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JMA EARTHQUAKE EARLY WARNING

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ABSTRACT: JMA is now developing Earthquake Early Warning system. In this issue, the methods used for prompt estimation of hypocenter locations, magnitude and seismic intensities, the warning dissemination criteria, and future plans are briefly introduced.

Key Words: JMA, Earthquake Early Warning, Seismic Intensity, Tsunami Warning

INTRODUCTION

At present, in case of large earthquake occurrence, Japan Meteorological Agency disseminates Seismic Intensity Reports in about two minutes, and Tsunami Warnings in about three minutes after the earthquake occurrence. Seismic Intensity Reports are used for emergency measures establishment, but are post-disaster information, so the new information to enable countermeasures before the strong motion arrival is expected. Tsunami Warnings are used for evacuation from the coastal area before the tsunami strikes, by using propagation velocity difference between the seismic and tsunami waves, but still, the time reduction for warning dissemination is necessary. To solve these two problems, JMA is now developing "Earthquake Early Warning" (formerly, called as “Nowcast Earthquake Information”) system to mitigate earthquake disaster brought by strong motion, by estimating hypocenters and magnitude using seismic waveform data observed at stations close to the epicenters, and by issuing anticipated seismic intensities before the S(major) phase arrival. This technique can directly be applied to quicken Tsunami warning dissemination as well.

We adopt a step-by-step manner to improve the accuracy and reliance of the estimation as the available data increases as time goes by, ensuring the promptness of the first estimation at the same time. Accordingly, Earthquake Early Warnings are disseminated repeatedly with improved accuracy and reliance with time. Earthquake Early Warnings are expected for online control of lifeline systems, emergent action of the citizens, and so on.

In this issue, we will briefly introduce the methods used for prompt estimation of hypocentral parameters and seismic intensities, dissemination criteria, and future plans.

HYPOCENTER, MAGNITUDE AND SEISMIC INTENSITY ESTIMATION

1 Hypocenter estimation

For the quick dissemination of the warning, we have to start hypocenter estimation just after the first detection of the P phase at the single station. To ensure the reliability of the estimation, we use the following two methods in combination.

1) Single station method

By fitting Bt*exp(-At) function to the log-transformed acceleration waveform(UD component) envelope of the first two seconds from the P onset, we extract the envelope feature characteristics by 'A' and 'B' value.

The 'A' represents amplitude growth duration in the first two seconds, and the 'B' the onset slope of the envelope. 'B' was found to have negative correlation with epicentral distance by the cooperative study with Railway Technical Research Institute, so that the epicentral distance can be estimated by the regression formula of estimated B value(Odaka et. al.(2003)). The negative correlation can be explained by the envelope shape deformation due to the scattering during the wave propagation(Tsukada et. al.(2004)). The azimuth of the epicenter from the station is estimated by fitting ellipsoid to the P phase particle motion of the first one second by a principal component analysis. Then the epicenter can be estimated from one station.

2) Network method

We use the P onset times as usual routine hypocenter determination. But to get quick and stable estimation even from very limited number of the stations, we use the following two methods depending on the number of the stations that detected P. When the number is one or two, we define a polygonal region as a "territory" to each station surrounded by perpendicular bisectors to the adjacent stations. The geometrical centroid of the "territory" of the first P detection station is regarded as the first epicenter. When the second P is detected at one of the adjacent stations, the "territory" is divided into subsections, and we can refine the epicenter estimation. The territory distribution is uniquely defined by the "alive" station distribution, and is updated every time the station reports its "death" or "revival". The hypocentral depth is assumed as 10km so far considering the worst case that a large earthquake occurred in the crust. For events inside of the network, epicenter estimation errors are within 30km, the half of the average distance between the JMA seismic stations. The territory can be open-ended for a coastal station, then we use information 1) in combination to get better estimation for events outside of the network.

When the number of the stations becomes three to five, we set a finite number of candidate hypocenters at discrete grids (at every 0.1 degree (lat., lon.) and 10km (depth)), and the optimal grid to explain P arrival time differences in the least square manner is chosen as the hypocenter. When the "grid search" area is set, the information that P are NOT detected yet at surrounding stations is taken into account. And grids at aseismic depths are excluded from the candidate. By these two procedures, we can get stable and seismologically proper estimation, reducing the computation time at the same time.

2 Magnitude estimation

It is essentially difficult to predict the final size of the earthquake by using the first few seconds of waveform data from the P onset for a large earthquake. The 'A' value mentioned above was found to have only a weak negative correlation with the final magnitude value. When the 'A' value is negative, it means that amplitude growth lasts in the first two seconds, and in most cases, the final magnitude value is greater than or equal to 6.0. This is in accordance with the scaling law for rupture duration time, but the scatter is substantial to draw a regression line.

