On a EEW system FREQL and its working situation at the time of the 2011 Tohoku Earthquake

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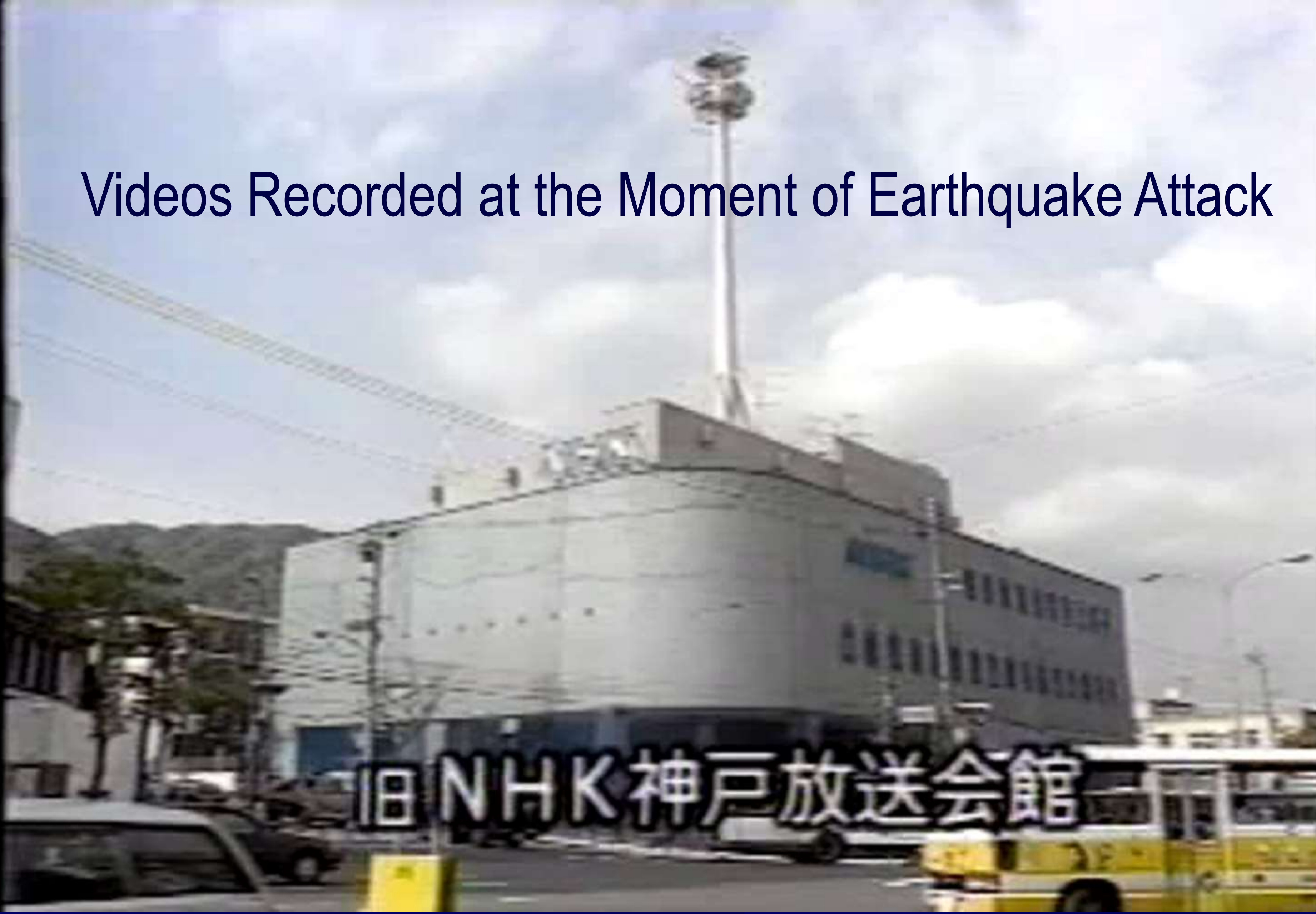
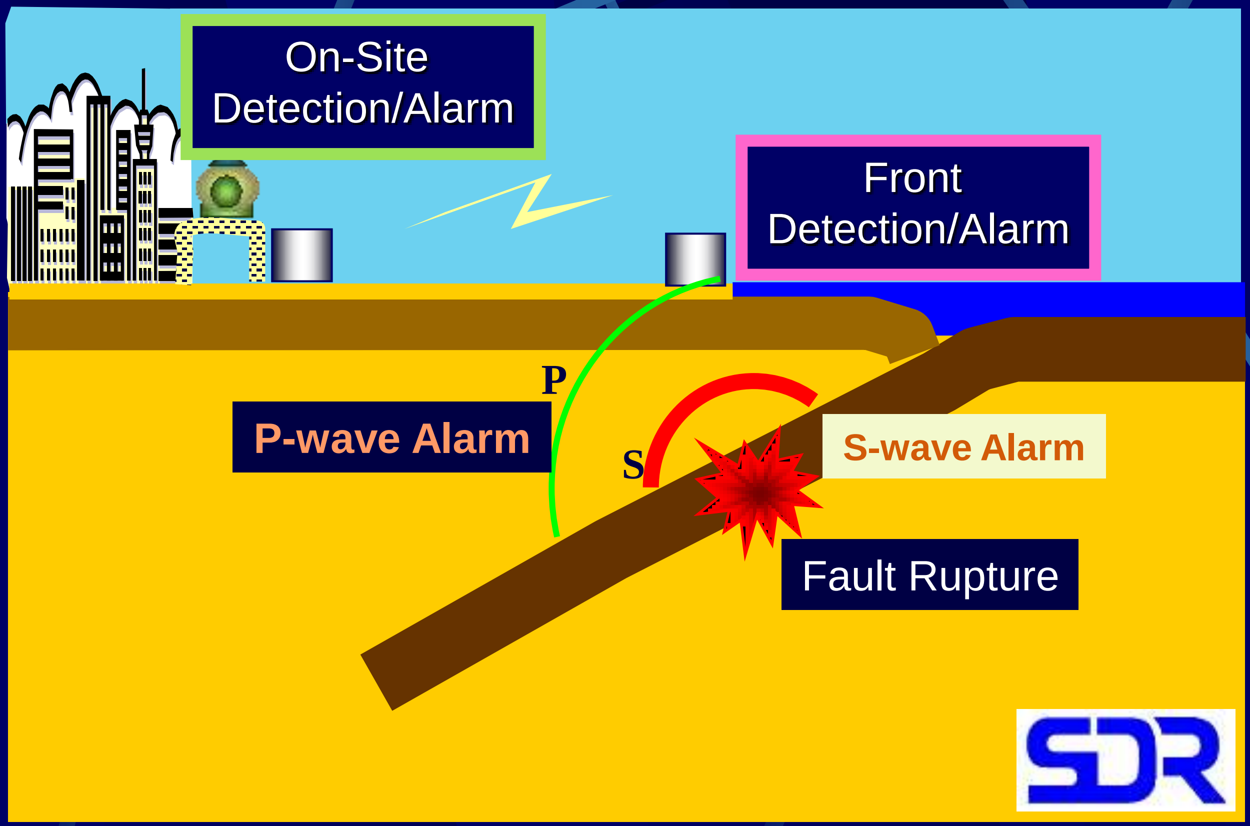
Videos Recorded at the Moment of Earthquake Attack



We can see for EEW based on experience as follows;

- **EEW can get only short time margin.**
- **It is extremely necessary and important for EEW to prepare and exercise in advance.**
- **In any case, only the immediate warning can be useful.**

