Seismic Performance of Water System – M 6.6 Lushan, China Earthquake of April 20 2013

By

John Eidinger, President, G&E Engineering Systems Inc., Olympic Valley, CA 96146
eidinger@geEngineeringSystems.com

Introduction

The Lushan earthquake occurred at 8:02 am local time, April 20, 2013. This earthquake is the result rupture on a nearby / adjacent fault segment from the great M 8.0 Wenchuan earthquake of May 12, 2008. The ruptured fault segment in 2013 was located south of the southern end of the rupture in the 2008 event. The distance between the Lushan EQ epicenter is about 83 km SSW of the Wenchuan EQ epicenter.

While the USGS lists the earthquake as moment magnitude 6.6, various other Japanese and Chinese agencies list the earthquake as surface wave magnitudes between 6.9 to 7.0.

This report covers the performance of the water system in Lushan. Lushan has a population about 25,000 people, or about 50,000 people including nearby towns and villages.

Within Lushan, the estimated ground motions were generally between PGA = 0.30g to 0.40g, locally higher (and lower). The near surface soils in Lushan are generally firm. Within Lushan , there were some localized liquefaction effects, and there were no landslides within the main city area.

Key Findings

This earthquake can be considered a subsequent earthquake of the 2008 M 8.0 earthquake. In other words, the 2008 event placed additional stress on nearby faults, and accelerated the time to which the nearby faults break. This report highlights:

- First, document the damage (or non-damage) to the water system
- Second, describe the "lessons learned" in this area of China with respect to the difference in earthquake hazard mitigation in the five intervening years. This covers both emergency response, as well as seismic design and construction practices.
- Third, describe the implications of the good and bad lifeline performance in the Lushan earthquake, and how these might be considered in US, Japanese and Chinese practice.

Table 1 lists some parameters that compare the 2008 and 2013 earthquakes.

	2008 Earthquake	2013 Earthquake
Magnitude, M	8.0 Ms	6.6 Mw (USGS)
Epicenter	31.0367N 103.3329E	30.277N 102.937E
Fault Type	Reverse Thrust	Reverse Thrust
Depth, km	19	14
Rupture Area, km^2	330x25	20x25
Azimuth		218°
Dip		39°
Maximum MMI Intensity	IX, many areas X, XI, XII	VII - IX (locally higher)
Affected area	Large	Small
Fatalities	87,000 people	196 people
Economic Loss	Very Large, appreciable impact to Chinese economy	Extensive in Lushan, small in China

Table 1. Comparison of the Two Earthquakes

Damage to the Water System

There was widespread damage to the water system. No seismic design practices were observed for buried water pipelines built pre-2008 nor those built during the 2008-2013 time period. The buried pipelines suffered substantial damage, resulting in widespread service outages that lasted, city-wide, for six weeks as of the time of the investigation; with no known schedule for permanent repair.

Emergency Response

The emergency response was generally good in the 2013 Lushan event. Rapid mobilization by nearly 10,000 emergency responders helped reduce the impacts of the earthquake. The response was faster and more comprehensive than in the 2008 earthquake, reflecting both lessons learned, as well as the relatively smaller affected areas in the 2013 event. The huge number of emergency responders were able to construct, within two weeks, an above ground temporary water system for the entire city of Lushan.

Implications for US Practice

The Lushan water system includes 300 km of buried pipe, ranging in size from 100 mm (4 inch diameter) to as large as 500 mm (20 inch diameter). Buried pipe uses cast iron and PVC pipes with push on joints (no seismic design). The water distribution system performed poorly, with sufficient buried pipe damage to basically shutdown almost the entire distribution system. There was not a lot of liquefaction or landslide movements in Lushan, so the damage to the buried pipes is assumed to be attributed largely to the effects of strong ground shaking. Implications for US and Canadian practice: similar poor performance can be expected by all US water systems that have not implemented latest seismic design practices for buried pipes; especially for smaller water systems (population served under 50,000 people) that lack a great deal of network redundancy or lack dedicated work forces able to make rapid repairs. ALA (2005) provides recommended seismic design practices for buried water pipelines, applicable to all communities in the US and Canada.

