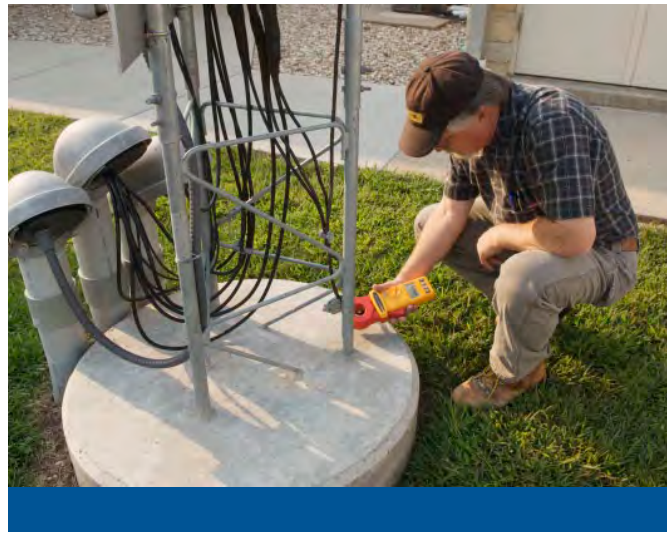
Taking care of an at-risk dam

Application Note

Completed by the U.S. Army Corps of Engineers (USACE) in 1962 as a flood-control measure, Tuttle Creek Dam sits on the Big Blue River, five miles north of Manhattan, Kansas. Made of rolled earth and rock fill and resting on an alluvial foundation, it's about 137 feet high and 7500 feet long. The dam holds back Tuttle Creek Lake, which amounts to 335,100 acre-ft at normal pool and approximately 1.9 million acre-ft during flood events.

Here's the problem: It's 12 miles from the Humboldt fault zone, a localized seismic "hot spot" that has a small but real probability of producing an earthquake of magnitude 5.7 to 6.6. Such an event would cause what's known as liquefaction, in which the earth (mostly silt and sand) on which the dam rests changes from a relatively solid base to what amounts to quicksand.

During the 1989 Loma Prieta earthquake in San Francisco, the soil under the city's Marina district liquefied, causing many buildings to collapse. A similar event at Tuttle Creek could cause the dam to fail. According to 2006 USACE estimates, this would release 381,000 cubic feet of water per second, flood parts of downtown Manhattan to depths of 17 feet, result in the deaths of up to 400 people out of a population of 13,000, and cause damages downstream of $458 million. The dam has even been featured on The History Channel's "Mega-Disasters: Dam Break" show.



Bob Frazey uses the Fluke 1630 to check all the grounding wires around the building that all the communications come into from various points around and across the dam. These include remote sensors, video feeds, and visual and audio warning stations.

In 2002 the Corps set out to make the dam safe, using a variety of methods, including the construction of soil-cement transverse panels to strengthen foundation soils beneath the toe of the dam. But it would take years to finish that, and in the meantime the area downstream would still be at risk. The answer was to put in place a Dam Failure Warning System that would sound an alert in time for the people to evacuate.

The Corps of Engineers contracted for the Tuttle Creek Dam Failure Warning System with the global engineering, construction and technical services firm URS Corporation. With 55,000 employees worldwide, the company has three divisions: URS Engineering Corporation; EG&G, a defense services company; and Washington Division, a large contracting company and builder. URS Engineering Corporation offers services to rehabilitate and expand public infrastructure, including surface, air, mass transit and rail transportation networks, and ports and harbors. The division also provides program management; planning, design and engineering; and construction and construction-management services for water supply, conveyance and treatment systems.

The Dam Failure Warning System is made up of a number of components and subsystems, starting with geotechnical instruments.

Automated geotechnical instruments

These devices include sensors to measure seismic shaking, detect embankment/foundation deformation, and monitor changes in foundation pore pressures. The data from these devices is sent to the Critical Systems Building (CSB) via radio, and many are solar-powered, which not only makes them immune to power outages but also eliminates possible voltage surges via ac power lines.

Pore-pressure sensors

For pressure sensing, URS often uses vibrating wire piezometers. Housed in sturdy metal cases with pointed ends, they are pushed 30 to 50 feet into the earth near the toe of the dam. They are connected via cable to a solar-powered datalogger which in turn sends its data to the central computer in the CSB for storage and analysis. The sensors' output signal is a frequency, which can be read at fairly long distances despite cabling losses. In addition, they have built-in protection against lightning surges, and when coupled with good lightning protection and grounding systems, give very stable readings for many years.