Concept of Earthquake Early Warning

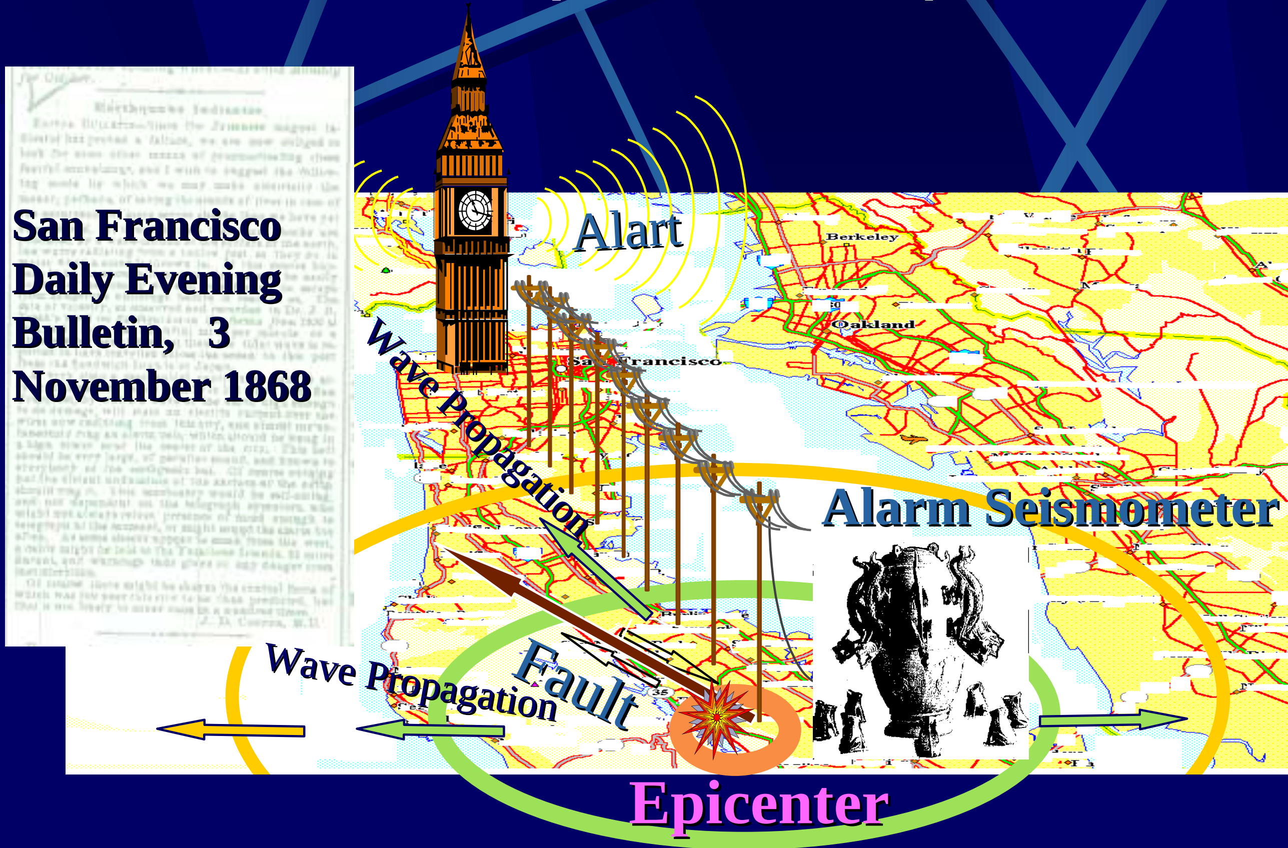


There are two kinds of the earthquake alarm. One is “On-site Alarm” which is the alarm based on the observation at the side of the objects to be warned. The other is “Front Alarm” which is the alarm based on the observation near the epicentral area to warn for the possible damaged area.

Both alarm types described can make use of two different triggers, also called “alarms”.

One is so-called “S-wave Alarm” or “Triggered Alarm”. And the other is “P-wave Alarm”.

Concept of the Front Alarm by Dr.Cooper, 1868



In 1972, researchers for earthquake disaster prevention in Japan advocated the "Strong earthquake alarm system 10 seconds before". Although this was an idea similar to Dr. Cooper's front detection system in 1868, nobody had put in practical use until then.

We have developed a prototype system for EEW as UrEDAS in early 1980's.

Introduction of UrEDAS

UrEDAS, Urgent Earthquake Detection and Alarm System, is the first real time P-wave alarm system over the world in practical use in 1992 for Tokaido Shinkansen.

It is characterized to be able to process digitized waveform step by step without storing waveform.

Amount of procedure is not differ from each other either earthquake occurs or not, so it expected not to be occurred the system down due to the over load.

UrEDAS is able to use not only for the On-site alarm but also for the Front alarm.

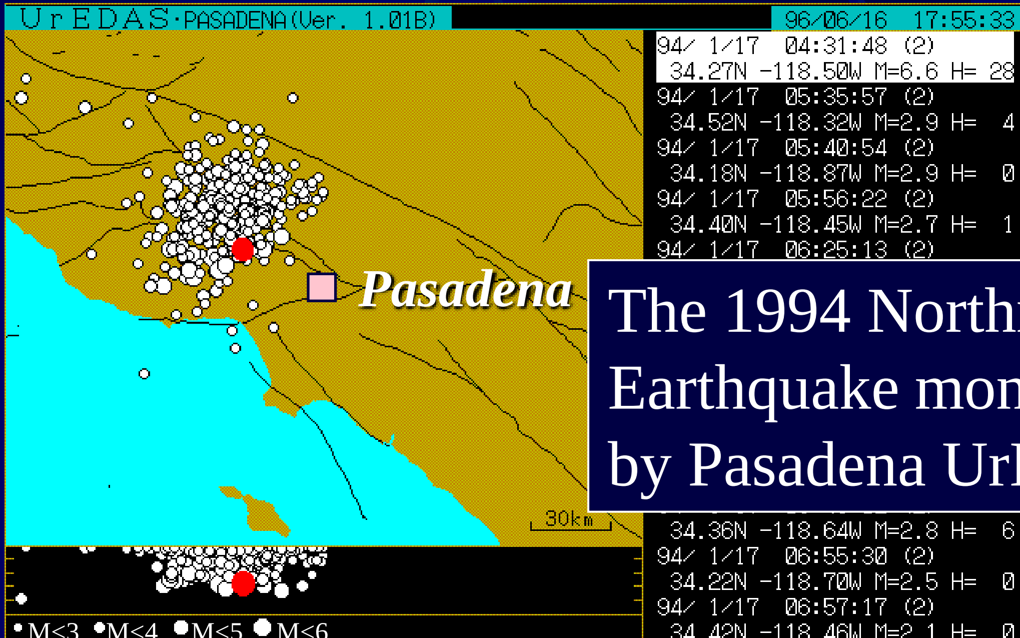
Functions of the UrEDAS

There are two types of UrEDAS; "**UrEDAS**" and "**Compact UrEDAS**".

