How to Prepare for a Strong Shaking?
Earthquake Early Warning in Japan

Masumi Yamada, Kyoto University
2011 Tohoku EQ

0sec  Earthquake

19sec  P-wave detected

27sec  Location and Magnitude determined
       Earthquake Early Warning issued

3min   Observed Seismic Intensity reported

3.5min
Damage to bullet trains
- Damage to cable column 540
- Damage to cable 470
- Damage to column 100
- Damage to rail track 20

27 bullet trains were stopped without derailments.
Providing Earthquake Early Warning needs
Providing Earthquake Early Warning needs infrastructure
Providing Earthquake Early Warning needs infrastructure
Providing Earthquake Early Warning needs infrastructure and information technology.
Earthquake occurred off Fukushima. Prepare for strong shaking.”
(Japan Meteorological Agency)
Automated Responses to EEW

- Public announcement
- Elevator: emergency stop
- Warning (alarm)
- Warning (flashing lights)
- Show alert on monitors
- Secure evacuation route
- Control machine
- Other
- Nothing
Providing Earthquake Early Warning needs infrastructure, information, technology.
Providing Earthquake Early Warning needs infrastructure, information technology, and seismology.
How to estimate shaking?

Step 1: Estimate location from P-arrival times

Step 2: Estimate Mag. from displacement ($A_d$) & R

Step 3: Estimate Shaking intensity from M & R

$0.72M_p = \log(A_d) + 1.2\log(R) + 5.0 \times 10^{-4}R - 5.0 \times 10^{-3}dep + 0.46,$

$0.87M_d = \log(A_d) + 1.0\log(R) + 1.9 \times 10^{-3}R - 5.0 \times 10^{-3}dep + 0.98.$

$log_{10}PGV = 0.58M_w + 0.0038D - 1.29 - \log_{10}(R+0.0028 \times 10^{0.5M_w}) - 0.002R$

$log_{10}ARV = 1.83 - 0.66 \log_{10}AVS30$

$SI = 2.68 + 1.72\log_{10}(PGV*ARV)$

http://www.seisvol.kishou.go.jp/eq/EEW/Meeting_HYOUKA/t02/index.html
Threshold of shaking to give EEW

Intensity is computed from acceleration waveforms.
2001 Gujarat Earthquake
Create Dataset | displacement amp.

Amplitude $\sigma = \pm 30\%$

Vp and Vs $\sigma = \pm 10\%$
Time History of Warnings

- **0 sec**: Earthquake
- **10 sec**: 1st P-wave triggered @Bhuj
- **40 sec**: 2nd P-wave triggered @ Bhavnagar
  Location and Magnitude determined
Time History of Warnings

0 sec  | Earthquake
10 sec | 1st P-wave triggered @ Bhuj
40 sec | 2nd P-wave triggered @ Bhavnagar
       | Location and Magnitude determined
60 sec | 3rd P-wave triggered @ Jaisalmer
       | Location error <10km
Time History of Warnings

PGA distribution ($10^X$ Gal) at $T=1061(21)$ s $M=7.43$
Japanese EEW Facts and Figures
Number of warnings

Accuracy

6th meeting of EEW improvement

False alarm for 2011 Tohoku aftershock
False alarm for 2011 Tohoku aftershock
2013 False alarm

EEW M7.8
Reality M2.3
Feedback on the False Alarm

- Upset: 3%
- Not upset, but concerned: 28%
- No choice: 40%
- Unconcerned: 5%
- Disinterested: 28%

http://www.data.jma.go.jp/svd/eqev/data/study-panel/eew-hyoka/05/shiryou3-2.pdf
Summary

Earthquake Early Warning System needs:

- Infrastructure
- Information Technology
- Seismology
- Education

Examples:

- 2001 Gujarat earthquake in India
- 2011 Tohoku earthquake in Japan
- 2013 False alarm in Japan
Problem 1: Underestimation

Problem 2: False Alarms

Before Tohoku:
- Exp.-Obs. ≥ 2: 5
- Warnings: 17

After Tohoku:
- Intensity Error (Exp.-Obs.) ≥ 2:
  - multiple events: 32
  - others: 12
- Warnings: 70

Failure of Hypocenter Relocation

Good!

Bad...

JMA website
Current Approach

Shake!
Shake!
Our Approach

Shake!

No shake
Performances

Before Tohoku
Exp.-Obs. ≥ 2
5
17 Warnings

After Tohoku
Intensity Error (Exp.-Obs.) ≥ 2
44
70 Warnings

This Study
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