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ON A RATIONAL STRONG MOTION INDEX COMPARED WITH OTHER VARIOUS INDICES

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SUMMARY

Ijma, instrumental seismic intensity of Japan Meteorological Agency, is just an artificial index without physical meaning and can not be calculated in realtime. On the other hand, DI [1] is defined by the logarithm of the absolute value of the inner product of an acceleration vector and a velocity vector with regards to the power of an earthquake motion, and can be calculated in realtime. The realtime seismic intensity RI was proposed derived from the DI. The differences of RI value, maximum RI, and Ijma were an average of 0.05 and standard deviation 0.132 for strong motion records at totally 910 sites with Ijma 1 to 7 of M4-M8 Earthquakes. Furthermore, a calculation method for the instrumental MMI, Modified Mercalli Intensity, based on DI value, maximum DI, was also proposed and the validity was verified. Based on this technique, a new palm-top digital alarm seismometer AcCo, Acceleration Collector, that gives a real-time display of the RI value or the instrumental MMI and the maximum acceleration by turns was developed.

INTRODUCTION

In Japan considering about standardization of seismic intensity, it is impossible to avoid thinking about Ijma, instrumental seismic intensity defined by JMA, Japan Meteorological Agency, although Ijma which is artificial index without physical meaning is expedient and has a difficulty that cannot calculate in realtime. In this paper, new index DI is proposed from Kg value, proposed to evaluate the vulnerability of ground, has a relationship with the damage of small buildings on the ground. DI is defined as a logarithm of an inner product of acceleration and velocity vectors. It has a physical meaning as a power of earthquake motion, and is easy to speculate maximum DI relating with damage, also can calculate in realtime, and DI and instrumental seismic intensity has almost the same property. Here some indices derived from DI are proposed and they are compared with ordinary indices as maximum acceleration, Ijma and SI value, maximum spectrum intensity originally defined by Housner [2]. By comparing DI value with maximum acceleration, Ijma and SI value, RI, Realtime Intensity derived from DI, which can calculate and indicate real time and instrumental MMI, Modified Mercalli seismic Intensity, based on DI value, will be proposed. Furthermore development of palm top digital alarm seismometer which gives a realtime display of the RI value or the instrumental MMI and the maximum acceleration will be reported.

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DI VALUE AND THE OTHER STRONG MOTION INDICES

Here the strong motion indices such as DI value will be viewed.
Kg value [3], index of vulnerability of surface ground using micro tremors, is found to have a relationship not only with the liquefaction of ground but also with the damage of surroundings. Research on DI was started at this point and the concept of DI was proposed in 1998 [4]. P wave alarm system based on the PI value, the maximum DI of P-wave part, was at work for Tohoku Shinkansen in the same year.
Defined formula of Kg value, Kg=A2/F, can be thought as follow. Inner product of an response acceleration vector $\boldsymbol{a}$ and an response velocity vector $\boldsymbol{v}$ can be considered to product of the amplification factor and a square of basement ground acceleration as the input by response of surface ground. Then Kg value correspond to the amplification factor. Thus sites which shows large Kg value has strong motion and cause extensive damage to structures. Therefore calculating the power in direct was thought by using acceleration record. Avoiding the value to be large, DI was defined by taking logarithm of power as below.

$$\mathrm{DI} = \log\left(\left|\Sigma(\boldsymbol{a}\cdot\boldsymbol{v})\right|\right) \tag{1}$$