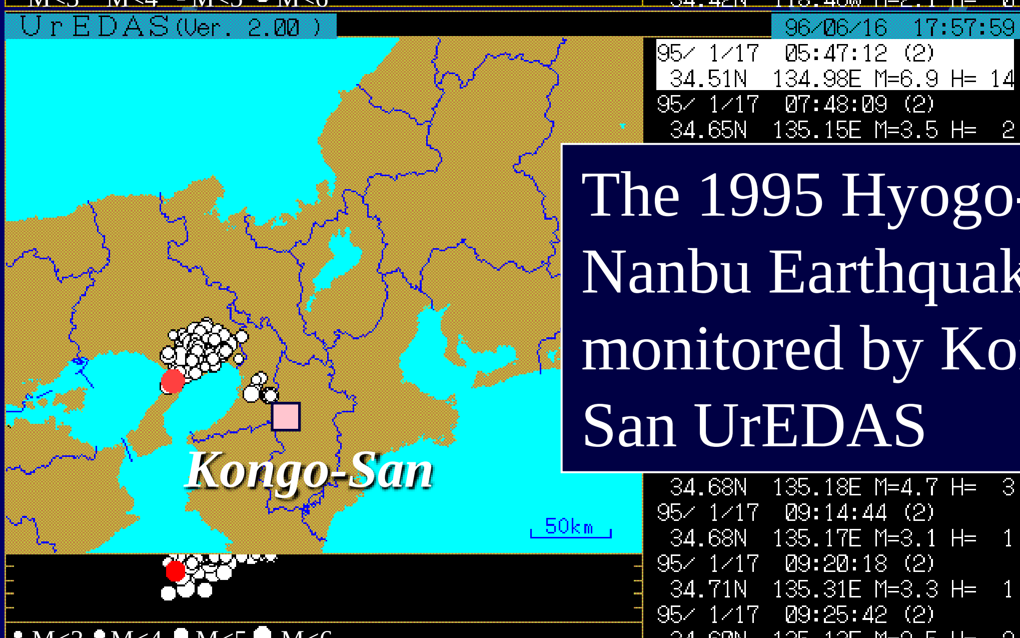
Function of the **UrEDAS** (1985) is to estimate the magnitude and the location of detected earthquake in **three seconds** after initial P-wave detection and issuing the alarm for expected damage area.

On the other hand, **Compact UrEDAS** (1998) can evaluate whether the earthquake will be destructive or not using Destructive Intensity **DI** and issues alarm **one second** after **P-wave** detection if needed.

Examples of Monitoring Earthquakes by UrEDAS



The 1994 Northridge Earthquake monitored by Pasadena UrEDAS



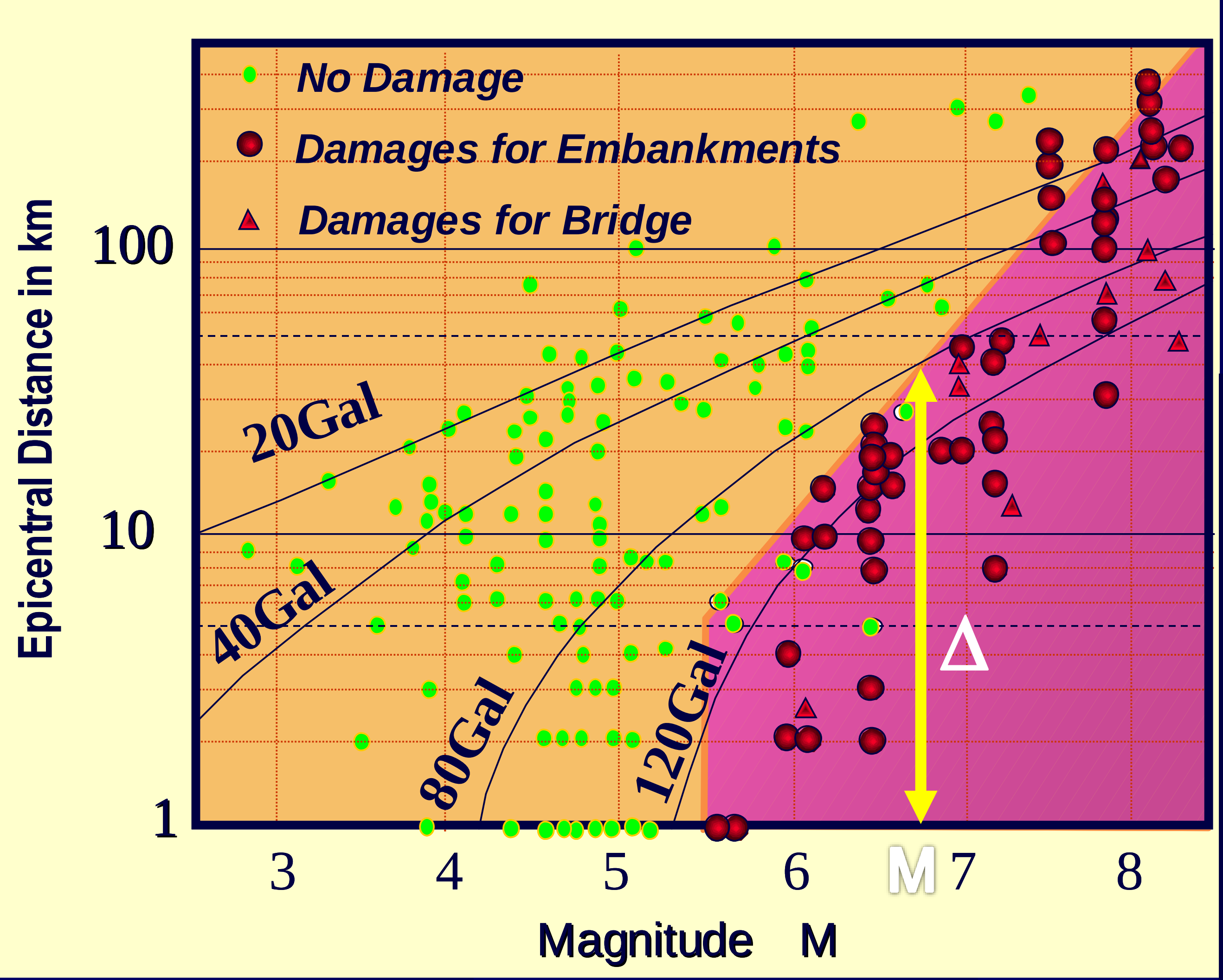
The 1995 Hyogo-Ken-Nanbu Earthquake monitored by Kongo-San UrEDAS

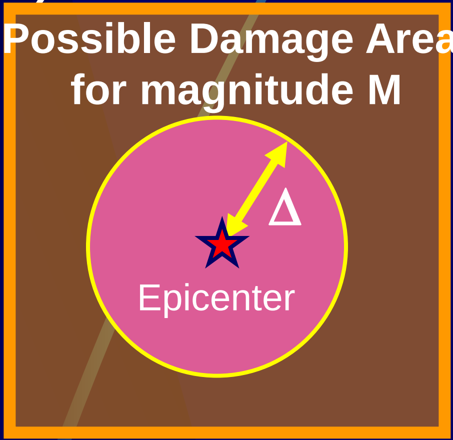
UrEDAS worked at the time of the 1994 Northridge Earthquake and the 1995 Kobe Earthquake.

During the first 24 hours after the Northridge earthquake, UrEDAS in Pasadena detected about 700 aftershocks. The upper figure shows the distribution of the aftershocks. Their magnitude and locations of hypocenter were automatically estimated.

Lower figure shows the result of monitoring the Kobe Earthquake sequence for two weeks after the main shock. Although these figures based on the data of only one UrEDAS station, aftershock activity was almost correctly traced.

UrEDAS Alarm based on M-Δ Diagram
after Bitoh, Nakamura and Tomita (1985)





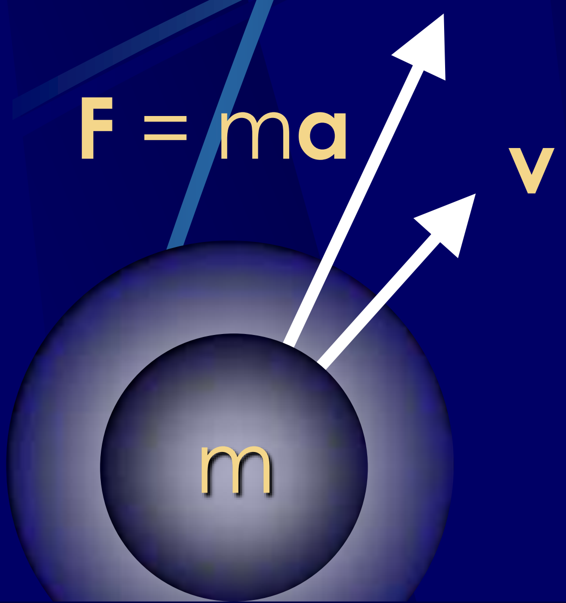
UrEDAS can issue an alarm based on the distribution of the past earthquake damage on magnitude to epicentral distance plane. This alarm is referred to as an M-Δ Alarm.