Water utility operators in the US and Canada (especially those in the Eastern US / Canada) should seriously consider adopting a minimum seismic design requirement for new construction, such as PGA = 0.3g plus concurrent geotechnical implications, given the importance of the water lifeline to society's well-being. With regards to existing water system infrastructure that lacks any seismic design, it is recommended that water utility operators consider large-scale buried pipeline replacement over a 50-year time frame, (with priority given to key buried utilities that traverse zones subject to liquefaction or landslide, as well as all critical non-redundant above ground facilities) as these older assets age and need functional replacement.

Seismic, Geologic and Geotechnical Issues

Figure 1 shows the general location of the cities of Lushan, Ya'an (at "A" marker") and Chengdu. The red ovals indicate the zones of highest ground shaking and damage from the 2008 and 2013 earthquakes (the ovals are not meant to be precisely located).

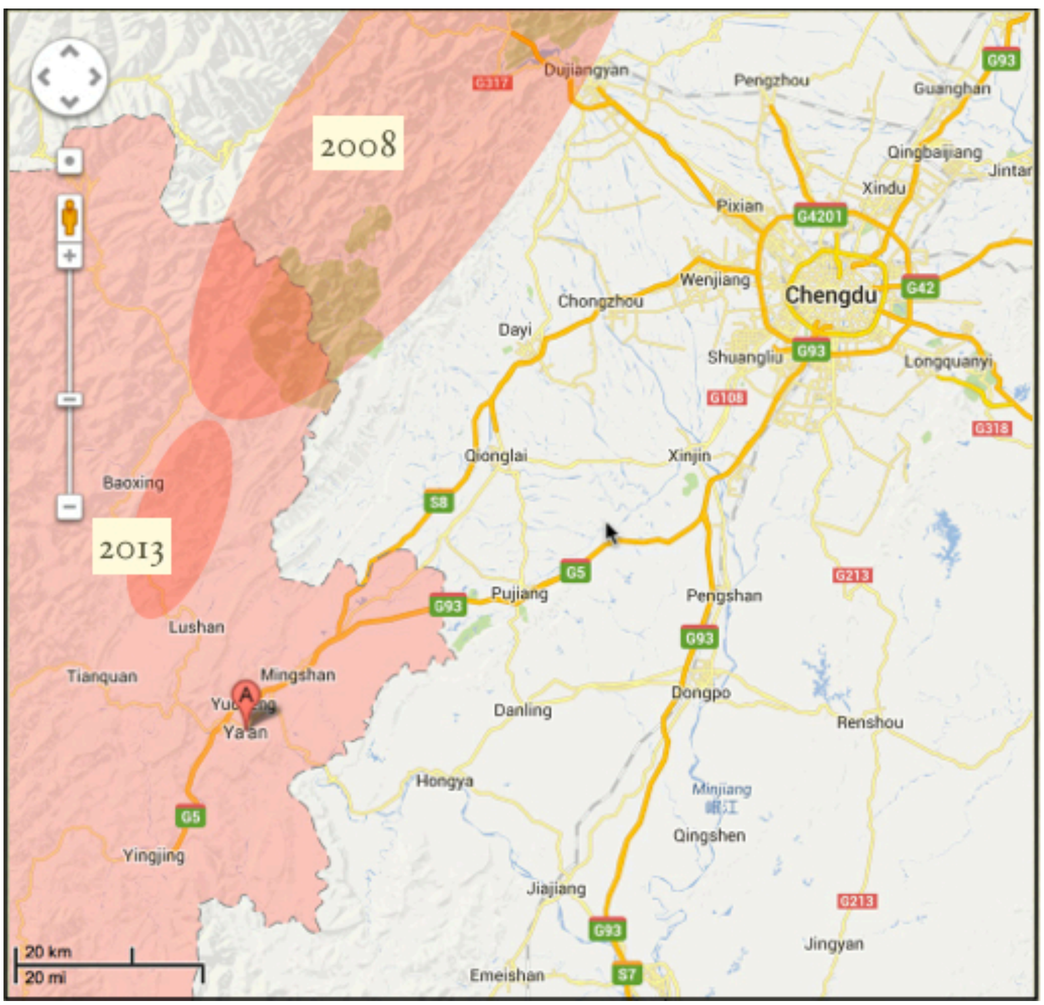

Figure 1. Regional Map

Figure 2 shows five strong ground motion instruments that recorded the 2013 earthquake in the vicinity of Lushan. In Figure 2, the "1" point is in the southern part of Lushan. The epicenter of the earthquake was about 15 km north of point 1.