We adopt another alternative, to update the magnitude estimation until it converges to a certain value by using the latest hypocenter location estimation and maximum displacement amplitudes(Amax) updated at every one second. We introduce the following type of magnitude formulas,

$$M = \log(Amax) + \log R + a1*R + a2 \qquad (R : \text{Hypocentral distance(km)})$$

for P phase as well as for S phase(Kamigaichi et. al.(2002)). The second and the third terms of the left side of the formula represent amplitude decay corrections due to geometrical spreading and Q-effect respectively. As an Amax, three dimensional vector summation of the displacement is used to be free from the phase polarization character. For the prompt magnitude estimation even from a P phase, we use P formula first, and switch to S formula at the time of theoretical S arrival. To avoid an apparent fall down of magnitude value by switching the formula due to S phase amplitude growth from zero, the P formula result just before the S arrival is held for an appropriate time being. The event magnitude is estimated by the station average. And to judge the magnitude value convergence, we introduce an empirical logic.

3 Seismic intensity estimation

By using up-to-date hypocenter and magnitude estimation, seismic intensity is estimated as follows(a. to c.).

a. Maximum velocity amplitude at the engineering bedrock is predicted by the empirical formula using hypocentral distance, hypocentral depth and magnitude(Si & Midorikawa(1999)). Spatial extent of the focal area has magnitude dependence(scaling law), and is taken into account to calculate minimum hypocentral distance for the safety.

b. Estimation of maximum velocity amplitude at the surface by multiplying amplification coefficient deduced from geology and geography at each site(Matsuoka & Midorikawa(1994)). (This method is also used in the strong motion hazard estimation by Tokai, Tonankai and Nankai earthquake in the Central Disaster Prevention Council.)

c. Conversion of maximum velocity amplitude(b.) to JMA seismic intensity at the surface by the regression formula(Midorikawa et. al.(1999)).

DISSEMINATION CRITERIA

JMA Earthquake Early Warning is composed of two categories, the forecast and observation report, and is disseminated as the following criteria, in principle fully automatically.

1 Forecast

1)The first warning

When the estimated event magnitude or maximum seismic intensity exceeds the threshold. The threshold is, as of now, set as 6.0 for magnitude and 5- for JMA seismic intensity scale. To avoid a false alarm, these estimations are done after the noise discrimination using the first two seconds of the waveform data.

In case of large earthquake occurrence just below the station, when the maximum acceleration amplitude exceeds the threshold(as of now, $100cm/s^2$), then the first warning simply to tell that strong motion has been observed is disseminated, even before the hypocenter is estimated. But, this is at least after the abbreviated noise discrimination by using the first one second of the waveform data is done.

2)The cancel report

In case of the false alarm dissemination, a cancel report is disseminated when there is no following P phase detection at the closest station within a pre-set time(depending on the 'alive' station distribution) after the first warning dissemination. The cancel report can also be disseminated manually.

3)The updated warnings

When the updated estimation changes from that in the latest dissemination more than the threshold. As of now, thresholds are 0.2 degrees for latitude and longitude, 20km for hypocentral depth, +0.5,-1.0 for event magnitude and maximum seismic intensity.

In case that only a slight change is made during the estimation update, to inform the latest estimation, dissemination at fixed timing(e.g. ten seconds after the first dissemination) is also done.

4)The final warning

The final warning is disseminated explicitly at earlier of the two timings, when the pre-set time has passed after the first detection of the P phase, or when the estimated magnitude value converged.

2 The quick seismic intensity observation report

After the first warning is disseminated, actually observed strong motion is reported by applying JMA seismic intensity calculation(JMA(1996)) to every ten seconds of the waveform data.

PRESENT STATUS AND FUTURE PLAN

JMA started test dissemination of Earthquake Early Warning in February, 2004 to specific users to examine the applications and to verify the effectiveness of the warning, for the events that occur in the region from the east coast of Kyushu to the north Kanto where JMA has integrated data processing functions at the seismic stations. The integration enables all relevant waveform processing (i.e. P phase detection, noise discrimination, onset time determination, envelope characteristics extraction, epicentral distance and azimuth estimation, maximum amplitude update, and so on) at the station to reduce the time delay caused by a waveform data packaging and transmission to the center(JMA headquarters). Data processing at the center is concentrated to the network processing and warning assembling and dissemination. We are planning the extension of the target region by the same integration to Tohoku and Hokkaido region in the fiscal year 2004.

JMA, in cooperation with Cabinet Office, Fire and Disaster Management Agency and Ministry of Land, Infrastructure and Transport, settled a committee to accelerate the examination of warning applications by utilizing the test dissemination results. And JMA will also improve the data processing technique in cooperation with National Research Institute for Earth Science and Disaster Prevention.

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