Moreover UrEDAS can support restarting operation based on the detailed earthquake parameters.

Captured Video at the time of the 1995 Kobe Earthquake

Motivation of Compact UrEDAS development is the Kobe Earthquake. On the Video, they noticed the initial P wave motion as something happening, and then the severe motion attacked them after a few seconds. Although there was only a few seconds between something happening and recognition of earthquake, it was anxiousness and fearful because they could not understand what happened and felt relieved after recognition of the earthquake occurrence. As the counter of this kind of feeling, the earlier earthquake alarm is required and I developed the Compact UrEDAS to make the alarm within one second after P wave arrival.

Definition of DI, Destructive Intensity,and Seismic Intensities RI (corresponding to JMA Instrumental Intensity) and MMI



$$\text{Power} = \mathbf{F}\cdot\mathbf{v} = m\mathbf{a}\cdot\mathbf{v}$$

$$\text{DI} = \log_{10}|\mathbf{a}\cdot\mathbf{v}|$$

unit for **a**: Gal (cm/s^2)
unit for **v** : kine (cm/s)

$$\text{Power Density PD} = \text{Power}/m = \mathbf{a}\cdot\mathbf{v}$$

$$\text{LPD} = \log_{10}|\mathbf{a}\cdot\mathbf{v}|$$

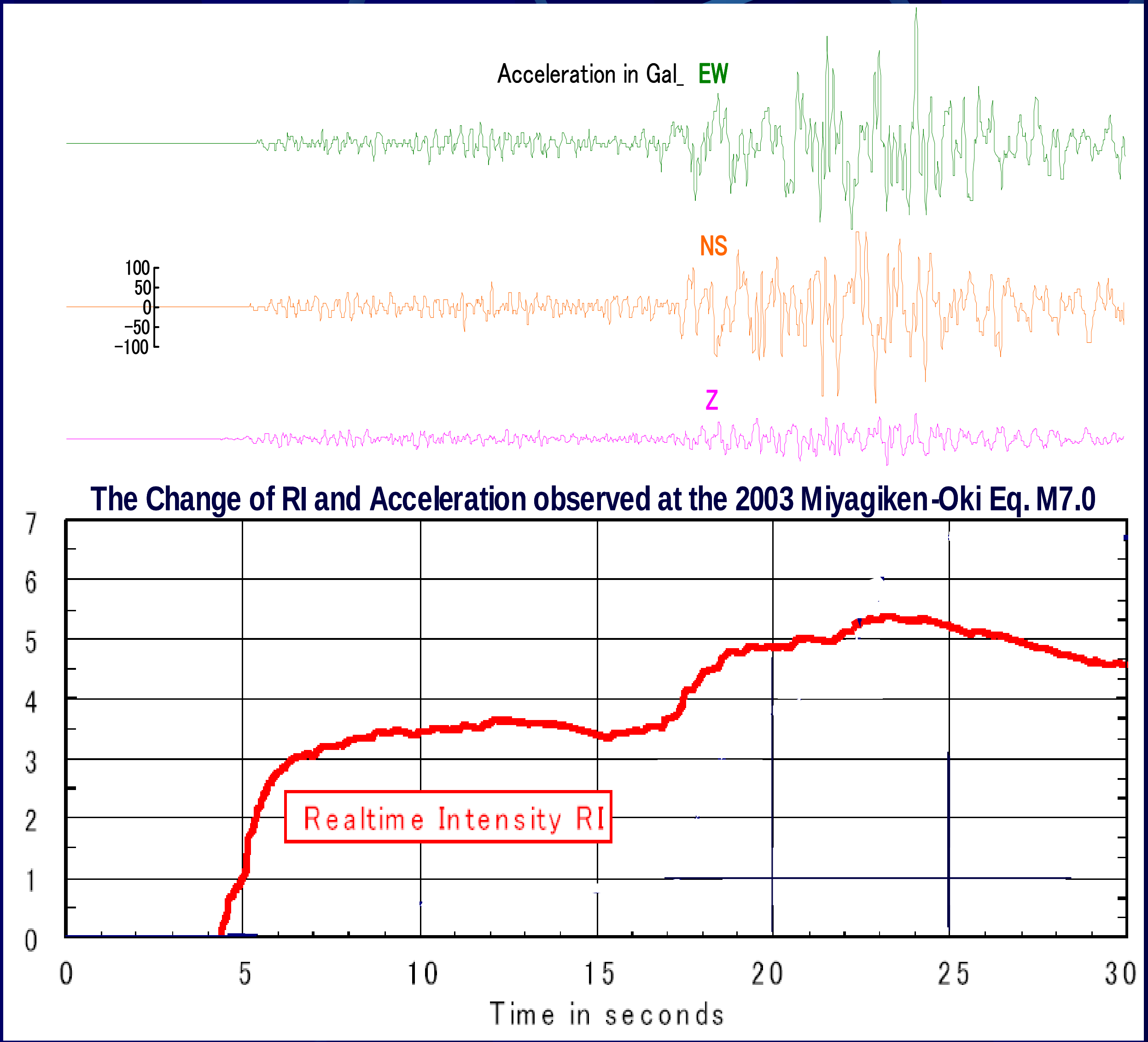
unit for **a**: m/s^2
unit for **v** : m/s

$$\text{RI} = \text{DI} + 2.4 = \text{LPD} + 6.4$$

$$\text{MMI} = (11/7)\cdot\text{RI} + 0.5$$

Compact UrEDAS estimates the destructiveness of the earthquake immediately from the earthquake motion directly, not from the earthquake parameters as UrEDAS, and then issues the alarm if needed. To estimate destructiveness of the earthquake motion, I defined DI, Destructive Intensity, as shown in this slide. Based on the DI, a new seismic intensity, realtime intensity RI, or MMI are defined as this slide.

