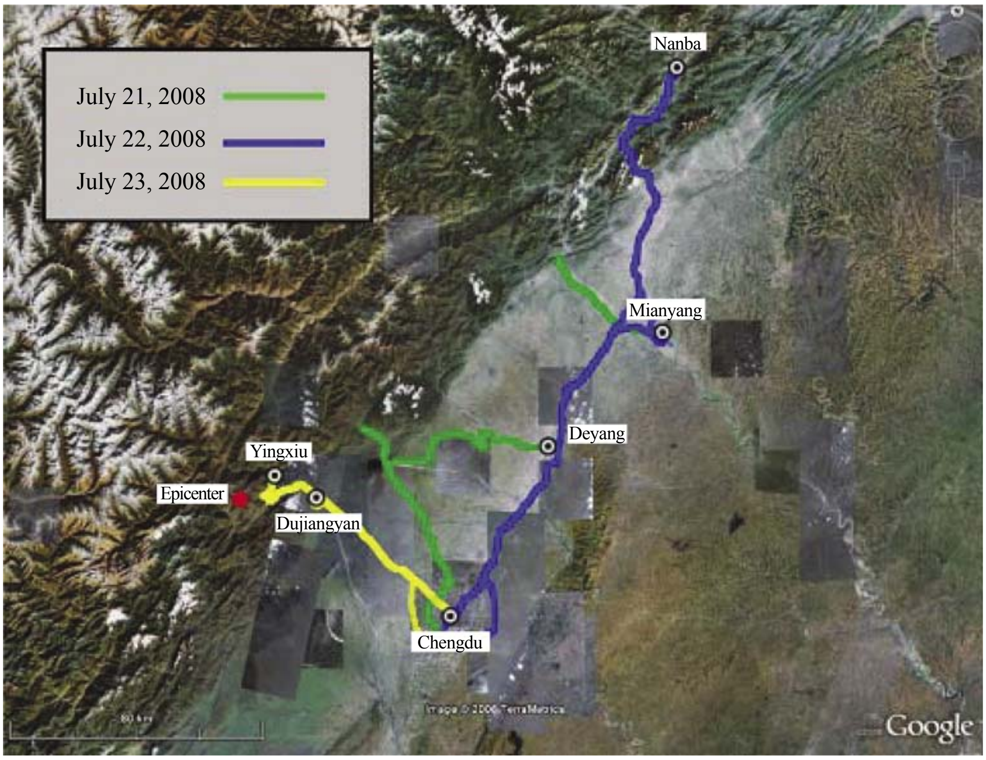


Fig. 1 Bridge sites investigated by reconnaissance team

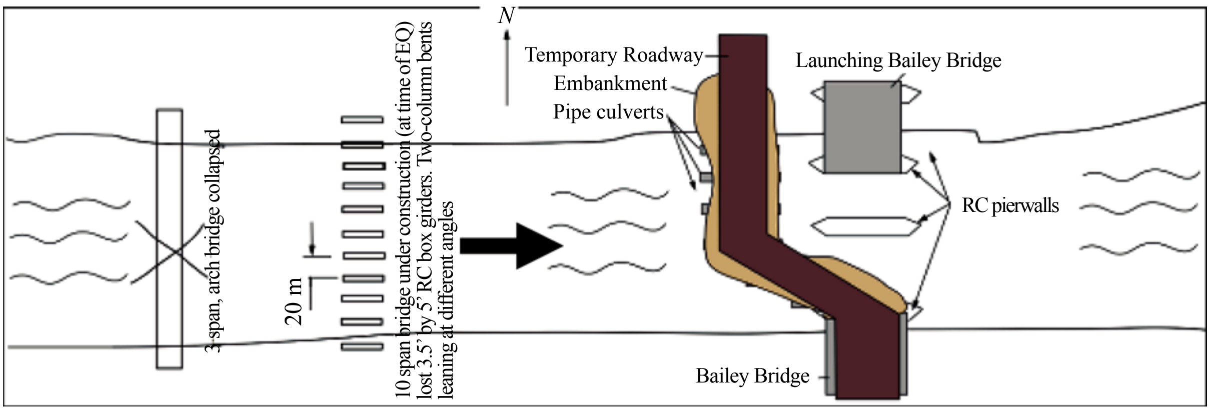


Fig. 2 Three bridges at Nanba Town

Fig. 3 Collapse of the old three-arch bridge

Fig. 4 Damage scenario of the 10-span bridge under construction during the earthquake

Fig. 5 Damage to the 10-span bridge under construction

bracing or shear keys, and girders were on a slight skew, all of which contributed to the damage. Also, many of the bents were leaning or distorted, but no damage was visible above the waterline.

