What if the ShakeAlert® Earthquake Early Warning System Had Been Operating During the M6.7 1994 Northridge Earthquake?

How will the ShakeAlert System likely perform now on a moderate earthquake impacting a major urban area? How much warning will you get? To answer this, let's do a thought experiment…

30 Years Ago

Early in the morning of January 17th, 1994 a magnitude 6.7 earthquake occurred near Northridge, California and the shaking it generated caused damage throughout Los Angeles County, including the San Fernando Valley, Santa Monica, Simi Valley, and Santa Clarita. There were 57 deaths, over 9000 injuries, and billions of dollars in property damage.

Thirty years later, the ShakeAlert® Earthquake Early Warning (EEW) system is operating in California, Oregon, and Washington and has the potential to alert people and automated systems that shaking from an earthquake that has just begun might soon arrive at their location.

How does ShakeAlert work?

The U.S. Geological Survey (USGS) and the States of California, Oregon and Washington have implemented public EEW alert delivery powered by data from the USGS-managed ShakeAlert System. All three states now have alert delivery via the MyShake™ app, the Wireless Emergency Alert (WEA) system, and by Google via the Android operating system[1] complementing existing alert delivery to automated systems. Another alert delivery service currently available for public alerting to cell phones in California is ShakeReadySD (via the Alert San Diego app).

How will ShakeAlert likely perform now on a significant earthquake impacting a major urban area? To answer that question let's start with how ShakeAlert works. EEW works because the data processing and communication systems used to deliver the alerts are faster than the speed of the seismic waves that cause Earth shaking. The amount of warning time you get depends on:

- How far away you are from the earthquake epicenter
- How quickly the USGS ShakeAlert system processes the seismic data
- What level of ground shaking you want to be warned about (see Earthquake Early Warning — Fine-Tuning for Best Alerts)
- How quickly the alert is delivered to you via the Internet, wireless delivery (e.g. to cellphones), or other communication pathways.

The USGS is now working with over 50 technical partners who use USGS ShakeAlert data for a variety of automated actions, including slowing trains, opening firehouse doors, and protecting water supplies. For example, both Bay Area Rapid Transit in Northern California and Metrolink in Southern California use ShakeAlert to slow public transit trains. As uses for EEW expands, more partners will deliver alerts and other information to the public through cell phones, other mobile devices, and specialized receivers.

People who have installed an App on their cell phone can receive push notifications that look like text messages or other types of notifications, depending on the App.

Also, EEW alerts are sent throughout the three states via the Federal Emergency Management Agency's WEA system, through which all the major carriers deliver alerts to users in a defined geographic area who have opted into WEA on their smartphones. WEA alerts warn the public about dangerous weather, missing children, and other critical situations through cell phones and other mobile devices.

What if…?

How much warning will you get? To answer this, let's do a thought experiment, asking: What if the ShakeAlert System had been operating with mid-2020's technology during the 1994 Northridge earthquake? Here we go.

For urban earthquakes like Northridge it is difficult for an EEW system to detect the earthquake and transmit the alerts to people fast enough that they still have sufficient time to take protective actions in the locations where shaking is strongest[2]. The Northridge earthquake started relatively deep below the Earth's surface in an urban area. The most severe shaking is within about 20 miles of the epicenter (see Figure 1), reaching strong levels throughout the entire San Fernando valley almost immediately.

