REALTIME LONG-PERIOD GROUND-MOTION PREDICTION SYSTEM AND EXPERIMENTAL DEMONSTRATION FOR ITS PRACTICAL USAGE

S. Aoi[(1)], T. Kimura[(2)], T. Kunugi[(3)], W. Suzuki[(4)], Y. Dhakal[(5)], N. Koja[(6)]

[(1)] *Director-General, National Research Institute for Earth Science and Disaster Resilience, aoi@bosai.go.jp*
[(2)] *Chief Researcher, National Research Institute for Earth Science and Disaster Resilience, tkimura@bosai.go.jp*
[(3)] *Chief Researcher, National Research Institute for Earth Science and Disaster Resilience, kunugi@bosai.go.jp*
[(4)] *Chief Researcher, National Research Institute for Earth Science and Disaster Resilience, wsuzuki@bosai.go.jp*
[(5)] *Research Fellow, National Research Institute for Earth Science and Disaster Resilience, ydhakal@bosai.go.jp*
[(6)] *Scientific Officer, Japan Meteorological Agency, koja_naoto@met.kishou.go.jp*

Abstract

Current technology seems to be hard to predict an occurrence of earthquakes, but is capable to deliver realtime earthquake information just after the occurrence. For railway systems in Japan, the earthquake early warning (EEW) system for Shinkansen was utilized in 1990s. For nationwide warning and alerts, Japan Meteorological Agency (JMA) has operated the EEW system since 2007, and realtime information of ground motion plays an important role in society. On the other hand, the JMA EEW provides only seismic intensities, and not yet to alert broader-period ground motion information such as long-period ground motions. Long-period ground motions generated during large earthquakes shake skyscrapers and cause furniture overturning and damage of elevators in them. Recently, JMA issues the long-period ground motion levels based on 5%-damped absolute velocity response spectra (AVRS) in the period range of 1.6 to 7.8 s. Dhakal et al. (2015) constructed a ground motion prediction equation (GMPE) for AVRS in the period range of 1 to 10 s using 36 earthquakes and 12,401 strong motion recordings observed at K-NET and KiK-net stations. The GMPE has an advantage to use the JMA magnitude Mj that is available immediately after the earthquake, not moment magnitude Mw. We developed a realtlime long-period ground-motion prediction system using the GMPE and hypocenter locations and earthquake magnitudes provided by the JMA EEW. JMA plans to deliver alerts of the EEW for long-period ground motions that are similar to the current EEW for seismic intensities. A working group to investigate prediction information for various needs has been established at JMA to activate the plan. Realtime prediction information for ground motions is not allowed to open to the public based on the Meteorological Service Act in Japan. National Research Institute for Earth Science and Disaster Resilience (NIED) performs experimental demonstrations with JMA to deliver prediction information of long-period ground motions where NIED acts as a virtual business predictor. In the demonstrations, the information is automatically processed for various purposes such as elevator control and alert to building managers, and a web service to show the information on a map is also used. In this presentation, we introduce experimental demonstration, results, and future perspectives to deliver observation and prediction information using an EEW system for long-period ground motions, an application programming interface (API), and the long-period ground-motion monitor.

Keywords: long-period ground-motion; realtime prediction; earthquake early warning; experimental demonstration

1. Introduction

Recent progress not only in seismology but also in information and communication technology enables us to deliver realtime earthquake information about predicted ground motions just after an earthquake occurrence which is clearly different from a prediction of the occurrence. The realtime information called the earthquake early warning (EEW) can provide people with ability to respond an earthquake immediately and help reduce the earthquake's impact. In some countries such as Mexico, Taiwan, Korea and Japan, the EEW systems have been already developed and are delivering public alerts. In Japan, Japan Meteorological Agency (JMA) has operated the EEW system since 2007 for nationwide warning and alerts about the JMA seismic intensity, and the realtime information of ground motion plays an important role in society.

The seismic intensity predicted in the JMA EEW system is an index that is most sensitive to ground motion with a period of about 1-2 s, and information on ground motions with a broader period range, such as long-period ground motions (LPGMs), is not addressed in the EEW. LPGMs with periods longer than 1-2 s are primarily excited by large earthquakes, and can propagate to long-distances due to slower attenuation. They are also remarkebly amplified in large-scale sedimentary basins. Megacities like the Tokyo Metropolitan area in Japan and Los Angels in the United States are located on such large sedimentary basins, and have a number of large-scale structures such as high-rise buildings and long-span bridges with long natural periods. Therefore, LPGMs have provided significant shakings of high-rise buildings, and damaged the elevators and interior materials in the buildings. The JMA has established the "intensity scale for LPGMs," which indicates the degree of human perception and damage, such as toppling or shifting of furniturure and fixtures, in a high-rise building due to LPGMs. This scale is divided into four levels based on the maximum value of the absolute velocity response spectra (AVRS) computed from observed waveform on the ground with natural periods of 1.6 to 7.8 s for 5 % damping ratio. The observed intensity scale for LPGMs began to be issued by the JMA in March 2013.

