Development of the On-site Earthquake Early Warning System in Taiwan

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ABSTRACT**:** Taiwan located at circum-Pacific seismic belt and the junction of the Eurasian plate and Philippine Sea plate. In average, more than 4000 earthquakes occurred annually. However, with today's science and technology, the earthquake is still unable to estimate and evacuate the people in advance. As the source of seismic waves generated in the body of the earth, when the wave passes on the mantle through various distinct characteristics of the media, the wave velocity varied. The seismic waves can be divided into two kinds, P-waves and S-waves. The velocity of P-wave is about 5-7 (km / sec); the velocity of destructive S-wave is about 3-4 (km / sec). This research develops the on-site Earthquake Early Warning System (EEWS) by the physical characteristics of the P-wave velocity greater than S-wave velocity. The on-site EEWS only used the signal from the on-site sensor, the calculation time was less and suitable to provide earthquake early warning to the region which close to the epicenter. In the same time, the proposed on-site EEWS was integrated with the disaster reduction control system in a demonstration house and been tested on NCREE’ s shake table. The integrated on-site EEWS can provide the early earthquake warning through broadcast, TV and LED text display. Also, it will automatically park the elevator, shut-off the gas, switch the power, open the door and turn on the light of the escape route. Combine the on-site EEWS and disaster reduction control system, the life and economic loss can be greatly reduced. In the other hand, the on-site, long-term test results were also preceded. According to the validation test results, the proposed on-site EEWS can provide about 80% accuracy of the predicted intensity levels and at least 8 seconds response time around the epicenter region.

KEYWORDS: earthquake early warning, embedded system, shake table test.

1. INTRODUCTION

Taiwan is located on the Circum-Pacific seismic belt at the junction of the Eurasian Plate and the Philippine Sea Plate. Geological activities are frequent in Taiwan, with more than 4,000 earthquakes of various scales, including over 200 sensible earthquakes, on average each year. The earliest seismic occurrence can be traced to the Wanli period of the Ming Dynasty. Over the past hundred years, a number of majorly disastrous earthquakes have occurred in Taiwan. A significant earthquake in Hsinchu and Taichung in 1935 resulted in the death of 3,276 people, over 12,000 people were injured, more than 17,000 buildings collapsed, and over 36,000 buildings half collapsed. Earthquakes occurred in Chiayi in 1940, in Tainan in 1946, and in Tainan and Chiayi in 1964. The 921 Chichi Earthquake in 1999 resulted in the death of 2,434 people and nearly 11,000 buildings collapsed. Though each of these earthquakes caused heavy casualties and property losses, modern scientific technologies remain unable to predict earthquakes and make evacuation plans. Seismological monitoring networks, historical earthquake data, and local geological conditions are required to determine potential hazardous areas and plan earthquake rescue measures.

Similar to Taiwan, Japan is located on the Pacific seismic belt and is profoundly affected by earthquakes. The Japan Meteorological Agency (JMA) constructed an Earthquake Early Warning (EEW) system in October 2007 to reduce earthquake disasters, and promoted the system throughout Japan. This EEW system can issue warnings mainly because of the concentration of seismic stations (approximately one station every 20 km) established by the JMA and because computers can calculate rapidly the location of earthquakes and the direction of seismic wave propagation. Because seismic waves generated from seismic sources propagate within earth, the wave speed is affected by various stratum media of dissimilar features. Seismic waves can be divided into P-bands and S-bands. If the speed of P-bands is approximately 5 to 7 km/sec, the speed of S-bands, which can easily damage the earth's surface, is approximately 3 to 4 km/sec. This study develops an Earthquake Early Warning System (EEWS) by taking advantage of the superior speed of P-bands compared to the speed of S-bands. The EEWS estimates the arrival of S-bands based on P-band information, and determines the potential impact of S-bands on the buildings within the S-band impact range to limit the impact of earthquakes on socioeconomics by improving the response time before an earthquake strikes.

2. The Development of the Earthquake Early Warning System in Taiwan

Seismic waves can be divided into P-wave and S-wave. The speed of P-wave is approximately 5 to 7 km/sec, the speed of S-wave, which can easily damage the earth's surface, is approximately 3 to 4 km/sec. This study develops an Earthquake Early Warning System (EEWS) by taking advantage of the superior speed of P-wave compared to the speed of S-wave. The EEWS estimates the arrival of S-wave based on P-wave information, and determines the potential impact of S-wave on the buildings to limit the impact of earthquakes on socioeconomics by improving the response time before an earthquake strikes.