The Change of RI for Earthquake Motion

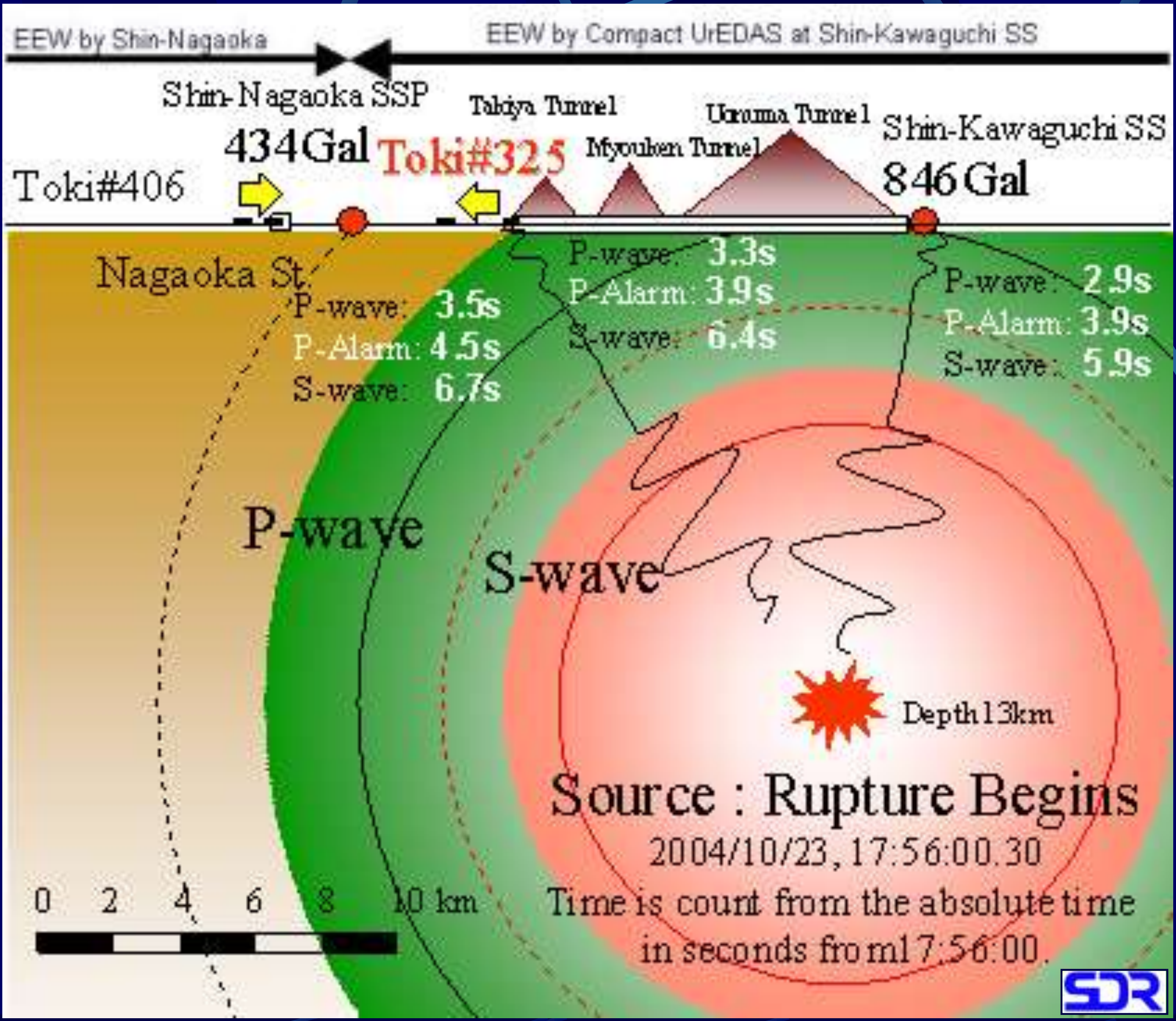


When P wave arrives, RI increases drastically. After initial P wave, RI keeps almost same value until the S wave arrival. After the arrival of S wave, it reaches to its maximum value. This value can be related on damage and Instrumental Seismic Intensity of JMA or other scales like MMI.

Instrumental JMA Intensity scale is defined to calculate artificially only after the earthquake termination. On the other hand, RI can be calculated in realtime with physical background. This can be concluded as, with the continuous observation of RI, earthquake alarm can be issued efficiently and damage can be estimated precisely.

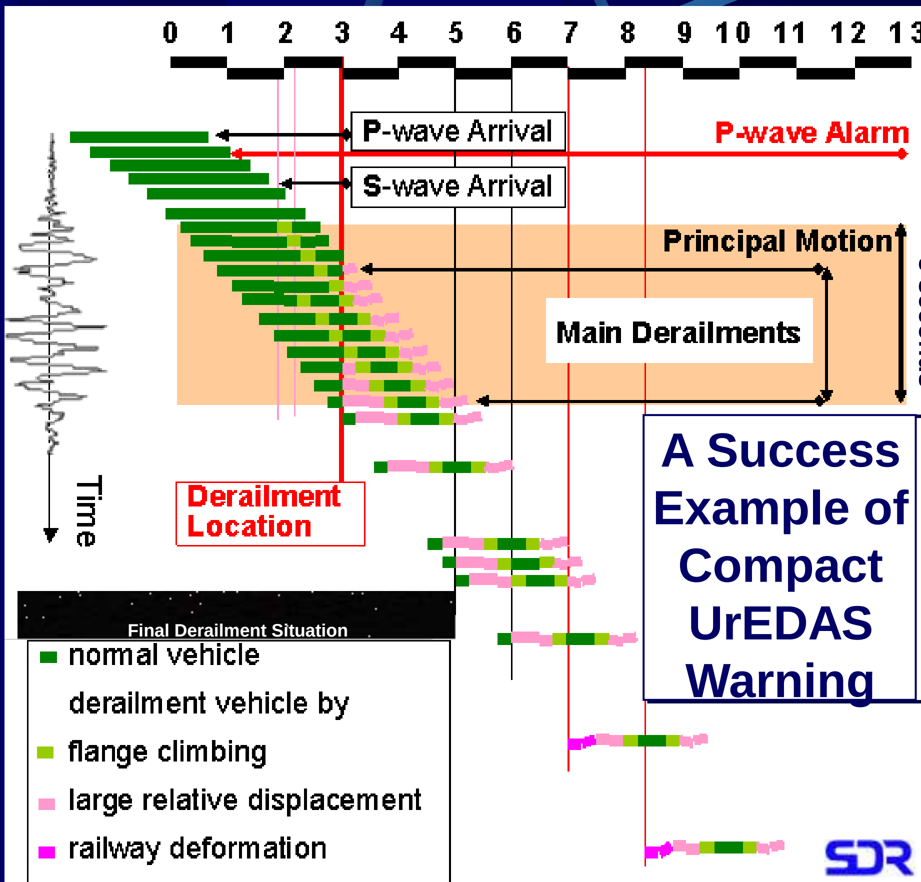
The ONLY Succeeded Example of EEW

the 2004 Niigataken-Chuetsu earthquake (M6.8) with Compact UrEDAS

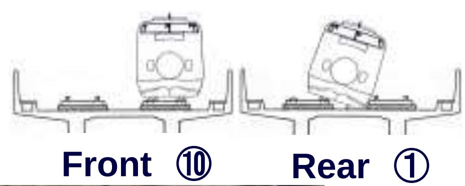


Kawaguchi observatory detected P wave 2.6 seconds after the earthquake occurrence, and one second after that, issued P wave alarm. When the derailed train, Toki No. 325, encountered the earthquake motion at the point running 75 m from the exit of Takiya tunnel, it was 3 seconds after the earthquake occurrence. 3.6 seconds after the earthquake occurrence, the train received the alarm from Compact UrEDAS and was interrupted the power supply. Shinkansen train is situated automatically to break immediately by the interruption of power supply. S wave hit the train 2.5 seconds after the alarm and then more one seconds after, large motion attacked the train. This large motion continued about five seconds.

The P wave alarm of Compact UrEDAS demonstrates the effectiveness as making the derailment not catastrophic



Vehicle ②:
You can see derailment situation and contact situation between body and railroad,



This shows the outline of the situation of the derailment. It seems that the derailed cars were running the large displacement section. The later the alarm reached, the more the number of derailed car, because of the risk of running the large displacement section. From the view point of this, the P wave alarm of Compact UrEDAS demonstrates the effectiveness for the derailment making not catastrophic.

All 154 passengers and stuffs have been survived without injury.

FREQL
(Fast Response Equipment against Quake Load)

- FREQL is developed for the earthquake warning system based on the experiences of development and operation of the world first P wave alarm system UrEDAS.
- FREQL function is combined the functions of UrEDAS, Compact UrEDAS and AcCo.
- P wave alarm is available 0.1 seconds in minimum after P wave detection (after 2009).
- Earthquake parameters are estimated with one second after the P wave detection.
- S wave alarm is also available based on acceleration and real-time seismic intensity, RI, same as AcCo.