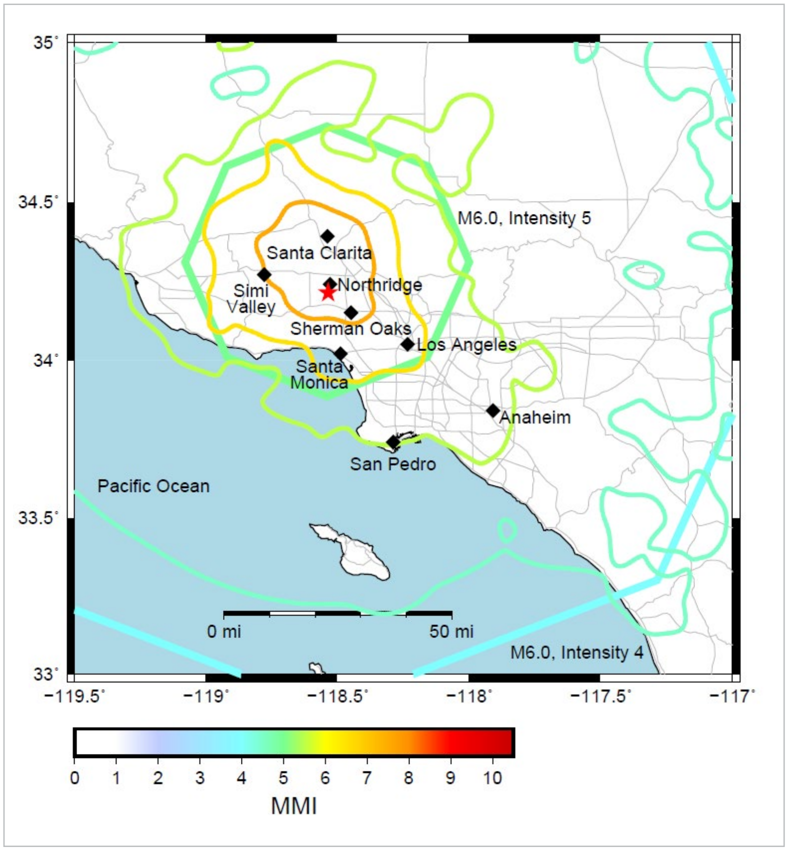


Figure 1. *Contours of shaking in the 1994 Northridge Earthquake from the USGS ShakeMap (Contours are given in Modified Mercalli Intensity (MMI) levels 4.5, 5.5, 6.5, and 7.5. The locations of cities discussed in the text are shown as labelled diamonds, the epicenter is shown as a red star. The extent of the area receiving alerts will grow during the initial seconds as the rupture expands over the fault and the estimate of earthquake magnitude increases. The initial magnitude estimate may be smaller (M5-6) than the final magnitude (6.7) and there may be errors in the real-time magnitude estimates. The green and light blue octagons denote the alerting regions for Android "take action" alerts (Intensity 5) and WEA (Intensity 4) when the magnitude estimate reaches 6.0 during the growing rupture. This indicates just one of multiple (expanding) alerts that would be sent out (see text). The Intensity 3 octagon, used by many cellphone apps, extends beyond the scale of this map.*

For every earthquake there is a zone near the epicenter (the late-alert zone) where people will feel shaking before they receive an alert because:

