SMALL SENSORS HELP MEASURE BUILDING DAMAGE AFTER QUAKE

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By Rosemary Clandos
Small Times Correspondent

PASADENA, Calif., Aug. 28, 2001— After an earthquake, building owners and employees sometimes wait several weeks before they can enter buildings where the extent of structural damage is unknown.

But inexpensive MEMS sensors now for sale commercially, and devices that are being tested at the University of California, Berkeley, could offer owners information about the safety of buildings and help predict what could happen in the next big jolt.

"A building owner could pay between $5,000 and $50,000 for a thorough engineering evaluation," said Gregory Fenves, a professor of civil engineering at Berkeley who is working with MEMS sensors to record quake activity. "After an earthquake, engineers are busy and that (delay) can be a problem for commercial properties."

Kinemetrics Inc., a Pasadena-based company that has been designing and manufacturing earthquake technology for 32 years, is using low-cost and low-power MEMS sensors in two of their products.

In late 1998, Kinemetrics began purchasing micromachined accelerometers from Analog Devices Inc. Kinemetrics added a microcontroller, memory, relays and supporting electronics and ended up with devices about the size of a pack of cigarettes.

One device senses and records shaking, and can assist earthquake engineers in determining structural damage when only cosmetic problems can be seen. The other device senses shaking and responds by shutting down equipment or closing valves.

"The Quake Data Recorder is the poor man's strong motion accelerograph," said Mel Lund, Kinemetrics' vice president. Compared with the sophisticated mechanical accelerograph that costs about $5,000, the QDR is a bargain at $750. It contains two MEMS sensors, and measures and records motion in tri-axis -- north and south, east and west, and up and down.

Additional hardware can be added so it can communicate by telephone, satellite or to a personal computer. After a temblor, a technician downloads information at the site and an engineer evaluates it to determine if a building is safe to enter. The data may also forecast what damage could occur following an aftershock or later earthquakes.

The MitiGator also contains two MEMS accelerometers that measure movement in tri-axis. When shaking reaches a certain predetermined level, the MitiGator sends an electronic message to shut off gas lines, stop elevators, and close valves and pipes containing hazardous material. The device costs $625 and is a top seller with elevator manufacturers in the United States.

Since Kinemetrics began marketing the devices two years ago, they've sold more than 500 units. Although the devices containing MEMS sensors cost less, they do not yet have the sensitivity of the traditional models.

"The smaller it gets, the less sensitive the instrument becomes," said Tom Heaton,

engineering seismologist at the California Institute of Technology, where earthquakes from around the globe are recorded. "Bigger is usually better in terms of sensitivity.

Kinemetrics' state-of-the-art, mechanical strong motion accelerograph is capable of detecting signals that are 2,000 times smaller than those that can be recorded using current MEMS technology, said Lund. Mechanical models are installed in high-rise office buildings, nuclear plants and historical sites like the Taj Mahal and the Parthenon.

In the Los Angeles area, buildings that are seven stories or taller are required to have three strong motion accelerographs. They are also used in bridges, dams, power plants and pipelines. But the QDR is not yet approved to meet building code standards, said Lund. Kinemetrics has not submitted the device for approval because the machine is unable to record relatively small motions or earthquakes.

"Currently, the resolution, or how small a signal they can get, is the problem," he said. The MEMS devices do not record low signals because of internal "noise," which are small random vibrations or electronic variations.

"We can't record some of the most important signals in the low frequency because of the distracting intrinsic noise," Lund said.

Earthquakes produce low frequency motion or vibration in a range below 200 hertz. The low frequency of the earthquakes closely corresponds to low and natural frequencies of large structures. That creates resonance and the potential for much greater motion in the structure and damage. In other words, the motions created by earthquakes can be amplified by the natural response of the buildings.

"Internal noise of the MEMS device is relatively high at low frequencies; and therefore, it makes it difficult or impossible to identify very small vibrations within the recorded data," Lund said. "As MEMS accelerometers get better and have lower internal noise at low frequencies, then the possibility of using them for other applications goes up because of the size and the price."

But building owners in countries hit hard by the economic downturn are purchasing the low-cost MEMS devices, even though they aren't the best for recording small earthquakes. Kinemetrics sells most of the QDRs to Japan, Mexico, Turkey, Puerto Rico and Greece.

The devices have other restrictions. Temperature fluctuations can affect readings and they can't be used in nuclear plants, Lund said.

"It's probably not the MEMS device that is not radiation tolerant," said Danelle Tanner, principal member of the technical staff at Sandia National Laboratories in New Mexico. "It's probably the silicon circuitry that does not tolerate radiation. You have to design the circuitry with radiation tolerance in mind and Analog Devices didn't do that. There are not many places around that can do that – it's not something that most companies generally do."

Kinemetrics supplies instrumentation to seismologists in remote locations, where temperature extremes or changes are also a concern, Lund said. "MEMS sensors may operate over a significant range of temperatures, but temperature change can result in variations in the signal output. So when you look at scientific information, that's a concern. It's an accuracy issue."

At Berkeley, Steven Glaser, professor of civil engineering, is part of the team working with scientist Kris Pister on smart dust to be used as seismic sensors that will communicate with each other through a network. Glaser estimates that when the sensors are mass-produced they will cost less than $50, so they can be densely packed in buildings. The sensors are expected to be more precise and should be able to monitor subtle and strong building movement and interpret the state of structural damage.

Unlike Kinemetrics' MEMS devices, "The sensors will contain a global positioning system which will allow you to get millimeter accuracy," Glaser said. "It tells you where you have absolute displacement – which is the knowledge of longitude, latitude and altitude. You'll have knowledge of where the building actually moved."

Another fundamental difference is that each sensor node is actually a computer that can communicate wirelessly with its neighboring sensors and the entire local and global

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sensor networks. The network can automatically download quake information for engineers at another site.

"You don't have to limit it to earthquakes," he said. "If you live in Florida, you may have to worry about hurricane damage."

Shake tests will be done next month and Glaser expects the technology to be ready for commercialization by the end of the year.

Lund said, "The natural progression is that as MEMS devices become more accurate, they will, of course, replace the larger traditional mechanical sensors."

In the future, Kinemetrics may be removing its mechanical sensors from the world's most treasured structures and replacing them with the world's smallest technology.