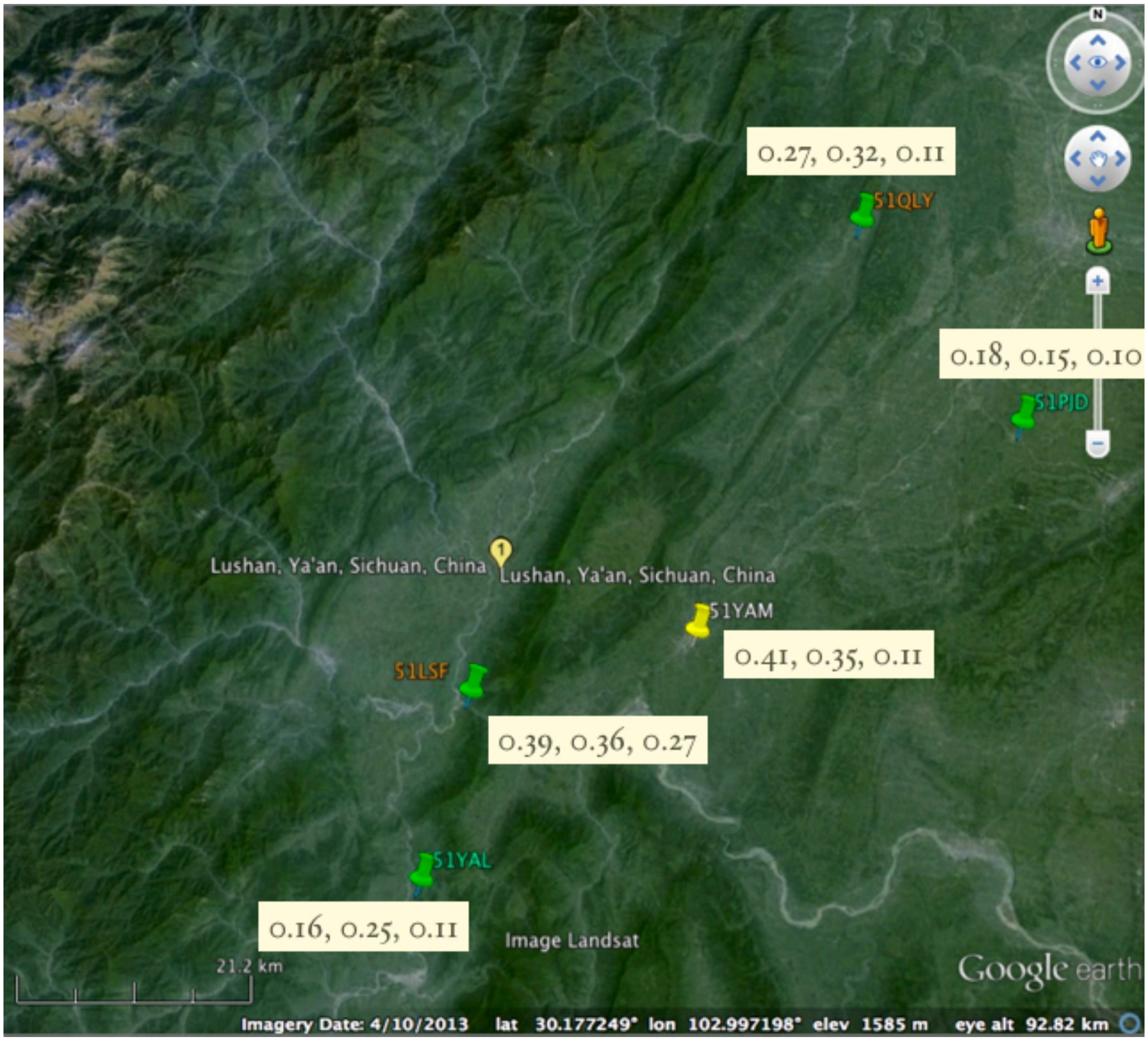

Figure 2. Recorded PGA Values (units in g, NS, EW, Vertical)

About 123 strong ground motion instruments were triggered by this event. Table 2 lists the data for 16 selected strong ground motion instruments. The coordinate values have been rounded to the nearest 0.1 degrees per the request of Chinese authorities; the locations in Figure 2 are precisely located for instruments YAM, LSF, QLY, YAL, PJD. The epicentral distances are based on a preliminary location of the epicenter north of Lushan; the precise location of the epicenter and fault plane remains under investigation.