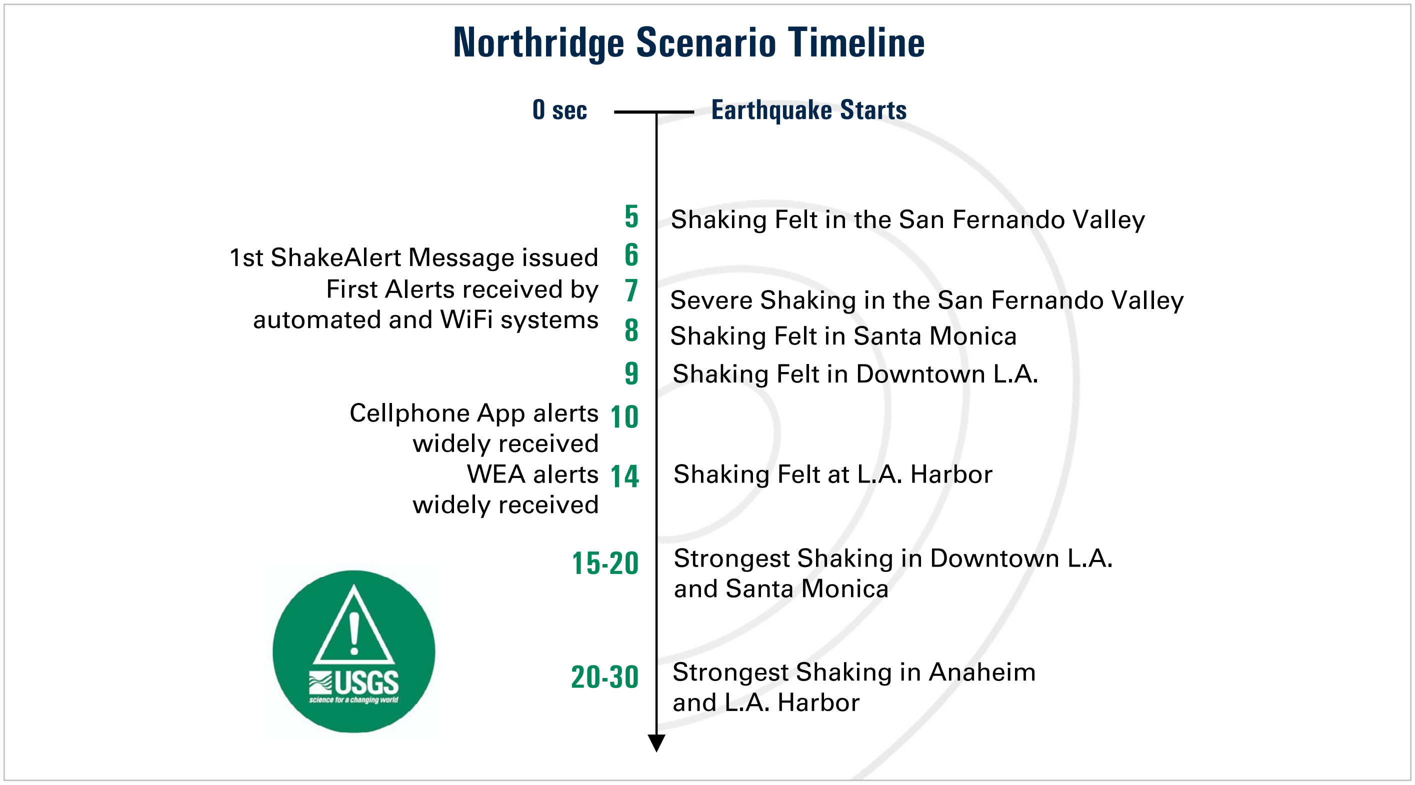
- The ShakeAlert system has to gather the initial seismic data, estimate the earthquake's location and magnitude and shaking before a ShakeAlert Message can be issued by the USGS and handed off to its delivery partners.
- Alert delivery to cell phones can range from less than a second for devices connected directly to the Internet to a few seconds or more for devices connected through cell towers depending on the alert delivery mechanism (see below), and some phones may not receive the alert at all.
- Even automated systems which typically rely on fast Internet connections may not be able to respond before shaking arrives.

However, the instrumentation used by ShakeAlert is densest in urban areas like Los Angeles, so once shaking hits the surface, the earthquake is rapidly detected and alerts are transmitted to those at greater distances.

For an earthquake such as Northridge, these factors would have led to warning times that range from no warning to fifteen seconds of warning before the strongest shaking arrived (see timeline diagram). The areas of greatest damage would have been in the late-alert zone.

As the fault is rupturing, the ShakeAlert system's estimate of the Northridge earthquake magnitude grows with time. The first waves reach the Earth's surface about 5 seconds after the earthquake began. It typically takes ShakeAlert about 1 second for the data from the seismic sensors to reach and be processed by ShakeAlert's computers. The first ShakeAlert Message is issued about 6 seconds after the earthquake began (see Figure 2) and is for a moderate magnitude, likely around M5.5. As the earthquake grows ShakeAlert's magnitude estimate increases. By about 7-8 seconds into the earthquake, ShakeAlert estimates it to be a M6.0 earthquake. Subsequent updates increase the magnitude towards its final value around M6.7 resulting in alert delivery to a wider geographic region.

Figure 2. *Timeline of ground motion (right side) and ShakeAlert system expected performance (left) in a Northridge-like earthquake scenario.*



We assume the alerts are delivered within less than 1 second for direct Internet users and cell phones connected to the Internet through WiFi™, 4 seconds for cell phone apps connected via cellular networks, and 8 seconds for the WEA system, though individual users will experience variable delivery times[3]. Following current ShakeAlert thresholds for public alerting and design specifications for Android alerting, we assume that Android users will be alerted to take action if the expected shaking is intensity 5 (moderate shaking) or higher, WEA users if the expected intensity is 4 (light shaking) or higher and cell phone App users if the expected intensity is 3 (weak shaking) or higher.