By analyzing DI changing by time and maximum DI, DI value, DI increases when seismic wave arrives and shows good relation between DI value and Ijma with shift. The amount of shift is 0.6 when DI value is calculated with the earthquake motion of acceleration in Gal (cm/s/s) and velocity in 0.001cm/s within frequency range of between 0.1Hz and 5Hz.
The influence of vertical motion to calculate DI value was considered with data set of 314 sites including the 2003 Miyagiken-Oki Earthquake, the 2003 Miyagiken-Hokubu Earthquakes, and the 2003 Tokachi-Oki Earthquake. Between DI value calculated from three component, and omitting vertical motion component, they have only differs average of 0.013 and standard deviation of 0.035. Therefore DI value will be calculated by two horizontal components, in this paper. However DI value is calculated, from cm/s/s about acceleration and cm/s about velocity, and also change the definition of “DI” from “Damage Index” [5] to “Destructive Intensity”.
Nowadays maximum acceleration observed at ground surface is publicized from many organizations, though frequency range is not definite. Maximum acceleration increases for wide frequency range. According to recent improvement of observation technique, observed frequency range is spreading. So the observed large maximum acceleration doesn’t cause damage expected from past experience. Contrary with this JR has already restrained the frequency range between 0.1 Hz and 5Hz for acceleration to alarm.
In this paper, records of several earthquakes observed by K-NET, KiK-net and also by Taiwan Meteorological Agency are adopted. The range of data set for Magnitude and Ijma are M3.8~8.0 and 0.6~6.6, respectively. Main samples of earthquakes are the 1995 Hyogoken-Nanbu Earthquake (M7.2), the 2000 Tottori Earthquake (M7.3), the 2001 Geiyo Earthquake (M6.7), the 2003 Miyagiken-Oki Earthquake (M7.0), the 2003 Miyagiken-Hokubu Earthquakes (M5.4-M6.2), the 2003 Tokachi-Oki Earthquake (M8.0), and the 1999 Chi-Chi Earthquake of Taiwan(M7.6). Maximum acceleration (PGA) publicized based on these data are calculated by two horizontal component or three component waveform without filtering and including up to 30Hz. To distinguish PGA from maximum acceleration with JR alarm characteristic, “5HzPGA” will be used.
Ijma is calculated by each organization based on the definition of JMA. SI value has several variations, but here the definition of Tokyo Gas Company, acknowledged as SI sensor is adopted. This SI value is slightly smaller than the SI value defined by Incorporated Administrative Agency Public Works Research Institute (PWRI).

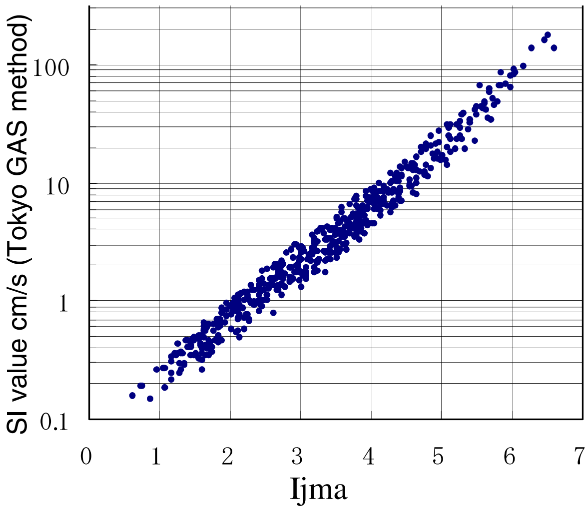


Figure 1 The relationship Ijma and SI value.

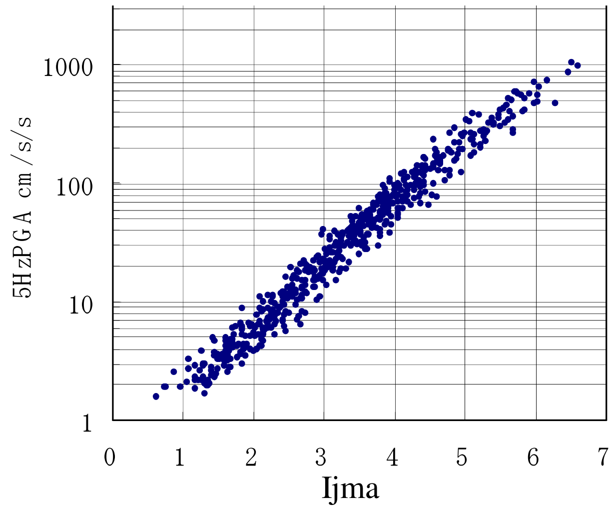


Figure 2 The relationship Ijma and 5HzPGA.

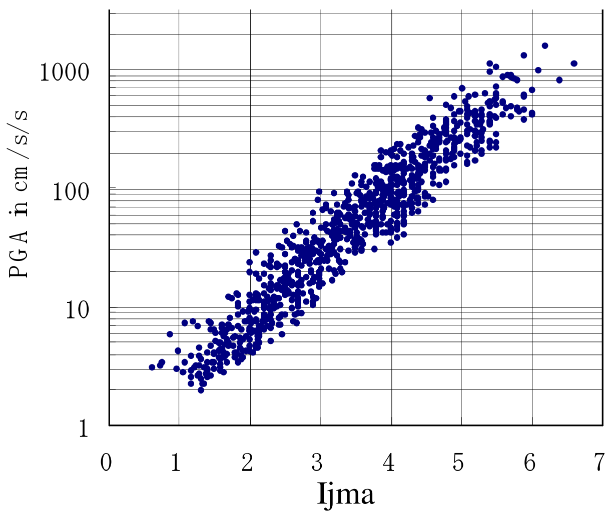


Figure 3 The relationship between Ijma and PGA.