There was no indication that the ten-span bridge suffered any damage due to a fault crossing. As such, the three-span arch bridge must have been damaged by ground shaking, perhaps exacerbated by soil movement. Liquefaction, lateral spreading, or other soil movement may have also been responsible for the distortion of the two column bents. The reconnaissance team was not able to discern what type of foundation system the bents were supported on, but apparently they were not sufficiently embedded into adequate material.

On the east side of the old and new bridges is a temporary structure that was being constructed by launching Bailey Bridges onto new RC pier walls at the time of field reconnaissance. As shown in Fig. 6, vehicles were driving across the river on fill material temporarily laid over culverts.

2.2 Miaoziping Bridge

Miaoziping Bridge from Dujiangyan to Wenchuan was under construction during the earthquake. It consists of a tunnel at Zipingpu and a bridge over the Mingjiang River as schematically shown in Fig. 7. The tunnel is shown in Fig. 8 and experienced little damage during the earthquake. The bridge was scheduled to open in October, 2008. Near the bridge is the well-known Zipingpu Dam. The bridge of approximately 1.4 km long consists of three parts: a main span and two approach spans as shown in Fig. 9.

As shown in Fig. 10, the approach span near the tunnel is a two-span, RC girder structure each 50 m in length. The bridge deck is supported on five RC girders and two-column bents with several cross struts. As indicated in Fig. 10, the bridge deck is continuous

(a) Overview of a temporary bridge construction

(b) Bailey bridge pushed in place

Fig. 6 Construction of a temporary bridge

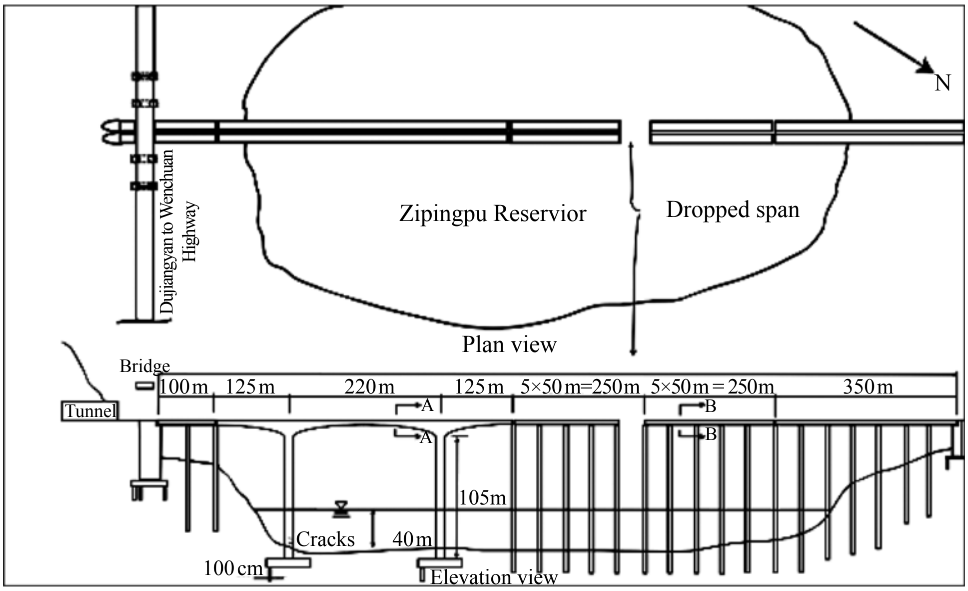
but the girders are simply supported on the bents. From Figs. 7 (a) and 7 (b), the main bridge is a continuous, non-prismatic, three-span structure supported on two intermediate wall piers with 125 m, 220 m, and 125 m length, respectively. The superstructure is a single-cell box girder structure. The depth of the girders varies to a maximum depth of 4.0 – 4.5 m.

The approach bridge on the other side of the main span has three parts of 250 m, 250 m, and 100 m, respectively. Any of the first three parts has five spans of 50 m long, supporting ten RC girders. All girders are simply supported on the bents for dead load but the bridge deck is continuous for live load. The bents are as tall as 105 m. In some locations, they are 40 m deep into water in the Zipingpu reservoir of the Zipingpu Dam in the main span of the bridge. Expansion joints are used between the parts and between the approach and main bridge.