Because the Central Weather Bureau has already established a centralized seismography network and a regional earthquake early warning system, the regional system can monitor and calculate earthquake data based on data collected from seismometers distributed throughout Taiwan, and warning can be issued following the calculation. Data calculation requires time; for inland earthquakes, the average time for data processing is approximately 18 to 20 s on average. However, seismic waves can disperse a considerable distance during this period, and areas in proximity to epicenters (within a 50- to 70-km radius) would not receive warnings before earthquakes arrive. These areas are called the “blind zone” of earthquake warning systems. The size of Taiwan is relatively small, the north-south orientation is approximately 300 km and the east-west orientation is approximately 100 km. The epicenters of disastrous earthquakes are primarily located within the island; for example, the epicenter of the 921 Earthquake in 1999 was in Chichi Township along the south Provincial Highway. The calculated blind zone potentially includes regions as far north as Hsinchu County and as far south as Tainan County; this blind zone is also the areas hardest hit by earthquakes. Therefore, minimizing the blind zone is urgently required. Thus, the National Center for Research on Earthquake Engineering began developing an on-site earthquake early warning system. The system includes on-site immediate strong earthquake alarm modules, structural quick response estimation modules, the integration and test of embedded systems, customized display of earthquake warnings, and automatic disaster reduction controls.

3. Development of On-Site Earthquake Early Warning System

The National Center for Research on Earthquake Engineering has developed two methods, body-wave method and artificial neural network technique, for detecting micro P-wave that are imperceptible to humans before earthquakes strike. Using the signals of the wave profile, they estimate the seismic intensity and scale of subsequent earthquakes. These two methods have been used to study and test hundreds of thousands of earthquake records over the years in Taiwan; these methods have accurately and effectively estimated earthquake parameters, such as the scale and intensity of earthquakes. Besides the prediction of the earthquake parameters, NCREE has also developed the rapid estimation of the structural response modulus. With this modulus, the floor response at any point of the structure can be predicted and the important facilities and high-tech factory can take the suitable reaction to reduce the seismic loss. Both the earthquake warning and rapid estimation of structural responses have been verified by numerical analyses. After that, the National Center for Research on Earthquake Engineering start to proceed the integration test with an embedded real-time calculation system (dSpace, Micro-box) to link the on-site high-precision seismometers and embed the warning technology into the real-time computing core to further implement the related technologies. Earthquake warning information, such as the estimated seismic intensity, can be provided by detecting the lead micro P-wave vibration with high-precision seismometers and performing instant calculations.

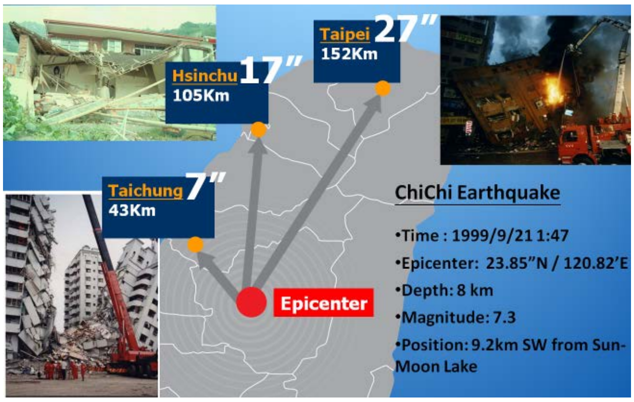

Figure 1: The response time provided by the proposed on-site EEWS in the historical ChiChi earthquake.

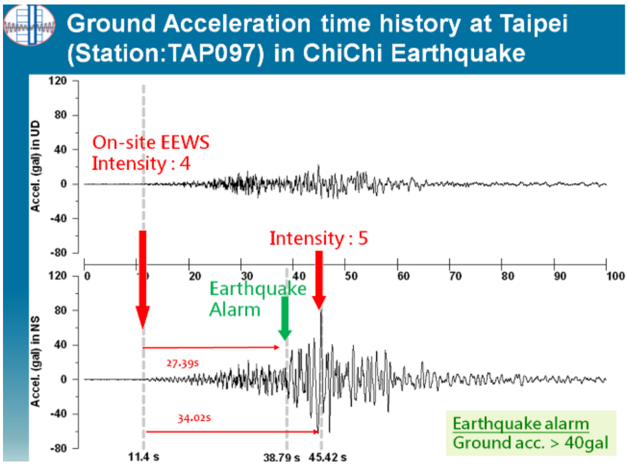

Figure 2: Time history of the ground acceleration and the alarm message.