RELATIONSHIP BETWEEN IJMA, SI VALUE AND 5HZPGA

In this section, 3 types of practical major indices, Ijma, SI value and 5HzPGA will be mutually compared. **Figures 1 and 2** show relationships between Ijma and 5HzPGA, and between Ijma and SI value, respectively. According to these figures, range of dispersion corresponding with Ijma, SI value shows almost same as 5HzPGA. **Figure 3** shows wide dispersion on the relationship Ijma and PGA. These figures show that acceleration generally does not have good relations with damage, but 5HzPGA omitting high frequency component shows conformity with SI value which shows good relation with damage.

Here, to discuss on same frequency range are proposed because maximum acceleration depends on it.

PROPOSAL OF RI VALUE AND RELATIONSHIP WITH IJMA

RI value corresponded to Ijma will be defined as below.

$$RI = DI + 2.4 \quad (2)$$

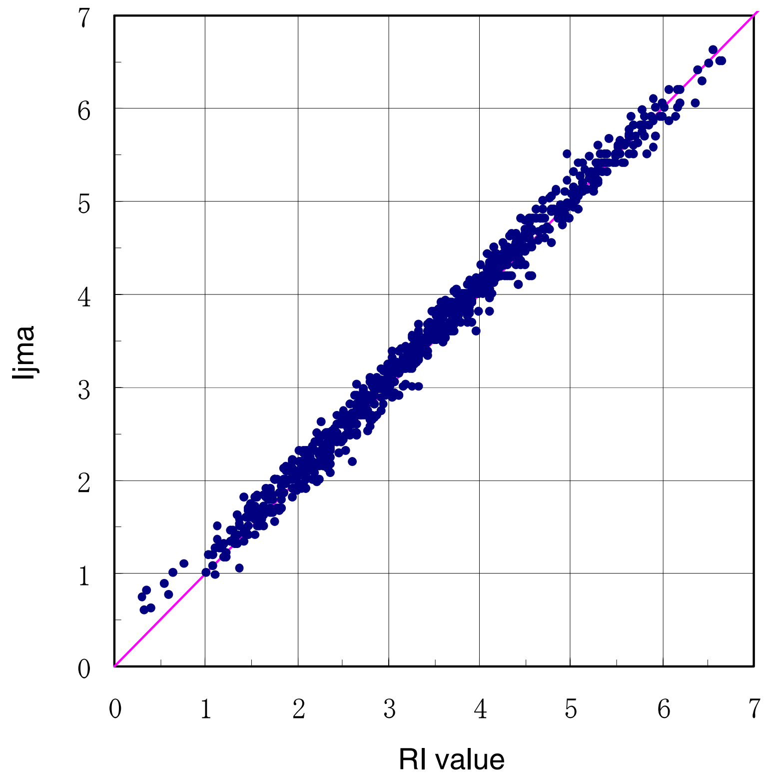


Figure 4 The relationship between RI value, maximum RI, and Ijma

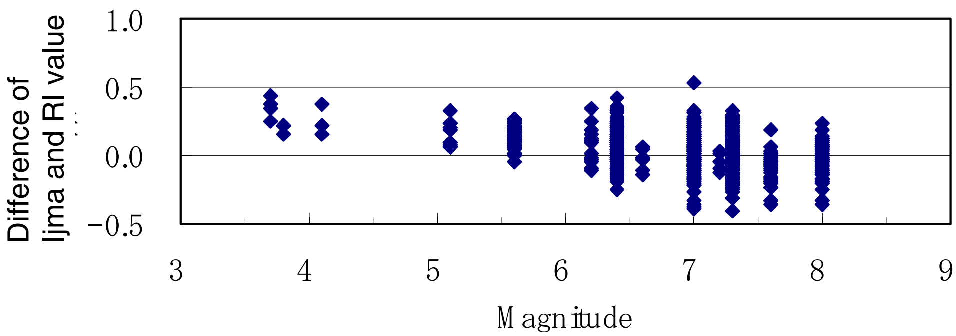


Figure 5 The relationship between magnitude and difference of Ijma and RI value

Figure 4 shows the relationship between RI value, maximum RI, and Ijma. Data set used here has magnitude range of M3.8 to M8.0 and Ijma range of 0.6 to 6.6. Number of strong motion data is 910, difference between Ijma and RI value is average 0.050, standard deviation 0.134. Thus both RI value and Ijma can be seen same practically. **Figure 5** shows relationship between magnitude and difference of RI value and Ijma. It tends that RI value is a little smaller than Ijma when M<7, a little larger than Ijma when M>7. Since predominant frequency becomes smaller as magnitude becomes larger, RI value becomes smaller than Ijma when predominant frequency is high, and when predominant frequency becomes lower it becomes larger than Ijma. From a trend of recent relations between damage of earthquake and earthquake motion, this characteristic of RI value seems more proper for index of strong motion.