With these shaking intensity alerting thresholds, the initial alert triggers cell phone Apps, WEA, and Android alerts to be sent to users within 125, 45, and 12 miles of the epicenter[4], respectively. The alert distances would have then increased to about 200, 100, and 30 miles, respectively when the magnitude estimate reaches M6.04. Even these initial alerts would have covered almost all of the areas that experienced MMI 4 or greater shaking[5] in 1994 (Figure 1).

Let's do some analysis:

The 1994 earthquake occurred at 4:30 a.m. local time, meaning that most potential users of the warnings would likely have been asleep and not been able to quickly take protective actions. Earthquakes that occur during daytime, particularly during commuting and normal working hours have significantly higher rates of injuries than earthquakes that occur at night.

So for purposes of illustration, let's assume the "What if...?" earthquake occurs during business and school hours. We assume that automated users like L.A. Unified School District (LAUSD), the Santa Monica Public Library, and the Port of Los Angeles will receive an alert via the Internet with a delay of 1 second after the ShakeAlert Message is issued. Android users connected to WiFi will also receive alerts with about a 1 second delay[3]. We also assume cell phone app users and WEA cell phone users connected via cellular towers will experience delivery delays of 4 and 8 seconds, respectively. There will be variations in each of those times for any individual, but they represent typical experiences that many users will have. Alert delivery may get faster in the future, as cell phone network and WEA alerting technologies improve. For this thought experiment, some examples of what would occur are below and the overall timeline is shown in Figure 2:

- Shaking reaches severe levels in the San Fernando Valley before the first alert is received via any of the delivery mechanisms.
- At 7 seconds into the earthquake (i.e., after it starts at depth), the initial Internet alert is received by ShakeAlert enabled LAUSD and 'Drop, Cover, and Hold On' messages are then broadcast. Students in the San Fernando Valley and those north and east of downtown would have already felt shaking. Students south and west of downtown would not yet have felt shaking.
- At 7 seconds, Santa Monica Public Library (13 miles from the epicenter) would have initiated automatic actions about the time shaking was first felt and had about 10 seconds of warning before severe shaking.
- At 8 seconds, Android users connected via WiFi within about 30 miles would receive the 'take action' alert. This is about the time shaking is felt in downtown LA and Santa Monica. These alerts would provide about 4-10s of warning before strong shaking (MMI 6) and 10-12 seconds of warning before severe shaking (MMI 8) in these locations.
- Most cell phone users in Northridge, Simi Valley, Sherman Oaks, Santa Clarita, Santa Monica, and downtown LA would feel shaking before receiving the first alert from a cell phone App or WEA through their cellular service. Shaking would be felt out to roughly 25 miles from the epicenter before most cellular-connected App alerts arrive and out to about 45 miles before the first WEA alerts arrive.

- In downtown L.A. (20 miles) Internet alerts would be received about the time shaking is felt. Cellular-connected app alerts would be received a few seconds later, providing 5-10 seconds of warning before severe shaking occurs here.
- If ShakeAlert were being implemented in San Pedro – L.A. Harbor (35 miles) then Internet alerts would initiate automatic actions about 5 seconds before felt shaking with 15-20 seconds of warning before severe shaking begins.
- At locations such as Disneyland Park and Angel Stadium in Anaheim (48 miles) cellular-connected app warnings would be received about 5 seconds before shaking is felt and about 15 seconds before strong shaking. In the 1994 Northridge earthquake the scoreboard in Angel Stadium collapsed onto several hundred seats, but fortunately the stadium was vacant at the time.

These estimates are specific to an earthquake about magnitude 6.7 with an epicenter located near Northridge, as in 1994. For other California earthquakes of similar size with epicenters in different urban areas, we can expect a similar range of outcomes.