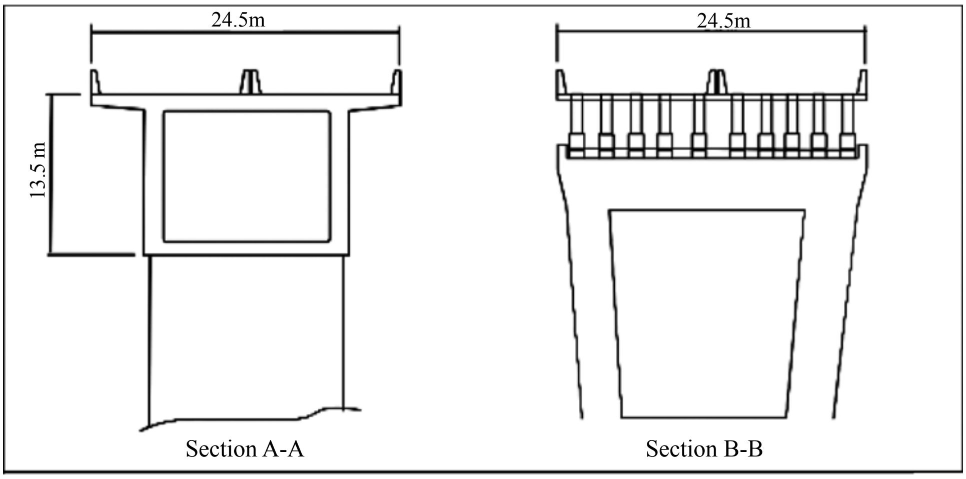
The construction of the bridge was near completion except for the installation of expansion joints at the time of the earthquake. The most severe damage was to the end span of a five-span T-girder segment that became unseated at the expansion joint end, fractured in the continuous deck at the other end due to gravity load, and fell off the supporting bent caps during the earthquake. The bent seats were approximately 300 mm in length but the bridge experienced at least 500 mm of longitudinal movement due to earthquake shaking. Since the columns of each bent are approximately 105 m tall, the accumulated displacement at the bent cap was likely significant during the earthquake. There were other indications of large longitudinal movement. In Fig.11, the barrier rails were overlapped by about 300 mm at the southeast expansion joint. The barrier also displaced transversely for approximately 250 mm. Divers found cracks at the bottom of the main span columns due to earthquake shaking. Shear key failure was also observed as shown in Fig. 12. After the earthquake, the bridge deck was jacked back into place with hydraulic jacks.

The end of the Miaoziping Bridge near the tunnel is divided into two parallel elevated structures in order to guide two lanes of traffic to be in alignment with the twin tunnels as indicated in Fig. 13. Over the southeast approach is a four-span RC girder bridge built in 2004. The bridge supports the old highway from Dujiangyan to Wenchuan and Jiuzhaigou. The old highway was built along the mountain terrain, perpendicular to the Miaoziping Bridge at Zipingpu Reservior. The bridge showed shear key failures and embankment cracking as shown in Fig. 14.

In the vicinity of the Miaoziping Bridge, there are several RC girder bridges as shown in Fig. 15. These bridges appeared to suffer little damage. No weight limits were posted on these bridges.



(a) Plan and elevation



(b) Cross section of main span and approach bridge

Fig. 7 Schematic view of the Miaoziping Bridge

Fig. 8 Miaoziping Tunnel

Fig. 9 Overview of the Miaoziping Bridge

Fig. 10 Drop-off span and construction details between two spans

Fig. 11 Longitudinal and transverse offset of bridge deck

Fig. 12 Shear key failure

Fig. 13 End of the Miaoziping Bridge (left) and its overpass for the old highway (right)

Fig. 14 Damage to shear key (left) and embankment of the overpass (right)

Fig. 15 Bridges in the vicinity of Miaoziping Bridge

2.3 Baihua Bridge

The Baihua Bridge is part of a Class 2 Highway from Dujiangyan to Wenchuan. It was built in 2004 by the owner of a nearby hydroelectric plant to bring in workers. As schematically shown in Fig. 16, the bridge is an 18-span, RC structure with a total length of 450 m. The bridge superstructure was supported on two-column bents of varying heights as it climbs over the hilly terrain. The tallest bents have one or two struts to provide transverse restraint between the columns. The bridge has both straight and curved spans. For convenience, the bridge structure can be divided into six sections as summarized in Table 1. The superstructure was a prestressed box girder with a drop-in T-girder span between Bent 9 and Bent 10. There were expansion joints at Bents 2, 6, 9, 10, 14, and at the two seat-type abutments. For the drop-in span, the bridge deck just rested on the bent cap at its both ends.