Station	Longitude °E	Latitude °N	Distance to Lushan	Epicentral Distance (km)	Site conditions	PGA (g) EW	PGA (g) NS	PGA (g) Vertical
51BXD	102.8	30.4		19.4	Rock	-1.02	0.84	0.49
51BXZ	102.9	30.5		21.5	Rock	0.59	0.32	0.39
51BXY	102.9	30.5		26.5	Soil	0.44	0.30	0.25
51YAM	103.1	30.1	20	27.7	Soil	-0.41	0.35	0.11
51QLY	103.3	30.4	46	28.2	Soil	0.27	0.32	0.11
51BXN	102.7	30.4		30.0	Soil	-0.39	0.20	0.13
51LSF	102.9	30.0	15	32.6	Soil	0.39	0.36	-0.27
51YAD	103.0	30.0		35.0	Soil	-0.53	0.41	0.20
51PJD	103.4	30.2	50	40.8	Soil	0.15	-0.18	-0.10
51YAL	102.8	29.9	31	50.4	Soil	-0.16	0.25	0.11
51DXY	103.5	30.6		59.4	Unknown	0.003	0.008	-0.006
51TQL	102.4	29.9		73.0	Soil	0.28	0.29	0.15
51KDZ	102.2	30.1		81.8	Rock	-0.024	-0.027	0.020
51LDS	102.2	29.0		85.4	Unknown	-0.006	-0.007	-0.010
51DJZ	103.6	31.0		98.3	Soil	-0.075	0.080	0.031
51PXZ	103.8	30.9		99.3	Rock	0.013	0.012	-0.010

Table 2. Strong Motion Instruments Recordings[1]

The precise mechanism of rupture remains under investigation. From initial observations, it would seem that the rupture was reverse thrust, with the fault plane dipping down southeasterly; but remains conflicting data suggesting that the dip might have been otherwise. As of early June 2013, no evidence of surface rupture has been observed, making this a blind thrust event.

The instruments BXD, BXN, BXZ, BXY all recorded strong motions, and are all located north and west of Lushan, and are likely atop the hanging wall of the rupture. Instruments QLY and PJD appear to be on (or very near) the foot wall, and have lower motions.

[1] China Strong Motion Networks Center (2013a), Sichuan Ya'an Lushan M_w 7.0 Earthquake 3rd Report, published on April 21, http://www.csmnc.net/selnewxjx1.asp?id=795, accessed June 27, 2013. Epicentral distances are based on an initial estimated location of the epicenter. Further study may revise these epicentral distances.

The absolute values of the maximum of the NS, EW and Vertical PGA motions are plotted in Figure 3, as a function of epicentral (per Table 2) distance.