LPGMs are mainly induced by surface waves which propagate more slowly than body waves, and the EEW information about LPGMs could help modern society in the reduction of the earthquake damages. In this study, we have developed a practical EEW system for LPGMs, and have conducted experimental demonstrations with the aim of verifying the effects of application of prediction information and promoting understanding of LPGMs in the society.

2. Early Warning System for Long-Period Ground Motions

For EEW of the LPGMs, a ground motion prediction equation (GMPE) for AVRS in the period of 1 to 10 s [1, 2] were constructed using 12,401 strong motion recordings from 36 earthquakes observed at the K-NET and KiK-net stations [3, 4, 5] in Japan, which are operated as one of the MOWLAS network [6] by National Research Institute for Earth Science and Disaster Resilience (NIED). The GMPE can provide accurate predictions with correction factors which is a function of the depths of the top of the Vs 1.4 km/s layer beneath the sites from the subsurface velocity model provided by the Japan Seismic Hazard Information Station (J-SHIS) [7]. The velocity model is constructed over the Japanese Islands, and the predicted value can be calculated at an arbitrary site in Japan with the resolution of about 1 km. Moreover, the GMPE has an advantage to use the JMA magnitude, Mj, which is available immediately after the earthquake, instead of moment magnitude, Mw.

This GMPE, together with hypocenter locations and earthquake magnitudes provided by the EEW enabled us to develop a realtime LPGM prediction system as shown in Fig. 1. By using the source information of the current EEW, we can predict AVRS with the natural period of 1.6-7.8 s for 5 % damping ratio and the intensity scale for LPGMs as quick as the EEW for the seismic intensity. In addition to the LPGM prediction information, AVRS for periods of 1.6-7.8 s for 5 % damping ratio are calculated recursively from acceleration records observed at the K-NET and KiK-net stations [6] in the system. The observed AVRS information can be provided in realtime and continuously.

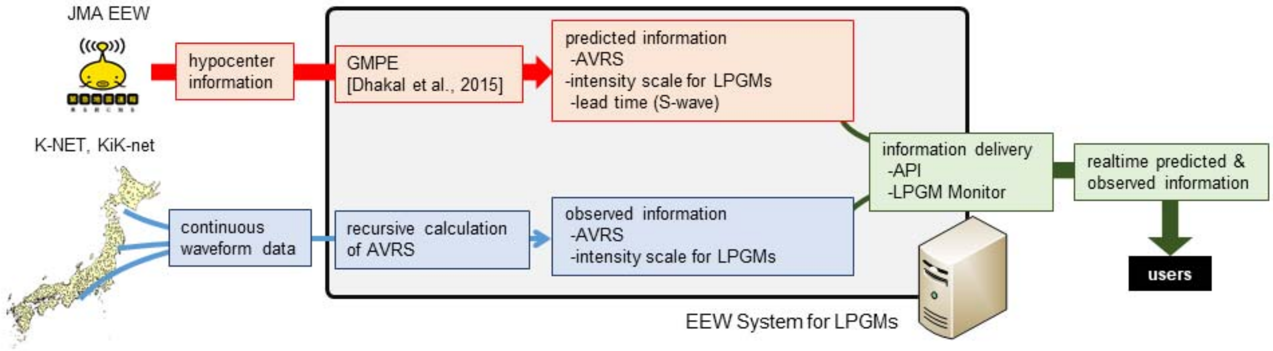

Fig. 1 – Flow chart of the EEW system for LPGMs developed in this study.

The EEW system provides the predicted and observed information on LPGMs to users through two-type interfaces. One interface is the application program interface (API), and the other is the LPGM Monitor which is a web service to visualize both the realtime predicted and observed LPGM information on a single map. We developed an API through which users can request predicted LPGM values as a function of time and location, and observed values as a function of time and station name of K-NET and KiK-net. Users can obtain predicted values at arbitrary points and observed ones at arbitrary stations in realtime by requesting them every second, and can use obtained value for various purposes such as the automatic control of infrastructures and the user-specific information delivery.

In the LPGM Monitor (Fig. 2), observed AVRS or intensity scale values for LPGMs are displayed at each station location on a map, and are updated every second. When an earthquake occurs and the JMA EEW is issued, a distribution of predicted values with an approximately 5-km mesh underlays the points showing observed values. Thus we can compare the predicted values with observed ones visually on a map. The arrivals of P- and S-waves estimated from the hypocenter information of the EEW are also shown as circles on the map. In boxes under the map, hypocenter information and highest LPGM intensity scale in Japan are shown.

3. Experimental Demonstration of Long-Period Ground Motion Information

Using the developed EEW system for LPGMs, we have conducted experimental demonstrations with the aim of verifying the effects and methods of application of prediction information relating LPGMs and promoting understanding of LPGMs. In Japan, an individual or an institute other than the JMA who opens realtime prediction information on ground motions to the public should obtain a license for forecasting service from Director-General of the JMA, and the license for LPGMs has not been prescribed yet. Therefore, in the demonstrations, NIED takes on the role of licensed provider of forecasting service.