Figure 3: Photo of the press conference / integration test on the shaking table.

The feasibility and reliability of the entire on-site earthquake early warning system must be verified before it is implemented, NCREE has progressively initiated integration tests since the end of 2009. The integrated system includes a high-precision seismometer, a data acquisition system, an embedded computation core, and an automatic disaster reduction control and warning system. All theses thing were install in a demonstration house and be tested on the tri-axial seismic-simulation shaking table in NCREE. Consider the 921 Earthquake in 1999 for example, employing the system could provide an additional 7, 17, and 27 s of early warning time for Dali Township in Taichung County, the Hsinchu Science Park, and Da-an District in Taipei City, respectively. Figure 1 show the response time provide by the proposed on-site EEWS in the different area. The response time was compared to the seismic warning system of THSR (PGA>40gal). Figure 2 shows that the earthquake early warning system could have issued a warning of seismic intensity 34.02 s before the greatest seismic wave of the 921 Earthquake arrived in Taipei County; compared to the existing warning system of the Taiwan High Speed Rail (with an acceleration threshold value of 40 gal), the earthquake early warning system provides an additional 27.3 s of warning time.

The on-site EEWS was first proposing through the press conference in Feb. 22th 2012 in NCREE. The on-site EEWS and the automatically disaster reduction control and warning system were installed in the demonstration house and be tested on the shaking table as shown in figure 2. The integrated on-site EEWS can provide the early earthquake warning through broadcast, TV and LED text display. Before the destructive S-wave coming, the proposed system raised the alarm, the elevator stopped on the closet floor, the door open, the gas shut-up, the indicator of the escape route turn on and the LED display and broadcast automatically sending the warning message. All these automatically control system and warning system can help people to use the limited response time and dramatically reduce the seismic loss.

4. On-Site Verification Tests

To further verify the earthquake early warning system and to implement earthquake prevention education, this project established demonstration stations in Fanghe Junior High School in Taipei City, Yilan Elementary School in Yilan City, National Chung Cheng University in Chiayi… etc. Figure 4 shows the frame work of the EEWS demonstration station. Each of the demonstration stations can simultaneously receive regional earthquake early warning messages issued by the Central Weather Bureau and on-site earthquake warning messages provided by the National Center for Research on Earthquake Engineering. Either regional or on-site EEWS raise the alarm, the seismic broadcast system and LED display will immediately sent the warning to people in the demonstration station. The corresponding people will also receive the test message and e-mail. While constructing the hardware, we also trained teachers and students to use the system for sheltering and evacuating before an earthquake occurs according to the earthquake prevention drill plan of each school. An earthquake prevention drill involving the entire school and the propose EEWS will be held at least once a year to reinforce awareness of earthquake prevention through practical operation.

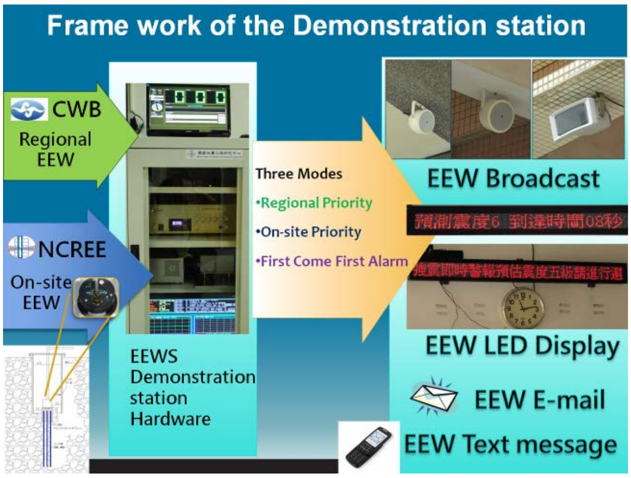

Figure 4 The frame work of the EEWS demonstration station.