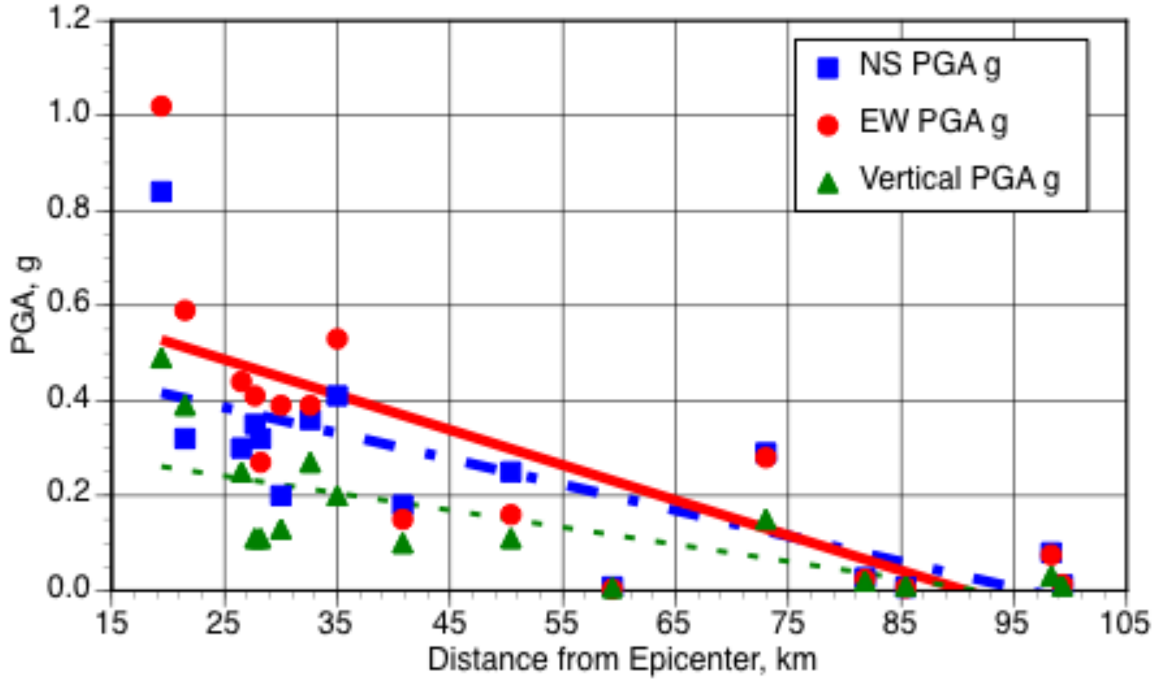

Figure 3. PGA as a Function of Epicentral Distance

The three straight lines are least square regressions through each data set (solid line for EW, dash-dot ine for NS, dash line for Vertical). For epicentral distances between about 25 and 40 km, the NS average is about 0.35g; EW is about 0.41g, Vertical is about 0.23g.

Figures 4 and 5 (plots courtesy of LADWP) provide selected recorded acceleration time histories. The recordings generally show about 12 seconds of strong ground motions (from the time PGA > 0.1g to the time PGA < 0.1g) (981 gal = 1g).

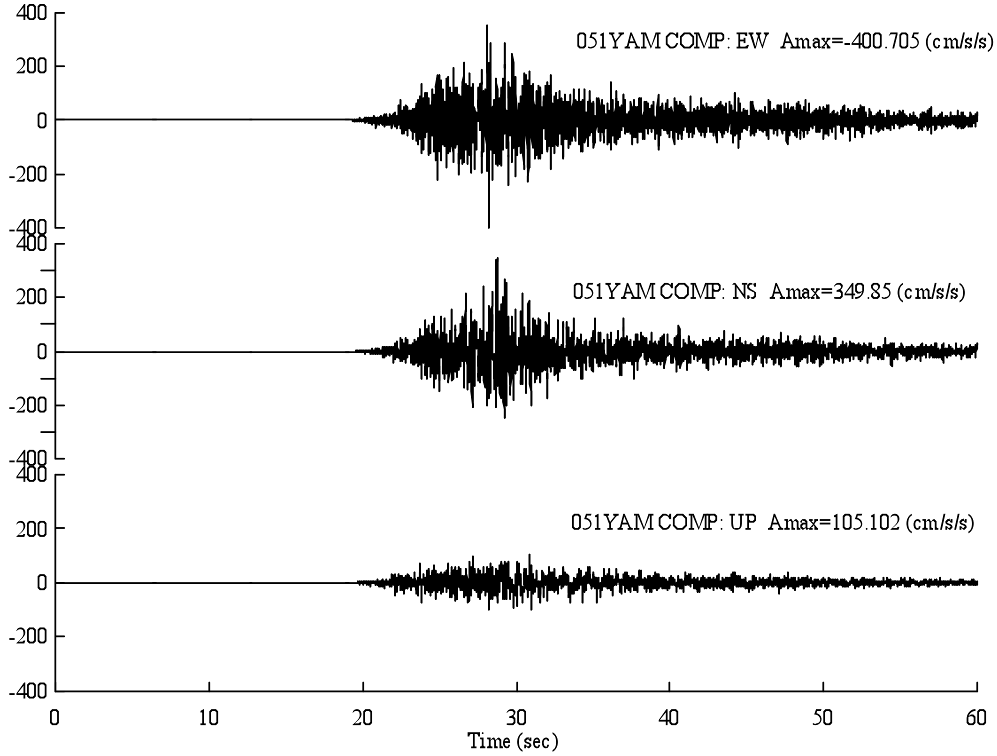

Figure 4. Time Histories, Instrument 51YAM (gal)