FREQL is toward to the new field, as for the Hyper Rescue Team in the risk of aftershocks

the 2008 Sichuan Earthquake Mw 7.9

the 2004 Niigataken - Chuetsu Earthquake Mw 6.6

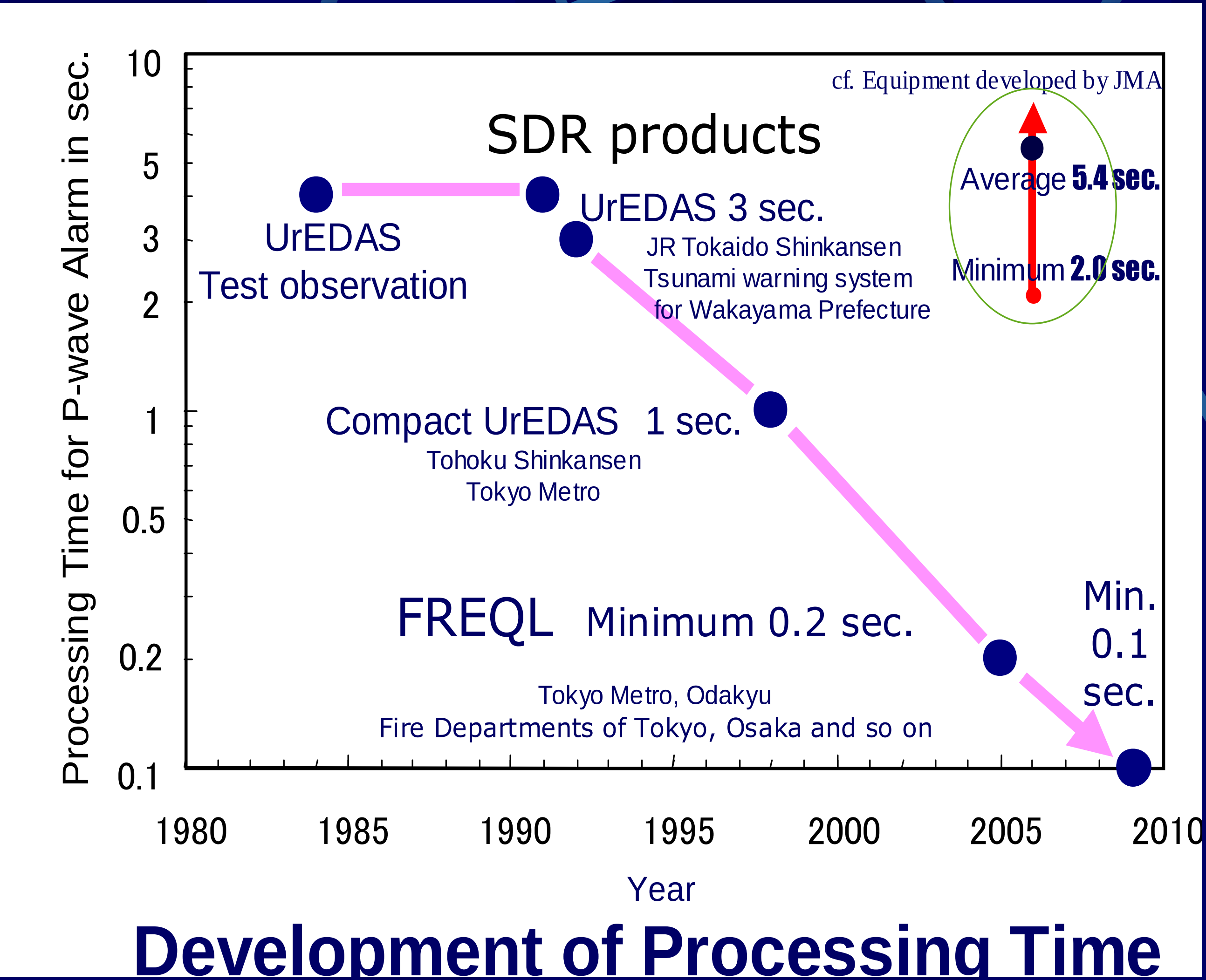
Rescue Activity of Hyper Rescue Team

Hyper rescue team acts in a risk of large aftershocks.

After the Niigataken Chuetsu Earthquake, the hyper rescue team approached us to adopt FREQL as a support system for the rescue activity.

Tokyo fire department and other departments in nation wide have adopted the portable FREQL as equipment to keep the safety against the risk of the second hazards caused by aftershocks during their rescue activity, not only in Japan but also in Pakistan, China and New Zealand.

Change of processing time for EEW

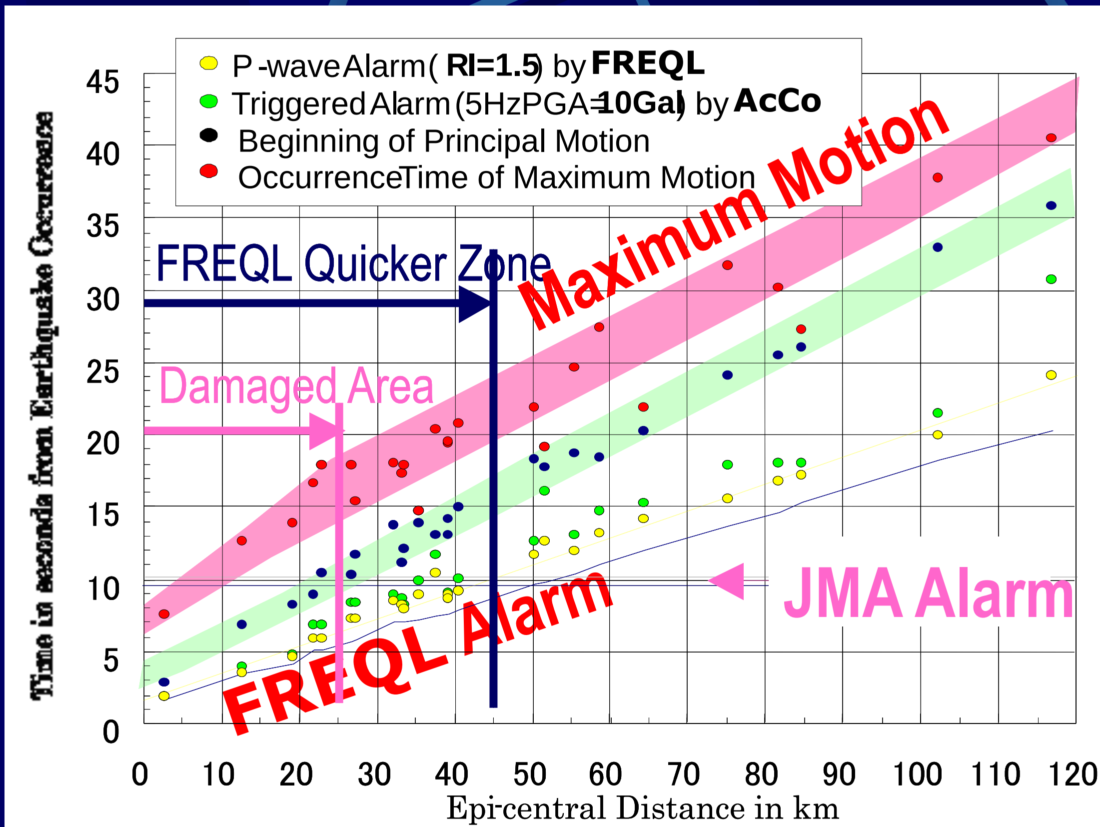


This figure shows the change of the processing time for EEW.

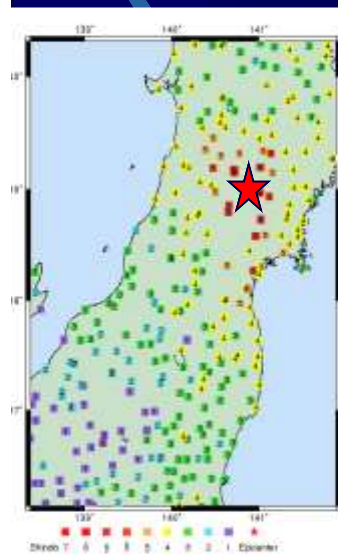
While JMA system performs every one second for the alarm processing intermittently with stored data,

UrEDAS and FREQL perform the procedure continuously in every sampling time.

