# Chapter 19
# How Useful is Early Warning and Can It Be Made More Effective?

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**Abstract** The methods to detect the development of a large earthquake at an early time and to issue an appropriate warning have made great progress. Nevertheless, for population centers at risk, warnings can generally be issued only about 5–10 s before the strong shaking arrives. Systems and facilities that can benefit from a warning with such a short lead time include: Transportation systems, fire departments, medical facilities, schools, industrial plants, petroleum and gas pipelines, elevators, and power plants. However, for the population at home in vulnerable apartment buildings or at work in office buildings and factories that may not have been built following modern codes, the warning is too short for a person to reach a safe place. Although taking cover under a table can protect a person from falling objects, a structurally strong Earthquake Protection Unit (EPU) is required to save lives and limbs in a partially collapsing building. If a culture of earthquake awareness and the knowledge of early warning capabilities were developed, in which strong earthquakes closets could be bought in the lumber yard like tornado shelters, then the fine advances in earthquakes early warning could result in lives saved.

## 19.1 Introduction

In today's world of transmission of instant news from the ends of the globe to the television screen in millions of living rooms, people become increasingly aware of the great potential earthquakes have to create disasters. The numbers of fatalities in one event are counted in units of tens to hundreds of thousands, the injured may reach a million in future earthquakes with magnitudes exceeding M8 and located

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F. Wenzel and J. Zschau (eds.), *Early Warning for Geological Disasters*, Advanced Technologies in Earth Sciences, DOI: 10.1007/978-3-642-12233-0_19,

below land, given that earthquakes with M $\leq$ 8 have injured many hundred thousand (Tangshan, M7.6, 1976, 700,000+, Sichuan M8.0, 2008, 375,000, Haiti, M7.0, 2010, 310,000; Daniell 2012; Daniell et al. 2011). The consumers of these startling news are perhaps shaken by the images of horror that invade their homes, but most of them don't think that they could be next, as they sip their coffee and listen to the announcer quote astronomical numbers of victims. Moved by the suffering they witness, many people donate money to help the survivors. If they knew that indeed they could be next, they certainly would invest ten to hundred times more to protect themselves, if a means to protect themselves were offered them.

Efforts to protect the population from disastrous earthquakes include attempts to develop methods to predict earthquakes, to construct new buildings such that they will resist strong ground shaking, and to retrofit existing weak buildings, so they are unlikely to collapse. Here we will briefly review these methods to reduce the earthquake risk and show that they are not very effective for the population at large.

Whereas this book is dedicated to detailing the technical advances, which have been and are being made in the field of earthquake early warning, some thought should be given to what degree early warning has been useful in disastrous earthquakes and how its effectiveness could be improved for protecting the population from collapsing buildings. Here we summarize examples of past experiences with earthquake early warning and we consider how effective Earthquake Protection Units (EPU) may become to allow families to make use of early warnings to save lives and limbs.

## 19.2 Earthquake Prediction So Far a Story of Failures

If the location, occurrence time, and the magnitude of earthquakes could be predicted accurately and reliable, the population could be made aware of the impending disaster and the risk could be reduced. Although some earthquakes have happened where and when they had been predicted no reliable method exists.

One of the reasons that it is so difficult to predict earthquakes is that their source volumes, at more than 5 km depth (mostly at 20 km), are inaccessible for direct observation. Another obstacle is the fact the stress level in the Earth's crust cannot be measured directly. Only changes of stress can be inferred by measuring deformations at the surface. Thus, it is not accurately known how close to the failure stress any part of the Earth's crust may be.