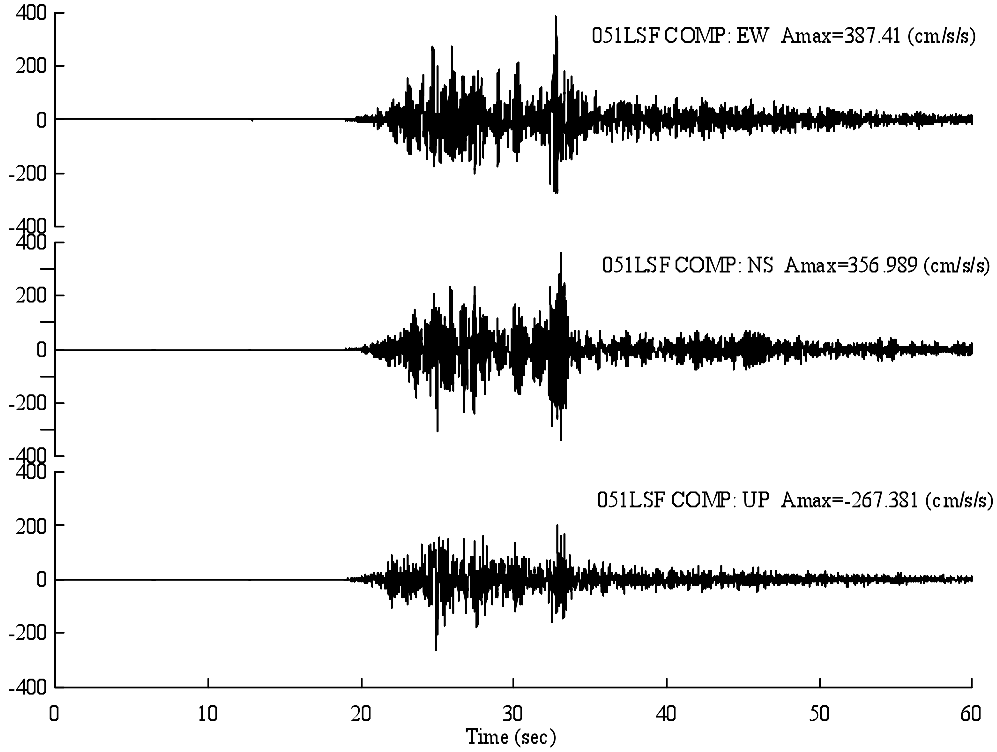

Figure 5. Time Histories, Instrument 51LSF (gal)

Performance of the Water System

The potable water system for Lushan is much the same as used in similar sized cities in the USA, Canada and elsewhere. It consists of a raw water pump station, pumping surface water from a river up a hill to a water treatment plant; conventional water treatment (settling, flocculation, filters, disinfection); and then gravity flow to the customers and fire hydrants via buried pipe.

The Lushan City managers reported that they focused on improving the water treatment plant for seismic performance after the 2008 Wenchuan earthquake; this was reflected in the new (2011 vintage) facility, that will be described below. Even so, the overall performance of the water system was very poor. As of six weeks post-earthquake, essentially none of the city of Lushan was being served water via the buried distribution system. This is relatively remarkable, as there was little liquefaction or landslide to speak of in the City, and thus the water system was exposed primarily to strong ground shaking.

The distribution pipe system was damaged, with (apparently) many leaks / pipe breaks. No attempt had yet been made to *any* make buried pipe repairs, even after 6 weeks after the earthquake.

Water Treatment Plant

A new (2011 vintage) water treatment plant had just been competed prior to the 2013 earthquake, using funding from the World Bank. Figure 6 shows the entrance, using a unreinforced masonry wall (the wall was damaged, but this did not impact the plant's performance).

Figure 6. Entrance to Water Treatment Plant

Raw water enters two sets of settling basins, flocculation basins and tube settlers, all in rectangular reinforced concrete structures, Figure 7. There was no evidence of damage to any part of these structures. Launders over the filters were steel, anchored to the reinforced concrete walls; the launders were undamaged.

Figure 7. Settling and Filter Basin Structures

Water leaves the filters and enters two partially-buried rectangular reinforced concrete clearwells, Figure 8. The two clearwells appeared to be undamaged.

Figure 8. Two Partially Buried Clearwells

It appears that all the water-retention structures of this 2011-vintage-designed plant worked well. Whether this good performance is due to minimum requirements for water leak-tightness; or if these facilities were designed per modern seismic codes (or both), is an area for investigation.

Several other facilities at the water treatment plant were damaged. The control building is unreinforced, and suffered large cracks (but did not collapse), Figure 9. There were several large diagonal cracks through the exterior walls; these were repaired post-earthquake by inserting grout.