But they have a drawback, says Jim Hummert, Jr., PE, Vice President-Systems Engineering with URS Corporation: It takes about one second to get a reading from each sensor. While this is not a problem for applications like long-term performance monitoring for dam safety (which generally involves taking several readings over the course of a day), it's too slow for an early warning system, which must record a pore pressure signature immediately following an earthquake.

"We need to read these devices more quickly and be able to process the results and run through some type of algorithm or alarm-checking protocol for notifications," Hummert explains. For that reason URS added a set of strain gage pressure sensors with 4-20 mA output. These can be read 10 to 15 times per second or more with standard dam-safety data-acquisition equipment.

Remote controlled video cameras

The availability of economical wireless video cameras has been of great benefit in this area. In the Dam Failure Warning System, three video cameras provide remote visual inspection of the dam spillways, structural elements and weir flows following an earthquake. They transmit video via a 5.8 GHz radio link and receive operator commands to pan, zoom and tilt via 900 MHz spread spectrum radio. Video outputs are available using IP protocols so they can be viewed by all the stakeholders.

Automated data acquisition system (ADAS)

This solar-powered unit receives all the geotechnical instrument data and transmits alarm annunciation.

Deformation monitoring equipment

During an earthquake-induced failure, the crest of the dam could drop by as much as 30 feet. The early warning system includes four ways to monitor such an event. One is distinctly low-tech: A string of solar-powered "runway" lights along the crest and toe of the dam (officially called "Embankment Alignment Indicators"), which can be seen at night.

The second is slightly more complicated: A linear series of nested-loop cables is strung through a series of concrete weights extending 4000 feet along the dam crest, buried about two feet below grade. Officially called the "Dam Crest Integrity Monitor," these are simple twisted-pair cables shorted at one end, and their electrical resistance is constantly monitored by the data acquisition unit. "We measure the resistance on these cables, and they're varying lengths," says Hummert, "so if the dam were to breach we would be able to tell approximately where the breech occurred and about how wide the breach is."

The third is a set of Time Domain Reflectometry (TDR) cables to measure potential post-earthquake displacement in the downstream toe area. TDR cables can be used to measure variations in soil moisture and horizontal or vertical deformations continuously along a given length of cable. Individual cable lengths are limited to about 2000 ft. This type of device makes it possible to measure along a continuum instead of only at discrete points, which is a limitation of most geotechnical/structural instruments being used today.

The fourth is a set of automated inclinometers placed along the toe of the dam. An inclinometer measures the "tilt" of a hole or pipe in the hole. The inclinometer instrument is slid down this pipe using small grooves in the pipe. Over time, if the pipe moves sideways at some point it indicates that the ground is moving and shifting sideways—a clear warning sign of other issues. Inclinometers are installed about ten feet apart; taking repeated readings at each ten-foot increment shows the tilt at each level with depth over time.

Other features of the system include:

- Dam Safety Status Indicators (DSSIs), which are alert-notification units custom-built for First Responders.
- A web portal which provides remote access to instrument data, dam safety status, recent earthquake information, video camera images, and lake level data.
- The seismically hardened Critical Systems Building, which integrates the ADAS with DSSIs and computers at remote locations. It processes and transmits alarms, data and video to the remote users via a private wide area frame-relay network and backup satellite network. All internal communication in the CSB is via Ethernet. The CSB is equipped with uninterruptible power supplies and a propane-fueled backup generator.
- A siren warning system with six 4500-Watt solid-state tone- and voice-capable sirens located in the evacuation zone; siren tones include voice, tornado warning and evacuation.

Bob Frazey works in one of the sensor service panels that lay across the base of the dam. These service panels are all low voltage panels that house ground swell sensor communications and support systems. He uses the Fluke 189 DMM to check the 12 V dc battery charging system that comes from a nearby solar panel. He also uses the Fluke 771 Milliamp Process Clamp Meter to check the 4 mA to 20 mA signal from the pressure sensors and transducers.

The Fluke 1630 is also used to check the grounding wire on the mast of the radio antenna and solar charging panel. Frazey also uses the Fluke 189 DMM with a Fluke i410 current clamp to look at the current output of the solar panel to the battery charger inside the service panel.

- Indoor tone alert units at facilities that require special evacuation attention, such as schools, daycare centers, and facilities for the elderly and handicapped.
- An education and evacuation plan for nearby communities.

What happens when the alarm sounds

If the dam's strong motion accelerograph (SMA) units detect ground shaking corresponding to a significant earthquake (greater than about 4.5 magnitude), an autodialer will call key personnel and play a pre-recorded message detailing the conditions detected at the dam. In addition, the DSSI units will provide remote locations with information on the status of the dam using colored indicator lights to represent various safety conditions.