Actual Example with Simulated Results of FREQL or AcCo for Recent Damaged Earthquake in JAPAN



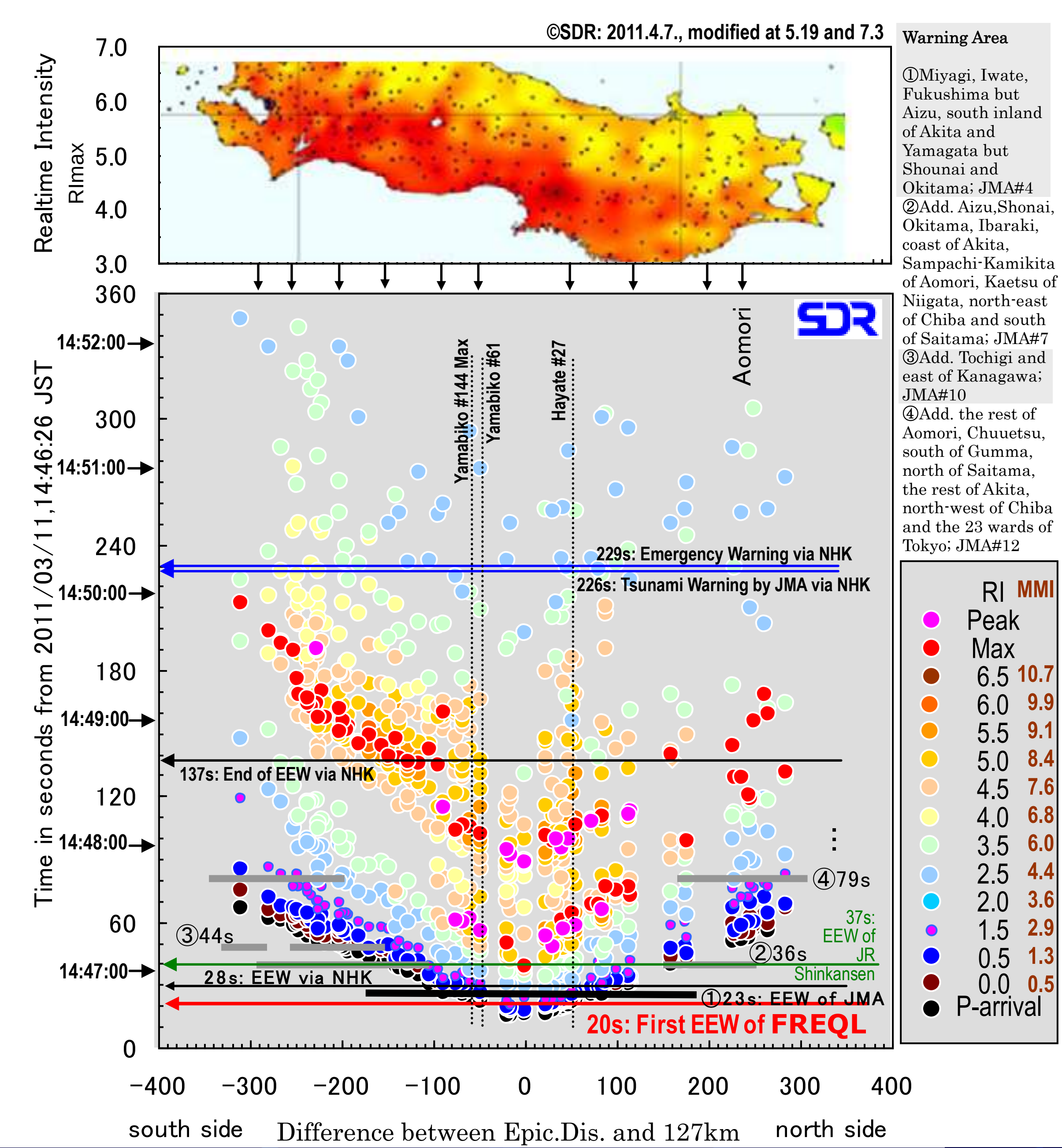
2008.6.14, Mjma 7.2, Depth8km



This figure shows comparison between the EEW by JMA and the simulated on-site alarm of FREQL and AcCo using strong motion records.

Horizontal axis is epicentral distance, Vertical axis is time from occurrence of Earthquake. Solid line shows P-wave arrival.

JMA alarm spread after the strong motion in damaged area. In contrast this, the time margin by FREQL alarm is several seconds before the beginning of strong motion, even at the epicenter itself.



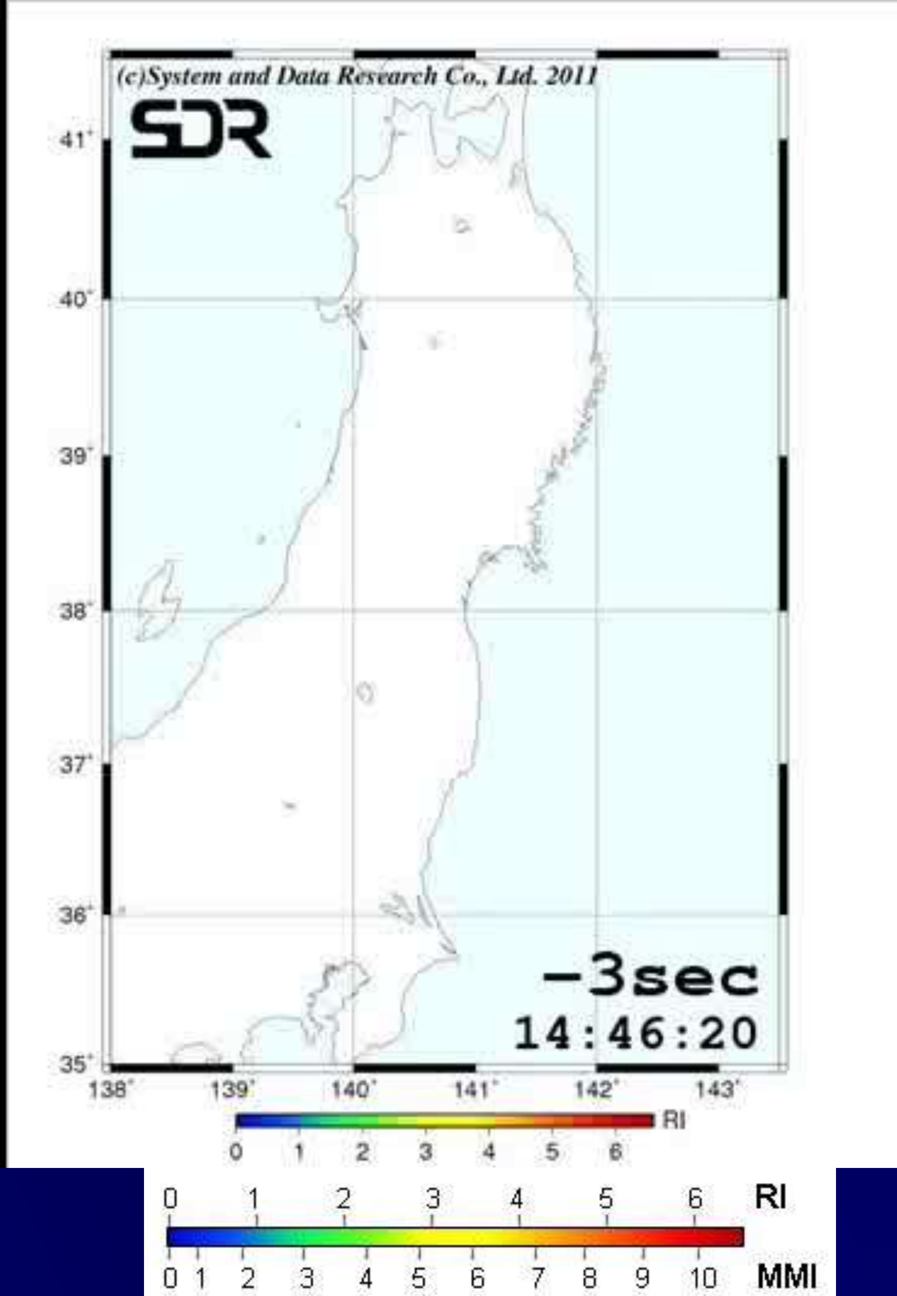
The 2011 Tohoku Earthquake

This figure shows the Realtime Intensity RI varied in time and space.