Many of the worst injuries in 1994 were concentrated in the San Fernando Valley, where shaking would have been felt almost right away at the start of the earthquake before any alert arrived. If you feel shaking, take a protective action such as Drop, Cover, and Hold On. Do not wait for the EEW alert. ShakeAlert users farther away in locations like Santa Monica, Downtown L.A., Long Beach, or Anaheim, where less damage and some injuries occurred in 1994, may have received an alert in time to take a protective action. Regardless of location, so long as they were located outside of the late-alert zone, automated (Internet-based) systems and cell phone alerts delivered via WiFi would have responded the fastest, offering the greatest protection for people and property.

What's next?

With support from the USGS and partners in California, Oregon, and Washington a team of scientists and engineers from the USGS, universities and other partner organizations are continuously working to make all aspects of the ShakeAlert System better, so that the alerts reach end-users faster and are more accurate and useful. These efforts range from installing new seismic stations, to testing improved algorithms for detecting the earthquakes, to improved delivery mechanisms.

Where can you learn more?

Visit the ShakeAlert website (ShakeAlert.org) for more information on how the ShakeAlert system works and how you can get ShakeAlert-powered alerts on your phone. Visit the Earthquake Country Alliance (earthquakecountry.org) to learn about personal protective actions you can take such as Drop, Cover, and Hold On when you feel shaking or receive an alert.

— *Written by Jeff McGuire and Robert de Groot,*
U.S. Geological Survey, July 2020 and updated in 2024

Footnotes

1. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

2. For further information on the limits of EEW including descriptions of the late alert zones and likely warning times, see Minson et al., (2018), Science Advances 4(3): eaaq0504; Minson et al., (2019), Scientific Reports 9:2478; Meier et al., (2019), J. Geophys. Res. 125, e2019JB017718; and Wald, D. J. (2020). Earthquake Spectra, https://doi.org/10.1177/8755293020911388.

3. The time to deliver an alert to an individual user by any mechanism will be variable. For the purposes of illustration in this study we chose recent estimates of representative values for Internet-based alert delivery (including to cell phones on WiFi), cellular delivery via apps operating on local cellular networks, and cellular-network delivery via WEA. The 8 second value for WEA is within the range of delivery times observed in tests conducted by ShakeAlert® partners in summer 2019. The 4 second value for apps is within the range of delivery times reported to ShakeAlert® from tests of the MyShake app via cellular delivery in early 2020. For cellphones connected to WiFi, we expect a large number of users to get the alerts within a few seconds based on tests results reported to ShakeAlert® by Google in spring 2020, and the 1 second value is within the range of those delivery times. Individual alerts may be faster or slower than these times, and alerts may become faster in the future. Alert distances use the current ShakeAlert® ground-motion contour product definitions for shaking Intensity 3, 4, and 5 for apps, WEA, and the Android operating system for "take action" alerts, respectively. Additionally, it is important to note that USGS-mandated alerting thresholds for WEA and apps differ. For WEA the USGS will distribute a ShakeAlert® for earthquakes M5 or greater to users who could feel Intensity 4 (light shaking) or greater. Distribution of alerts via apps are for earthquakes M4.5 or greater and to users who could feel Intensity 3 (weak shaking) or greater. The Android system will deliver 'take action alerts' for earthquakes M4.5 or greater and to users who could feel Intensity 5 or greater shaking. Android will also "be aware" notifications for M4.5 or greater earthquakes for users who are expected to experience Intensity 3 or greater, but without prompting them to take action.

4. The 125-, 45- and 12-mile radii for the initial alert assume a point source and are from the Ground Motion Prediction Equations and Intensity Conversion equations currently implemented in ShakeAlert® for California. The shaking intensity experienced at any particular distance from the epicenter can vary widely. ShakeAlert publishes contour products that are defined in terms of the distance where the median expected intensity is a particular value. Currently, the intensity 3 contour product corresponds to the median intensity 2.5, the intensity 4 contour product corresponds to median intensity 3.5, and the intensity 5 contour product corresponds to median intensity 4.5.

5. We use the terms "felt shaking", "strong shaking", and "severe shaking" to correspond to intensity values of 4, 6, and 8 respectively based on the seismograms recorded in 1994.