If the SMA units detect ground shaking corresponding to a severe earthquake (>5.7 magnitude) and damage to the dam is detected, the DSSI units will also display a countdown timer with a delay of between 30 minutes and 2 hours before automatic activation of the downstream warning sirens. The delay provides time for USACE to assess the dam and potentially stop automatic activation (or initiate manual activation) of the siren warning system.

Keeping things working with Fluke equipment

All these subsystems and components require careful setup, maintenance and troubleshooting, and the URS people on site use Fluke equipment almost exclusively for the purpose. Take lightning protection and grounding, for example. This part of Kansas is subject to severe thunderstorms, so surge protection of the equipment is a must.

"We spend a lot of time designing the grounding systems and the lightning protection systems for these systems," says Bob Frazey, field superintendent with URS Corporation. "These are pretty sophisticated data acquisition units, remote-located out on the embankments of the dam, for the most part, or down in the instrumentation galleries or in the power house," he continues, "so when we're designing the grounding systems, and the grounding conductors and so forth, we're checking resistance to ground, bonding resistance between the various connectors that we're using." Frazey uses a Fluke model 1630 Earth ground clamp meter to check equipment ground and lightning-protection grounding installation.

Frazey uses a number of Fluke instruments to check the 4-20 mA measurement loops on the strain gage soil pore pressure sensors and the equipment they feed. He uses a Fluke 707 Loop Calibrator to check and calibrate both 4-20 mA instruments and controls, and a model 771 process clamp meter to monitor, test and adjust 4-20 mA system controls without breaking into the current. "We always check and verify that you get zero and full scale and some intermediate value as well when you do the installation," says Jerry Zimmer, Senior Consultant with URS Corp.

Frazey uses a Fluke 189 Digital Multimeter (DMM) with its accessory Fluke i1010 amp clamp for general volt ohm testing and for checking the output frequencies of the direct-push vibrating-wire pressure transducers. He also uses the 189 with an ac/dc amp clamp to check amperage draw on solar charging systems and batteries. There's another way to check solar charging systems with the 189, adds Zimmer: Hook everything up and then check that the battery voltage is increasing over time. "We usually stand and watch that for five or ten minutes to make sure things are moving along like we would expect," he explains.

"The 189 DMM is also used to occasionally check electronic components and a temperature probe is used to check small air conditioning systems on a few of our pump control boxes," adds Frazey.

A Fluke Networks MicroScanner 2 Cable Verifier and the Microprobe signal tracer accessory are used on Ethernet systems to make, check and repair the CAT 5-6 ethernet cable. The MicroScanner has been of great help, says Zimmer, "to verify our Ethernet cables before those get connected, because we always make those to length, we don't just buy little 3-footers; we're always stringing cables out, and I know at Tuttle Creek, as an example, we had to verify before we pulled them through some conduits underground." It was the MicroScanner, he continued, that alerted them to a problem with one brand of Ethernet cable connectors and led them to change suppliers. The MicroScanner is used to test for length to an open or short, and occasionally to check and repair coax cable.

Frazey uses a Fluke 971 Temperature Humidity Meter to monitor environmental conditions in dam galleries that may cause condensation inside control boxes. In addition, he has built a mobile electronics lab and small machine shop to use when installing and doing maintenance on the systems.

Results

The Tuttle Creek Dam Failure Warning System was completed in March 2005. The system won the 2006 grand award with the American Consulting Engineers Council (Missouri chapter of ACEC). URS has put together a number of similar systems in other locations, including the Wolf Creek dam in Kentucky.

The foundation modification work at the dam site has recently been completed. Later this year, once the walls have hardened and the buried collector system has been completed, the DFWS will be decommissioned. The siren system is being turned over to Riley County and will become part of the existing county tornado siren warning system. In the mean time, URS continues to provide operations and maintenance support.

The URS people seem pretty well sold on Fluke equipment. "I've recommended Fluke equipment for a number of years," says Zimmer, "but when we're outside working on equipment I don't even think about the thing not working, because I know that Fluke stuff just works all the time. So I always feel really good, I always buy that, because I don't have to worry about it breaking."

Fluke. *Keeping your world up and running.®*

Fluke Corporation
PO Box 9090, Everett, WA 98206 U.S.A.

Fluke Europe B.V.
PO Box 1186, 5602 BD
Eindhoven, The Netherlands

For more information call:
In the U.S.A. (800) 443-5853 or
Fax (425) 446-5116
In Europe/M-East/Africa +31 (0) 40 2675 200 or
Fax +31 (0) 40 2675 222
In Canada (800)-36-FLUKE or
Fax (905) 890-6866
From other countries +1 (425) 446-5500 or
Fax +1 (425) 446-5116
Web access: http://www.fluke.com

Printed in U.S.A. 1/2010 3610922A A-EN-N