Locations of increased probability of large earthquakes can nevertheless be identified. The simplest method is an estimate of the accumulated strain (and thus amount of slip) stored along a plate boundary where the plate displacement is being monitored. Where the last release of strain (stress) has occurred hundred to a few hundred years ago, the possibly available slip amounts to several meters because the rate of plate motion is typically several centimeters per year. The occurrence dates and the amounts of slip can be determined approximately by excavating slip evidence for pre-historic earthquakes (e.g. Sieh 1984; Sietz et al. 1997; Clark et al. 2010). These paleoseismological efforts are only possible where fault traces are exposed on land; under water they cannot be investigated. Where this information can be dug up, it becomes evident that the repeat intervals and the amounts of slip vary considerably along any single fault segment. In addition, the strain due to plate motions is relieved to an unknown amount along many plate boundaries by a-seismic creep, which renders the estimate of accumulated slip inaccurate.

In spite of these difficulties, the North Anatolian fault south of Istanbul (e.g. Stein et al. 1997; Kalkan et al. 2009) and the Himalayan plate boundary (e.g. Khattri 1999; Bilham et al. 2001; Bilham 2004) have been identified as locations where large earthquakes are bound to happen in most of the local population's lifetime. These are locations where early warning efforts can be useful, and that is why such efforts have been concentrated in Istanbul, for example Atakan et al. (2002), Fleming et al. (2009).

The M8 algorithm and its derivatives are methods to map Temporarily Increased Probabilities (TIPs) for large earthquakes, updated annually on the internet (http://www.mitp.ru/en/predictions/20110311.html). Although the authors have repeatedly been able to claim success (e.g. Kossobokov et al. 1999; Kossobokov 2012), the public as well as many seismologists are not aware of this warning method. For example, the New York Times and the Neue Zuercher Zeitung, among many newspapers, have published interviews in which seismologists asserted that the recent deadly earthquakes of May 20 and 29, 2012 in Emilia Romagna, Northern Italy, were surprises in a zone believed to be a-seismic, although a TIP warning, issued by Peresan et al. (2012) (http://www.ictp.trieste.it/www_users/sand/prediction/prediction.htm), was in effect for this region. The effectiveness of TIP warnings are reduced because they are perceived as vague due to their large radius (427–667 km), their large time window (3 years), and because they are mostly unknown to the public and experts.

## 19.3 Earthquake Engineering Solutions are Expensive and Marginally Implemented

The political will to protect the population is reflected by the fact that in the 1970s many countries introduced codes that require minimum quality construction practices, and in some countries the existing codes were upgraded to more stringent ones, during these years. One problem with this approach to reduce earthquake risk is that for a long time to come the majority of the population will continue to live in weak buildings constructed before the codes went into effect. The second problem is that in many countries the code is not enforced.

In countries where the building codes are enforced, such as for example the United States, Japan, and Taiwan the ratio of injured/fatalities is higher by about a factor of 10 than in developing countries. Using 1,400 fatal events with deaths to injury ratio from 1900–2012, where human development index at the time of the event is higher, it can be seen that the ratio of injuries to deaths is also higher (Fig. 19.1). Human Development index is the best measure of the development of a nation and is a combination of life expectancy, education and GDP per capita. It is well correlated to building code enforcement.

This ratio can be taken as a measure of the ability of the built environment to resist strong shaking because in well constructed buildings few fatalities are to be deplored, while some occupants are injured in strong earthquakes.

Retrofitting poorly constructed buildings is almost never done because it is expensive. Private owners cannot be persuaded to spend money to prevent a disaster that they doubt will ever occur and governments in regions where weak buildings are at risk usually have other problems depleting their coffers and turn a blind eye to protecting their office workers from earthquakes which likely will not happen during their tenure in office.

Although there exist some spectacularly elegant means of detaching a building from the ground upon which it rests, such that it is not subjected to strong shaking by seismic waves, few people actually benefit from the engineering solution to the earthquake problem for the reasons given above.

## 19.4 Experience with Early Warning in Past Earthquakes

So far, little documentation exists regarding the value of Earthquake Early Warning Systems (EEWS) in disaster mitigation, specifically life-saving. There are only two systems in Mexico and Japan that actually issue alarms and where recent experience is available.