The demonstration using the API began in February 2018, and a total of 13 organizations took part, including construction companies and real estate developers. The participating organizations conducted activities such as developing a system for the purpose of elevator control based on delivered information. Also, the prediction information reproducing the 2011 Tohoku earthquake was compared and verified against actual values held by the participating organizations, and it was found that, the predicted results were in good agreement with the observed results in buildings. This means that the prediction information can be used in response decisions before the building actually starts shaking due to LPGMs.

We also conducted the experimental demonstration using the LPGM Monitor, where we collected users of the LPGM Monitor on the website. Phase 1 of the demonstration was conducted from November 2017, and there were 1,440 participants in the experiment at the end of March 2018. A questionnaire survey of the users was carried out, and more than half of the users answered the survey. More than 75% of respondents replied that their interest in LPGMs had increased or their understanding had improved, showing that the experiment was successful in terms of promoting the participants' understanding of LPGMs. Phase 2 of the demonstration experiment was conducted from October 2018 to March 2019, and users were recruited. In Phase 2, a function displaying the LPGM Monitor and the Kyoshin Monitor in parallel on a window was added. The Kyoshin Monitor shows predicted and observed seismic intensity, which is the index sensitive to ground motions with shoter periods than LPGMs, on a map in realtime similar to the LPGM Monitor. The above function helps the users to understand the difference between the LPGMs and seismic intensity visually by comparing the two monitors. In addition, a function displaying predicted values at a point location specified in advance by each user was also added. These new functions were introduced based on the Phase 1 questionnaire results. There were 1,924 participants in Phase 2, and more than half of them responded to the second questionnaire.

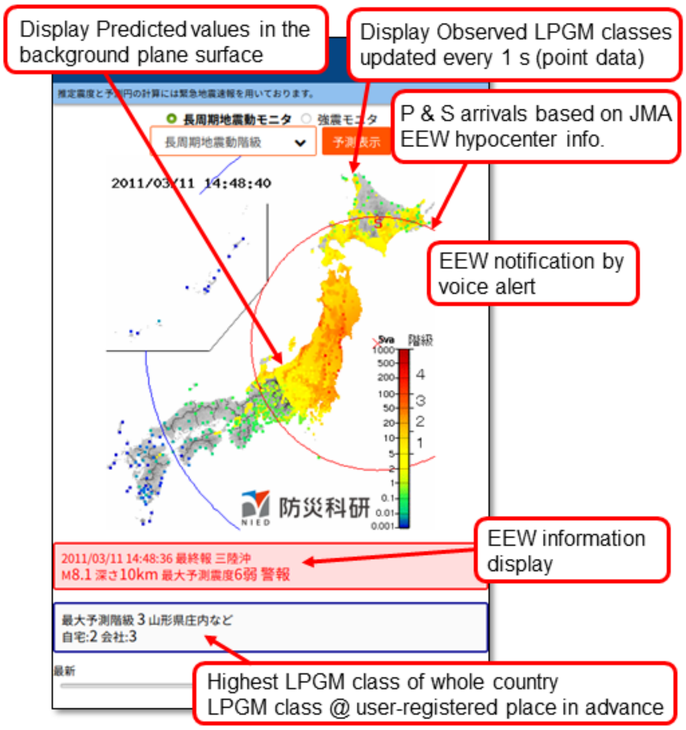

Fig. 2 – Screenshot and display contents of the LPGM Monitor reproducing the 2011 Tohoku earthquake.

4. Conclusions

We developed a methodology to predict LPGMs as soon as the current JMA EEW system gets activated, and a system to provide the predicted information with the realtime observed information obtained from nationwide seismograph networks. The developed system delivers the information to users through the API and the LPGM Monitor. We have conducted experimental demonstrations of LPGM information based on this system for about two years. In the demonstrations, some of the participants have developed systems to use the delivered information for the purpose of their infrastructure control and the preparation for the action to coming shaking. Participants using the LPGM Monitor provided useful feedback through questionnaire surveys to us for the improvement of the prediction information and the system.

LPGMs excited by a large earthquake coud be amplified in major cities situated on large plains such as Tokyo and Los Angeles, and would shake high-rise buildings severely for a long time, causing damage to elevators, and furniture in the building to move/topple over, even in places far from the hypocenter where the seismic intensity is not very high. The EEW information of LPGMs could allow effective action to be taken in the society, such as controlling elevators to reduce damage and alleviating fear by psychological preparation. Algorithms and prototype systems required for realtime prediction of LPGMs and information communication have been already established. In addition, public and private sectors have collaboratively performed experimental demonstrations for an effective use and verification of the new realtime information about LPGMs. We will continue and expand the experimental demonstraions to establish effective methods on the utilization of the information on LPGMs.

5. Acknowledgements

We are grateful to all the participants of the experimental demonstration of LPGM information for their cooperation and useful feedback.

6. References

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