Figure 9. Damaged Control Building

The chemical tanks rocked, Figure 10, damaging the attached PVC pipes, Figure 11. The small plastic "seismic stops" (4 of them) did restrain the tank from sliding, but not rocking. The rocking led to damage of the attached restrained PVC pipe.

Figure 10. Plastic Tank for Chlorine Dioxide Disinfectant

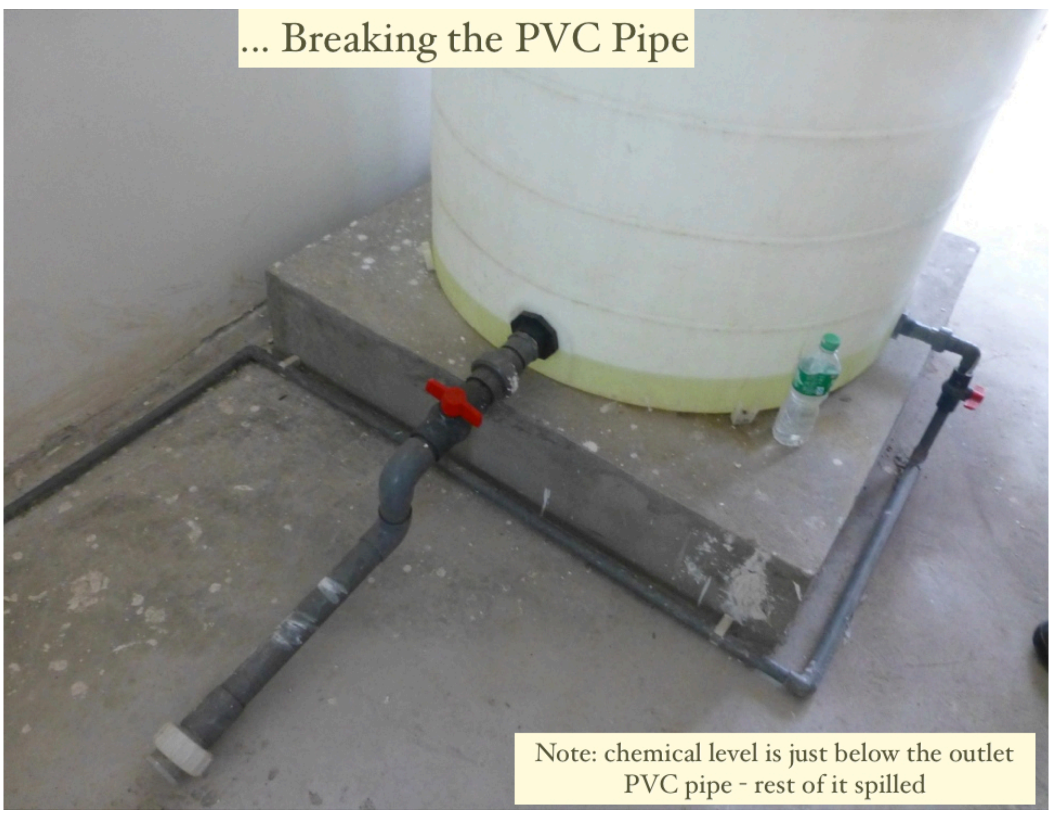

Figure 11. Broken PVC Pipe (the motor and pump also broke and have been removed)

Water Distribution Pipes

Lushan city has about 300 km of water distribution pipes. Most are cast iron (dating back 50+ years) and newer pipes are PVC. Most distribution pipes are 100 mm diameter; 500 mm diameter is the largest pipe in the system. Figure 12 shows the author with a fire hydrant. Note the temporary office buildings in the background: dozens of such buildings were placed on main city streets in Lushan, providing needed services: life insurance, telecom, banking, etc.

There were zero reported fire ignitions in Lushan. Within Lushan, it is common to use propane for cooking, and some buildings have natural gas supply. The lack of fire ignitions suggests a possible change to the ignition rate in HAZUS and similar models, where applied to a building inventory of a similar style as in Lushan. Similar trends have been observed in recent earthquakes in Christchurch (earthquake sequence of 2010-2011) and the Japan (Great Tohoku Earthquake of 2011). Perhaps the lack of ignitions was due to the widespread power outages (lasting at least 28 hours in Lushan City), coupled with the prevalent use of masonry-style construction. The lack of ignitions in Lushan cannot be attributed to lack of building collapses (there were hundreds) or a lack of toppled non-structural items (these were widespread).