The Ometepec earthquake of Mexico (20th March 2012, 12:02 p.m. local time, magnitude of 7.4) occurred in the state of Oaxaca in South-Eastern Mexico. The earthquake was also strongly felt in Mexico City. The earthquake warning system (SAS) responded to this event and issued a warning about 60 s before the arrival of strong ground motion in Mexico City, such that the Metro system could stop operations and information on evacuation could be provided.

One Metro line sustained damage to rails, so that a chance for derailment existed. Stopping the trains because of the early warning was probably instrumental in avoiding a derailment. The fact that we cannot say for certain that lives have been saved in this case, and how many lives, highlights the problem that damage and losses are recordable, but avoided losses are very difficult to assess. The only fact we know is that no injuries were reported in the entire Metro system (EERI 2012).

The earthquake occurred during a Mexican Senate hearing, which was recorded by video. The meeting was, as shown in the video, interrupted by participants and immediately an orderly evacuation of the room took place (http://tremblingearth.wordpress.com/2012/03/31/mexico-city-earthquake-early-warning-it-works/).

The early warning system operated by the Japanese Meteorological Agency (JMA) since October 2007 issued so far more than a dozen alarms to the public. They are commonly issued by TV, radio, mobile phone services, and internet. The recent $M = 9.0$ Tohoku earthquake of March 11, 2011, posed a particular problem because the size of the expected earthquake consequences were updated for more than

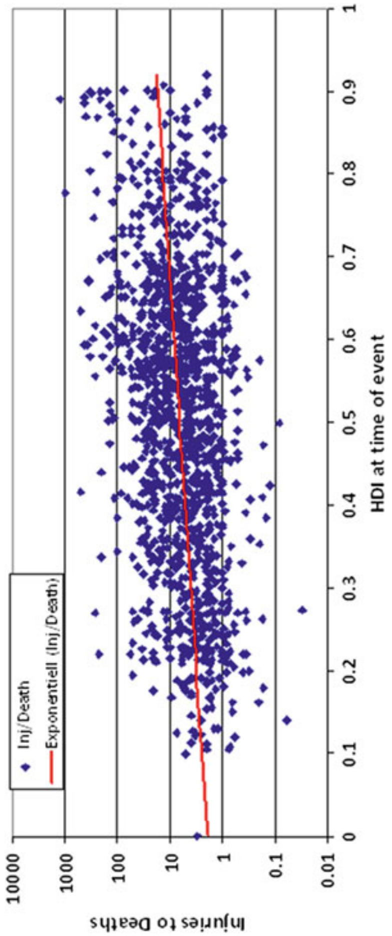


**Fig. 19.1** CATDAT Damaging Earthquakes Database: 1,400 fatal events with an injured to fatalities ratio versus Human Development Index at time of event from 1900 to 2012

one hour, giving varying information on magnitudes and expected ground shaking (Cryanoski 2011). After 8.6 s of the first trigger at station OURI warning was provided estimating that an $M = 7.2$ earthquake had occurred, and forecasting the seismic intensity to be 5-lower (on the JMA scale) for the Central Mijagi prefecture, where Sendai City is located. The actual ground shaking in this area turned out to be intensity level 7 (the highest on the JMA scale).

Problems with the early warning for very large earthquakes have been identified earlier (Bose et al. 2009) as finite earthquake source models have to be used, but were not implemented during the Tohoku earthquake in the JMA procedure. The JMA system will be upgraded in the near future with additional instrumentation and methods (see Yamada 2012; this volume).

## 19.5 Early Warning Use for Protection Lifelines and Critical Facilities

Application of earthquake early warning for infrastructure systems has a long history in Japan. Instrumentation of bullet train lines, nowadays the Shinkansen lines, started in the 1970s and was completed for the Tokaido Shinkansen line in 1992 (Nakamura et al. 2007). The systems were upgraded after the Kobe, 1995, earthquake for a variety of other Shinkansen lines.

Applications for industrial production facilities have been demonstrated during the Kyoto 2009 Early Warning Conference. An outstanding example is presented by the protection of a semi-conductor protection facility which capitalises on the JMA signal but determines operational steps with ground motion records on the site of the plants.