During the earthquake, the more highly curved section of the bridge completely collapsed as illustrated in Fig. 17. The rest of the bridge suffered varying degrees of damage, including shear cracks and failure at columns and struts, shear key failure, and bearing failure as shown in Figs. 18–21 for Bents 3, 9, 15, and 18, respectively. At Bent 3, typical damage occurred between the strut and columns in the form of spalling and cracks. At Bent 9 with expansion joints, the superstructure had significant transverse displacement, knocking off the shear key. At Bent 15, the bridge section was completely collapsed most likely due to the shear and flexural failure of the columns. At Bent 18, in addition to cracks between the column and strut, significant spalling occurred underneath the bridge deck.

At the curved part of the bridge, the bridge is likely subjected to higher deformation and stress under the earthquake, resulting in collapse. Even on the straight part of the bridge, due to tall columns, the damage in various sections resulted in tilting of the columns that pushed the superstructure almost off their support at several locations. A detour had been graded along the side of the damaged bridge. Considering the high risk of further collapse during an aftershock that could endanger people using the detour, the rest of the bridge was demolished with dynamite as illustrated in Fig. 22.

Similar to the previously described Xiaoyudong Bridge, this bridge could have been damaged by surface faulting though there is no clear surface fault feature observed by the reconnaissance team near the bridge site. Considering the complex vibration system

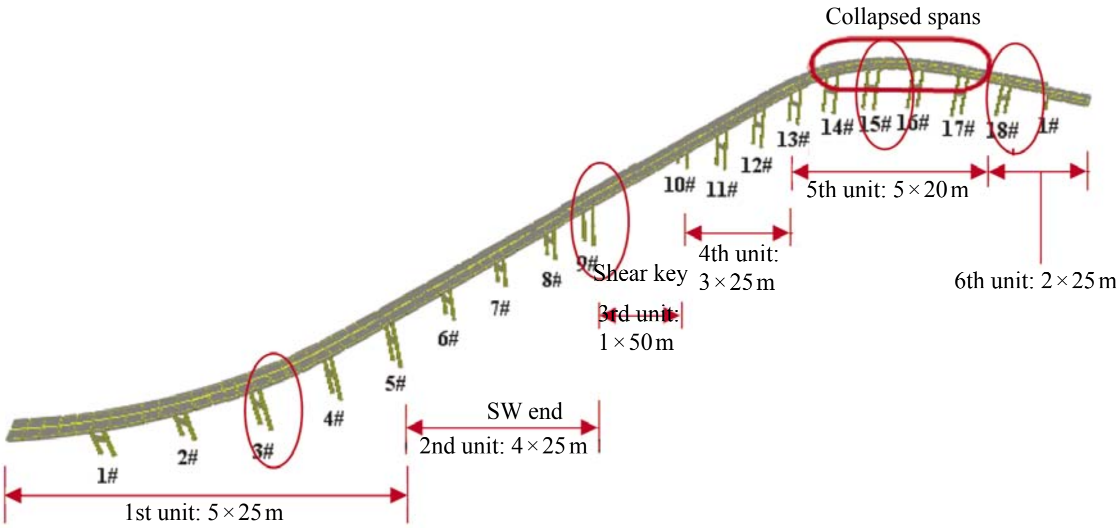


Fig. 16 Schematic view of the Baihua Bridge before the earthquake

Table 1 Parameters of the Baihua Bridge

Section	No. of span	Span length (m)	Section length (m)
1	5	25	125
2	4	25	100
3	1	50	50
4	3	25	75
5	5	20	100
6	2	25	50

Fig. 17 Post-earthquake damage

Fig. 18 Damage at Bent 3

Fig. 19 Damage at Bent 9

(a) Column shear and flexural failure (b) Column shear failure and Section 5 collapse

