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Slightest movement

Early detection of earthquakes can save lives

When an earthquake begins, earthquake early warning systems (EEWS) detect the initial low-amplitude ground motions in real-time and perform a very rapid assessment of the potential severity of the seismic event.

As a result, citizens using roads, tunnels and bridges can be alerted and lives can be saved.

There are multiple applications for EEWS, based primarily on the functionality, number of sensors and their geographical distribution:

- Warn people about an oncoming earthquake so they can move to a safer location;
- Perform automatic response measures like shutting down transportation routes and structures, as well as gas pipes, electric motors and other high-hazard machinery; and
- Help build quasi real-time knowledge for organizations or companies that operate in large geographical areas, using the estimated damage distributions due to the strong ground motion.

The automated response is extremely important in the infrastructure and transportation areas, where traffic can be slowed or completely shut down in the critical sections. Entrance into tunnels or bridges can be halted by means of traffic lights, barriers or variable message signs.

The EEWS is not viewed as a substitute for a seismic-resistant design of the civil engineering structures, but rather a means to minimize potential risk to human lives and financial losses.

The EEWS based on the P-wave detection method uses information about the earthquake derived from the smaller-amplitude compression wave that propagates faster in the solids than the larger-amplitude shear wave, called an S-wave.

On-site EEWS installed at facilities such as roads and bridges detects the primary wave and issues a warning that can be used instantaneously if an automated response mechanism is implemented. The advantage of this approach is fast response, installation of a limited number of sensors within a small area and use of the private networks that are independent of the Internet, which often becomes unstable immediately after or during an earthquake.

The last feature frequently becomes a bottleneck of network-based systems that are forced to use satellite communication channels that increase maintenance cost over extended periods of time. As a result, an on-site EEWS is easier to use and offers the lowest operational cost in the long term.

Waves of P and S

An EEWS is installed at the George Massey Tunnel on a major highway near Vancouver, B.C.

The design of an on-site EEWS for critical facilities, based on P-wave detection, requires knowledge of local seismicity, analysis of strong-motion records and local geological settings.

The first system in western Canada incorporating this information was implemented by Weir-Jones Engineering Consultants Ltd. of Vancouver in 2009 to provide earthquake early warning and highway closure for a 2-km-long tunnel on a major highway in British Columbia—one of Canada's most seismically active regions.

The tunnel site may be subjected to strong earthquake shaking from three distinct source regions: deep earthquakes within the subduction plate (50 to 60 km beneath the site); giant subduction earthquakes about 150 km to the west; and shallow crustal earthquakes in the surrounding region.

The seismic waves can be roughly divided into the primary (P-wave), secondary (S-wave), Love and Rayleigh waves. A typical speed for the P-wave is ~5-6 km/s, and the speed of the S-wave is ~3 km/s. The modern EEWS is based on the principle of detecting a P-wave that propagates away from the seismic source faster than a more destructive S-wave, and serves as a precursor of the coming destructive ground shaking.

The makings of an early warning

The EEWS equipment consists of a set of triaxial vibration sensors installed below the ground surface. Mechanical vibration is converted into a fluctuating voltage signal that is digitized using a 24-bit analog-to-digital converter. Multichannel data streams are merged by the data acquisition equipment and sent to the central processing computer via local network, which does not rely on the Internet for its operation. Time synchronization is achieved using GPS technology. The central computer runs the seismic detection and proprietary classification software, which continuously analyzes data streams and triggers only when a set of multiple criteria is met.

These features enhance the reliability of the hardware/software system and guarantee accuracy of the issued alarms. Due to the multiple redundancies built into the system, a failure of individual components or subsystems has limited effect on the overall performance. For example, if a subset of the sensors fails, the software parameters will be adjusted to work with the remaining ones. Only high-reliability components were used to build the system, which has been operating continuously for more than two years without a failure or a false alarm.

The output of the EEWS is a binary signal, i.e., yes/no, reporting the absence or presence of a precursor of the strong ground motion associated with the S-waves. If the early warning system reports a positive state, meaning a target P-wave is detected, the central computer will generate a visual and audio alarm and will close the electric circuit connected to the external alarm subsystem. This autonomous decision making takes less than a second.

Taking two approaches

With respect to the EEWS, generally there are two approaches: network-based and on-site systems.

The network-based system covers a large territory close to the potential epicentral area and uses information from the multiple sites to trigger the alarm. The on-site systems are designed to protect an individual facility and are installed on a very small geographical area. Generally, the on-site systems work much faster, but the warning time they provide can be smaller than for the network-based systems. The choice between these two options is mainly controlled by the peculiarities of the seismic-hazard mitigation problem, geographical settings, budget and capabilities of the recipient facility to respond to the warning within the limited time frame.

The on-site EEWS are designed to minimize potential losses that strong ground shaking can produce. Imagine a high-risk facility such as a hospital or municipal utility that contains equipment sensitive to dynamic forces. The alarm triggered by the P-wave can shut down dangerous processes, close gas pipes and stop electrical motors, minimizing potential damage to the facility and the surrounding environment and even saving lives.

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The alarm triggered by the P-wave at an on-site EEWS can shut down dangerous processes, close gas pipes and stop electrical motors, minimizing potential damage to the facility and the surrounding environment and even saving lives.

A drop in risk

The ultimate success of the EEWS is measured in terms of reducing the risk to human lives and valuable assets due to a seismic hazard. The benefits are obvious: it provides an early warning—from a few seconds to dozens—allowing operators to stop critical processes; it informs people about the coming destructive ground shaking; it reduces potential damage to vulnerable components and subsystems; and it continuously records several months of the ground vibration for further post-processing and engineering investigations.

In our experience, the cost of the EEWS is a small fraction of the damages that might result from a severe earthquake in densely populated urban areas. The supplementary cost to install one of the systems at a major structure or building such as a bridge, tunnel, school, hospital or water treatment plant is small, probably less than 0.25% of the capital cost. **R&B**

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