An obvious application of EWS is the application to shutting down gas supplies or oil flow in pipelines. To avoid fires due to leakage of gas or oil from pipes that may brake due to shaking in an earthquake, a real-time safety control system, SUPREME, has been deployed and put into use for Tokyo Gas in 2005. SUPREME employs 3,800 intensity sensors and remote control devices to achieve quick gas supply shut off. It monitors the earthquake motion at a large number of sites on a real-time basis, interprets the data, and assesses gas pipe damage in order to decide whether or not the gas supply should be interrupted.

A similar installation was put in place in Taipei after the 1999 Chi Chi earthquake. It was successfully tested in a 2002 earthquake that generated higher ground motions in Taipei than the Chi Chi did (Shimizu et al. 2006). Several cities and companies in California and Europe have installed simpler systems with only a few sensors and a few valves that may be shut instantly when strong motions are detected.

### 19.5.1 Stopping of Elevators in High-Rise Buildings

Warnings not to use elevators in case of earthquakes or fires are standard displays encountered in hotels. In high rise buildings, trips on elevators take considerable time and therefore people are likely to become trapped, if strong shaking damages such a building. Thus, it is desirable to evacuate elevators and then stop them from taking on more passengers in case of strong shaking. For example, an elevator emergency management system based on EWS is installed in the 29 floors Kogakuin University building in downtown Tokyo. Trigger levels for P- and S-waves are used to stop the elevators at the nearest floor. Dependent on the degree of strong motion, the elevators resume operation after 60–90 s, or in case of strong motion, wait for inspection. The system worked well in over 20 earthquakes since installation (Kubo et al. 2008).

### 19.5.2 Evacuation of Schools

Although it is generally not recommended to run outside of buildings in a city in case of earthquakes because of falling debris, schools may be successfully evacuated because they are surrounded by open areas for recreation and sports. Also, in some earthquake prone regions, like in Lima, Peru, most schools have only two floors, which allows evacuation in 5–15 s.

Motosaka (2008) reports on school evacuation systems in Miyagi Province. Magnitude and hypocenter information is received from the JMA by a computer at the teacher's room. The computer estimates the countdown to the S-wave arrival and the expected seismic JMA intensity. Based on this information, the broadcasting system issues a warning voice message, audible in all parts of the compound. Voice/image warning information is also transmitted to a TV receiver in each classroom. The architecture of the school allows its evacuation in 15 s. Drills aimed at achieving rapid and orderly evacuation are performed several times per year. Demonstration tests at Nagamachi Elementary School in Sendai, started in 2004. A successful real-life test emerged during the June 14, 2008, Iwate-Miyagi Inland earthquake (M7.2).

### 19.5.3 Research for Implementing Additional Applications of EWS

Fujinawa and Noda (2007) and Fujinawa et al. (2008) developed a number of EWS applications for

- Fire departments,
- Medical facilities,
- Home electronics systems,
- Schools,

- Industrial plants,
- Liquid Petroleum and Gas pipelines,
- Outdoor activity systems,
- Building maintenance systems,
- Elevators, and
- Dams.

Their research was funded by the Ministry of Education, Culture, Sports, Science and Technology (http://www.bosai.go.jp/kenkyu/sokuji/index.htm).

Further applications that capitalize on dense accelerometer instrumentation in tunnels are reported from the new railway tunnel across the Bosporus (M. Erdik, personal communication).

## 19.6 Early Warning Use for Saving Lives and Reducing Injuries

In general, one could say that direct efforts to saving lives in residential buildings are currently not implemented. However, promises made by scientists regarding the potential of earthquake early warning are abundant. For instance, in Gasparini et al. (2007), the preface claims that 'this may be used to minimize property damage and loss of life in urban areas and to aid emergency response'. Contrary to these announcements, actual efforts to avoid fatalities and reduce injuries in residential-, office-, and industrial buildings are not visible, at the moment.