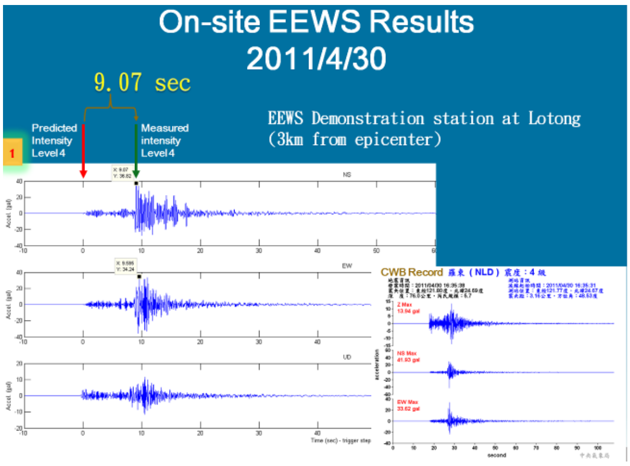

Figure 5: The time history of ground acceleration at Luodong Branch of Secom Ltd. in 2011/4/30.

A 5.8-magnitude sensible earthquake occurred at 10.1 km south east of Yilan County on April 30, 2011. The three seismic stations, Yilan Elementary School, Chung Cheng University, and Luodong Branch of Secom Ltd. all functioned normally and issued earthquake warnings. Figure 5 shows the measured records at Luodong Branch of Secom Ltd. with the south-north orientation and east-west orientation shown from top to bottom, and the vertical acceleration duration record. The red arrows indicate the time warnings were issued and seismic intensities were estimated. The green arrows indicate the time of maximum vibration and the measured seismic intensities; the estimated seismic intensities were consistent with the measured intensities. Luodong Branch of Secom Ltd. is located only 3 km from the epicenter, but it still had 9.07 s of warning time. National Chung Cheng University, which is 187km away from the epicenter, had 28 s of warning time. In the other hand, according to the long-term test results (~ 200 cases), the proposed on-site EEWS can provide about 80% accuracy of the predicted intensity levels and at least 8 seconds response time around the epicenter region.

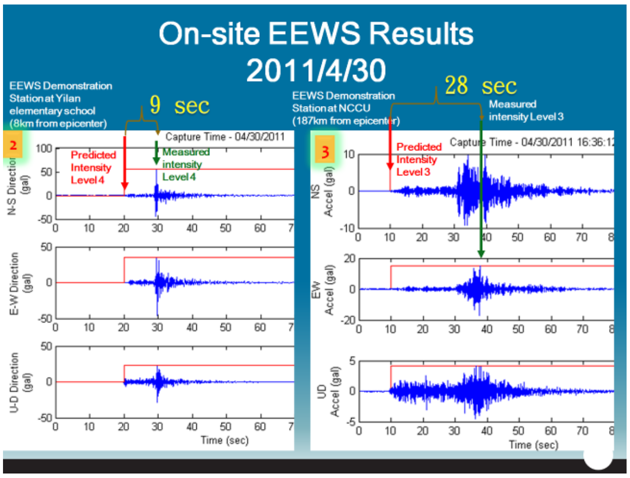

Figure 6: The time history of ground acceleration at Yilan elementary school and National Chung Cheng University in 2011/4/30.

5. Conclusion

Because of its unique geographical environment, earthquake disasters occur frequently in Taiwan. The Central Weather Bureau collated earthquake data from between 1901 and 2006 (Central Weather Bureau, 2007) and found that 97 earthquakes had occurred, of which, 52 resulted in casualties. The 921 Chichi Earthquake had the most profound impact. Because earthquakes have instant destructive power and current scientific technologies cannot provide precise early warnings in advance, earthquake prevention is crucial. The earthquake early warning system can provide seconds to tens of seconds of warning time before an earthquake strikes. Although the warning time is short, it is sufficient for implementing earthquake prevention measures and finding shelter. The National Center for Research on Earthquake Engineering has studied the core technologies for over 10 years; the proposed on-site EEWS has passed the validation test on the tri-axial shaking table. The integrated on-site EEWS can provide the early earthquake warning through broadcast, TV and LED text display. Also, it will automatically park the elevator, shut-off the gas, switch the power, open the door and turn on the light of the escape route. Combine the on-site EEWS and disaster reduction control system, the life and economic loss can be greatly reduced. In the other hand, the on-site, long-term test results were also preceded. According to the validation test results, the proposed on-site EEWS can provide about 80% accuracy of the predicted intensity levels and at least 8 seconds response time around the epicenter region. The National Center for Research on Earthquake Engineering is progressively promoting and applying the actual machine using a series of customized developments and tests to provide the Taiwanese people with more advanced earthquake prevention devices and to limit the damage caused by earthquakes.

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