Fig. 20 Damage at Bent 15

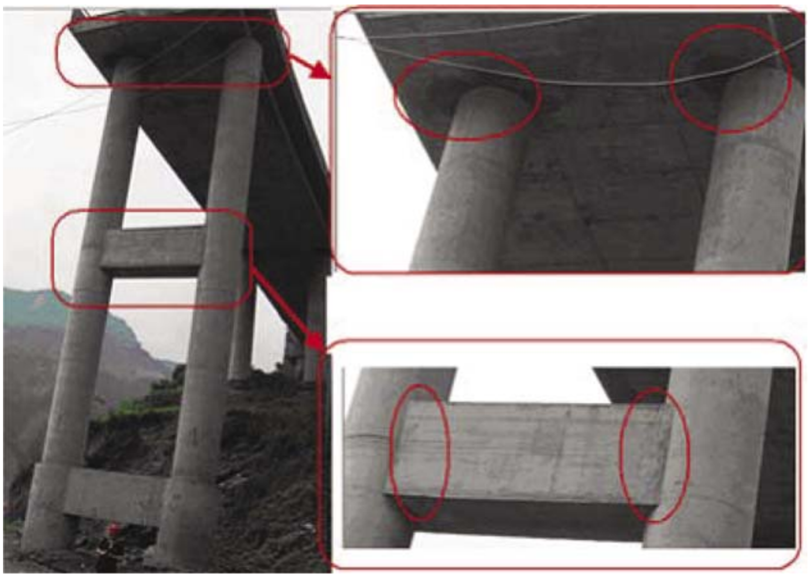


Fig. 21 Damage at Bent 18

(a) Blast demolition

(b) After demolition

Fig. 22 Post-earthquake demolition of Baihua Bridge

of the irregular structure with varying column heights and lack of continuity between the substructure and superstructure, severe shaking alone could result in collapse. Still, the bridge is very close to the fault and several photos (taken immediately after the earthquake) show what looks to be a surface fault under the bridge. During the field reconnaissance nearly three months later, all signs of the fault were gone and the bridge was lying on the ground.

3 Lessons learned from the post-earthquake reconnaissance

The bridge damage observed during the May 12, 2008, Wenchuan earthquake was reminiscent of the suffering caused by the February 9, 1971 San Fernando, California earthquake. In the 1960's and 1970's, the U.S. was expanding their highway network similar to China's efforts today. Before the San Fernando earthquake, Caltrans maximum seismic coefficient was 0.10 g, similar to China's current maximum seismic coefficient of 0.10 g. After the San Fernando earthquake, Caltrans greatly increased the seismic hazard used to design California's bridges, similar to how Japan increased the hazard for its bridges following the 1995 Kobe earthquake. It is hoped that this earthquake will have the same significance for China's bridge engineers and the seismic hazard for areas near known faults will be greatly increased. Also, the bridges studied during this reconnaissance trip had few seismic details such as long seats, large shear keys, or tightly-spaced transverse reinforcement. These details would greatly reduce bridge damage during future earthquakes. The various fault traces through the region need to be carefully identified and bridges should be designed for the seismic hazards at the bridge site, based on a low probability of the hazard being exceeded during the life of the bridge. This would ensure that China could rely on its highway infrastructure during the frequent earthquakes that strike this and other regions.

4 Conclusions

(1) The collapse of most arch and girder bridges is associated with surface rupturing of the faults in the Longmen Mountain thrust zone. A significant portion of roadways and bridges were pushed away or buried by overwhelming landslides in the mountainous terrain of steep slopes.

(2) The representative damage types in the bridge superstructure include unseating of girders, longitudinal and transverse offset of decks, pounding at expansion joints, and shear key failure.

(3) The bearings of several girder bridges were either crushed or significantly displaced.

(4) The substructure and foundation of bridges were subjected to shear and flexural cracks, concrete spalling, stirrup rupture, excessive displacement, and loss of stability.

(5) More damage occurred in simply-supported bridges in comparison with continuous spans. The curved bridges either collapsed or suffered more severe damage.

(6) Evidence of the directivity effects on the bridges near the earthquake epicenter were observed during the earthquake.

References

Burchfiel BC, Royden LH, van der Hilst RD, Hager BH, Chen Z, King RW, Li C, Lü J, Yao H and Kirby E (2008), "A Geological and Geophysical Context for the Wenchuan Earthquake of 12 May 2008, Sichuan, People's Republic of China," *GSA Today*, **18**: 4–11.

Stone R (2008), "Landslides, Flooding Poses Threats as Experts Survey Quake's Impact," *Science*, **320:** 996–997.

Wang ZM (2008), Sichuan China Earthquake Reconnaissance. Presentation Posted at http: //www.uky.edu/KGS/geologichazards/Sichuan_Earthquake.pdf, Kentucky Geological Survey, 228 MMRB, University of Kentucky, Lexington, KY 40506, zmwang@uky.edu.