When we consider the potential to benefit from early warning for people in their homes and at work indoors, there are three categories; those who live too close to the rupturing fault and cannot be warned, those who live far enough from the fault where the ground motions are moderate enough so people do not need to be warned, and those who can benefit from early warnings, if they can get to a safe place within 5–10 s, once they receive a warning.

Wyss (2012) has listed 10 examples of large cities located in the vicinity of faults capable of magnitude 7+ earthquakes where the warning time might be in the range of 5–10 s, under favorable conditions. This lead-time is not enough for a person to get to safety unless there exists an EPU on each floor of a multistory building.

At the work place, such a unit could take the form of one room per floor, which is constructed in such a way that it will not collapse even if the rest of the building suffers greatly. In a vulnerable apartment building that may partially collapse in a strong earthquake, an earthquake closet, installed in a surplus bathroom or in a structurally strong corner of the apartment, could save the family that dashes into it after receiving an early warning.

The earthquake closet could be a crude construction put in place by the occupant of the apartment, it could be an engineered closet for sale in a lumber yard along with prefabricated saunas, or it could be specifically tailored by an expert to optimally fit the particular construction of the apartment building in question.

The probability gain for surviving or escape injury in a strong earthquake inside an earthquake closet depends on the ratio of the resistance to shaking by the closet to that of the apartment building. Wyss (2012) estimated that the probability gain may range typically from 1,000 to 10,000.

## 19.7 Discussion

Currently, the standard advice for self protection in an earthquake is to crawl under a table. This measure is effective against falling objects, but not in partially collapsing buildings. Thus we advocate that in education programs about seismic risk, the usefulness of earthquake closets in serious earthquake disasters be stressed along side with the recommendation to dash under a table, if nothing else is available.

It is fair to say that early earthquake warning can be useful to stop mass transportation system and dangerous processes in critical facilities (United Nations 2006), but it cannot be used for people to protect themselves, unless they are in the vicinity of an earthquake protection unit.

Tornado shelters in the form of strong closets are sold by several companies. The interest in individual protection from tornadoes is stronger than that in protection from earthquake consequences because tornadoes sweep over the same regions almost every year, whereas large earthquakes rupture the same fault segments only every several hundred years. Nevertheless, a family that has been informed that they live in a vulnerable building near a fault section that is likely to generate a damaging earthquakes within the lifetimes of some family members may very well be motivated to spend a few thousand Euros to increase their chances to survive more than a thousand fold.

Seat belts in cars were opposed and ridiculed by many, at the time they were introduced. Today, it is mandatory to wear them and no one doubts that they save lives and injuries. People needed to be educated to the danger and the usefulness of the device.

The motivation of owners of office buildings and industrial plants to build earthquake protection units is more difficult to generate. Perhaps litigation, or the threat of litigation, is the only way. It is certainly tragic and difficult to understand why countless industrial facilities collapsed in the minor earthquakes (M5.9 and M5.8) in northern Italy on May 20 and 29, when very few other buildings collapsed, except abandoned, old brick farms and barns. In these earthquakes, more people died in industrial plants than in homes, even though one of them occurred at night, when almost no one was at work, but everyone was sleeping at home.

The earthquake closet is a low cost means of reducing the earthquake risk and it has the advantage that false alarms may readily be tolerated because it is a small inconvenience to briefly pop into the unit, even if no disaster follows.

## 19.8 Conclusions

We conclude that the important advances in delivering early warnings before the strong shaking due to large earthquakes arrives have already been applied to stopping rapid transport systems and dangerous process in industrial facilities. In a next step, we need to work toward making these warnings useful for the population at home and at work. If we can develop a culture of early warning that includes education about the risk and the concept of the earthquake closet, then we would be on the way to an important realistic means of protecting a part of the population from being harmed in earthquakes.

**Acknowledgments** M. Wyss thanks the support of the JTI Foundation, based in Switzerland. J. Daniell thanks the General Sir John Monash Foundation of Australia for their generous support.

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