The first EEW of FREQL is three seconds faster than that of JMA.

Even closest place, on-site FREQL alarm leads more than 20 seconds.

On the other hand, for various area, people felt it before sever motion without equipment.



14:46:46
FREQL Alarm estimated

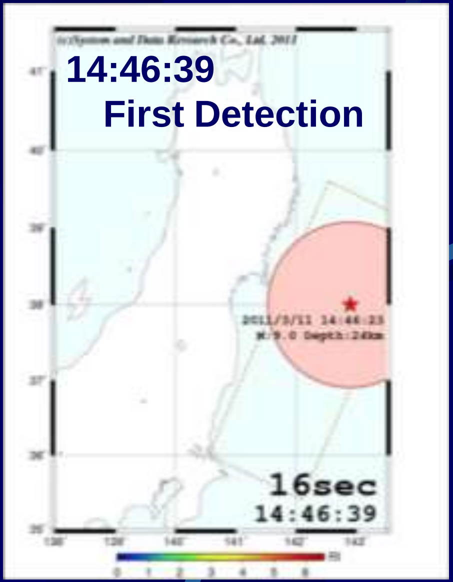
14:46:49
JMA EEW

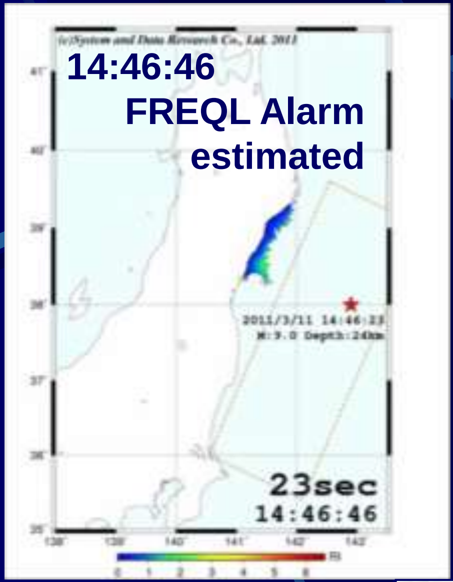
14:46:54
JMA EEW on TV screen

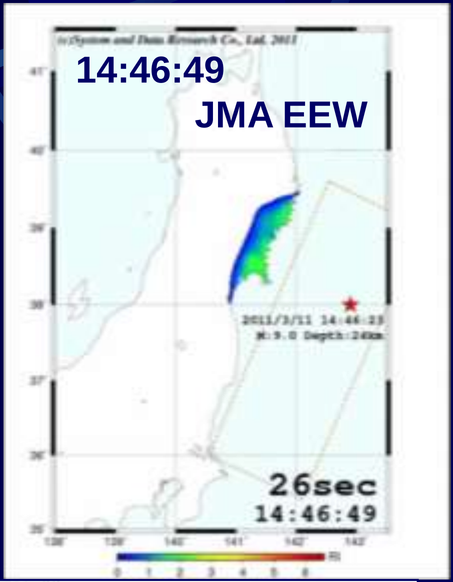
FREQL Alarm actual on rock site

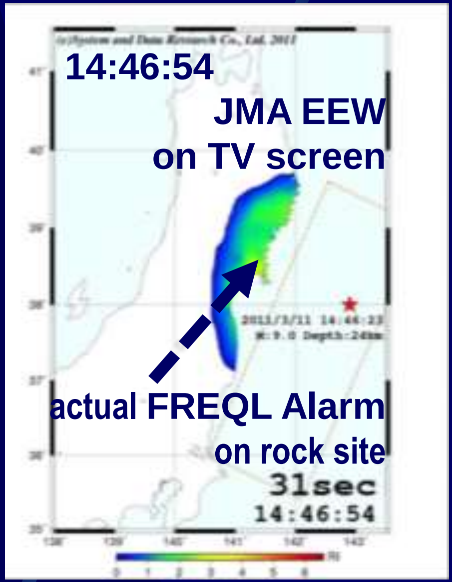
14:47:03
JR Alarm

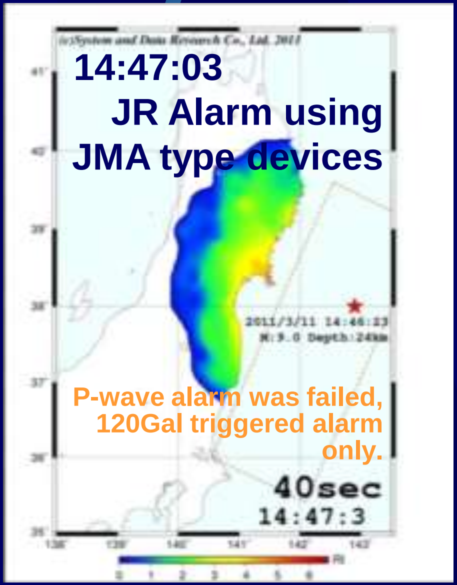
14:50:10
JMA Tsunami Warning

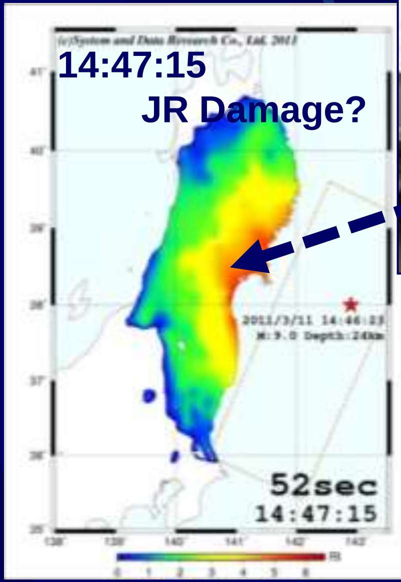




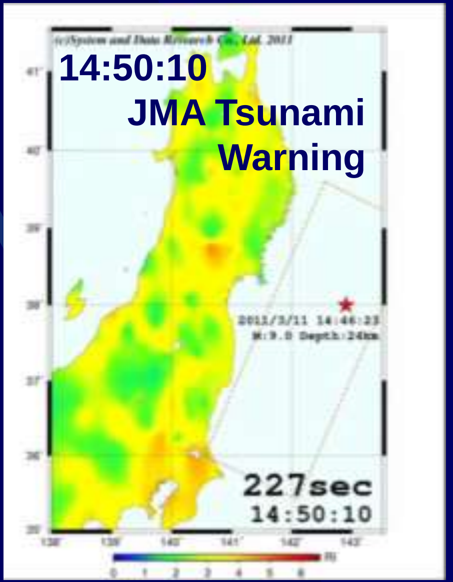








It is very sever situation for Shinkansen with extremely short time margin. It is lucky there was no vehicles around here.



EEW and
Earthquake Disaster Mitigation

Damage Examples of the 3.11 Earthquake (Mw 9.0)

- The Basic Countermeasure is Strengthening the Facilities
- EEW is only a Trigger for Quick Response against Quake
- It is important for EEW to avoid Overestimation and Crying Wolf
- Accurate earthquake Information is Extremely Important for Quick Response after the Event

END

Thank you for your kind attention!

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