Figure 12. Author and a Fire Hydrant in Lushan

As of six weeks post-earthquake, no attempt had yet been made by the local public works (water) department to locate the damage to buried water pipes. The city officials were asked why this might be so: they replied that "there was no money" and that they were waiting the "the central (Beijing) government to take care of this".

Possible reasons for the complete lack of repair activities by the local City officials are the following. A temporary water system that functions was installed, city-wide, soon after the earthquake. Also, all city public works department resources were devoted to aiding local with needed housing since many housing units were damaged or destroyed.

The People's Liberation Army (PLA) installed the above-ground water pipe network for most of the city immediately post-earthquake. Figure 13 shows a typical above ground pipe with hose bib; these were located on nearly every city street that the author visited during three days in Lushan. Note the damage to the sidewalk curb; this was repeated in many locations, in an attempt to bury the above ground pipes in shallow trenches through streets, to allow for vehicle traffic. It took the PLA one week to place the temporary water lines for the majority of the city and an additional week to complete the temporary network; the outskirts of the city have fewer people but took longer to place the system.

Figure 13. Above Ground Temporary Water Pipe

In this manner, nearly every Lushan resident was able to gather water from the hose bibs off these pipes, for gray-water / sanitary purposes. Traditionally (even without earthquakes), Lushan residents boil all water from the water pipeline system. Therefore, the water from the above ground system could be used by City residents for potable purposes, in a manner not totally different than under pre-earthquake conditions.

Emergency response also included use of bottled water delivery for drinking water.

Immediately after the earthquake the people could not purify water due to loss of power. There was a public health concern until power was restored. However, there was no reported outbreak of water borne disease after the earthquake.

Conclusions and Observations

The Lushan earthquake exposed the city to high levels of ground motions, commonly PGA ~0.35g.

The water distribution system, with about 300 km of buried cast iron and PVC pipes (without seismic design), was widely damaged, sufficiently so that essentially the entire buried water distribution system was shut down. Given the loss of water supply, the army installed a portable above ground water system throughout the city. There were no fire ignitions. There was widespread concurrent damage to poorly designed buildings. Given these issues, the water department made no attempt to repair and restore the buried water pipe system, through the first six weeks after the earthquake.

What is unusual about the performance of the water system in this earthquake are the following:

- Installation of a system-wide above ground water system. This strategy has not been considered viable for large cities in California, and probably is not viable except for smaller communities (population under 50,000 people or so).
- There was little or no liquefaction in the service area, no landslides and no surface faulting. So, the damage to the buried pipes (albeit having non-seismic design) appears to have been largely due to ground shaking. This is an unexpected outcome, and deserves further investigation.
- There were no fire ignitions. This good outcome might have been due, in part, to the area-wide power blackout lasting at least 28 hours (up to 3 days in some areas). With no fire ignitions, and an albeit limited capacity above ground water system, the need to repair the buried water pipelines was reduced to the point that the city officials decided to allocate scarce repair-crews to other more pressing needs, like construction of temporary housing, etc.
- There was good performance of the water retention structures at the newly constructed water treatment plant. Why did this occur? Possibly due to the requirement to make water-retaining reinforced concrete structures to be leak tight (lots of reinforcing steel at small bar spacing).
- The minimal attempt to "anchor" chemical tanks at the water treatment plant failed, entirely. Seismic anchors / restraints for such equipment need to be robust,

taking the full seismic loads, and ensuring that rocking of tanks / equipment does not impose differential movements on attached pipes and pumps.

Acknowledgements

The findings in this report were developed by the author as part of an ASCE - TCLEE earthquake investigation team. The investigation was done May 26-31 2013. The team included John Eidinger, Alex Tang and Craig Davis. There were many Chinese and other people who assisted in the investigation. Figures 4 and 5 were plotted by LADWP. More details about this earthquake, including a 100-page report on the performance of electric power, telecommunications, water, wastewater, roads and bridges and hospitals, will be available as an ASCE – TCLEE monograph later in 2013.

References

A 300+ page report on the performance of lifelines in the 2008 Wenchuan earthquake is available for free download from www.geEngineeringSystems.com.

ALA, Seismic Guidelines for Water Pipelines, American Lifelines Alliance, NIBS and FEMA, March 2005. A free copy of ALA 2005, is available for free from www.geEngineeringSystems.com, as well as AmericanLifelinesAlliance.org.