PROPOSAL OF INSTRUMENTAL MMI

In former section RI value related to Ijma was defined based on DI. In this section instrumental MMI will be proposed. Scales of Ijma and MMI are 0 to 7 and 1 to 12, respectively. First RI value corresponding to Ijma will be uniformly enlarged to MMI, then verified the validity comparing with maximum acceleration and maximum velocity. Proposed formula is below,

$$\begin{aligned} MMI &= (11/7)*RI + 0.50 \\ &= (11/7)*DI + 4.27 \end{aligned} \tag{3}$$

Figure 6 shows comparison between MMI calculated by formula (3) and PGA. In this figure relationship

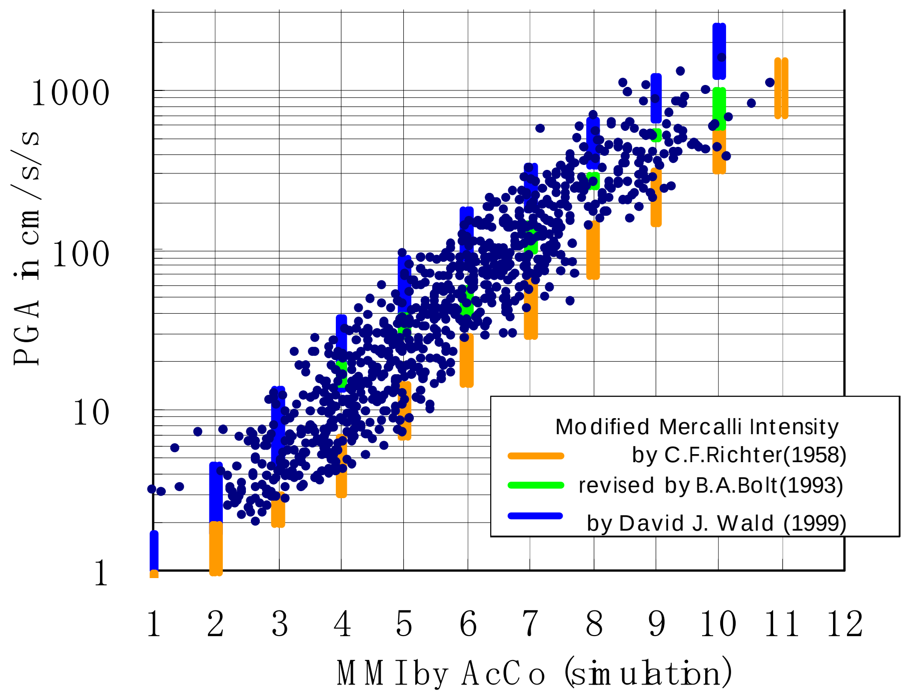


Figure 6 The comparison between MMI and PGA.

between MMI and PGA proposed by Richter [6], Bolt [7] and Wald [8] are shown. By this after the definition of Richter, PGA corresponding to MMI increases and relationship between instrumental MMI and PGA is including the relationship between PGA and MMI defined by Richter, Bolt and Wald.

Figure 7 shows relationship between instrumental MMI and 5HzPGA and this relationship well matches with relationship Richter's first definition. These figures can be interpreted as follows; the maximum acceleration is able to measure for high frequency range recently, since high frequency does not contribute well to damage, PGA including high frequency range deviated from seismic intensity. Generally strong motion of higher than 5Hz is not effective to damage. In past, the observation range was about lower than 5Hz, so the relationship between the instrumental MMI and 5HzPGA is expected to be similar to the relationship between MMI and PGA in original.

Figure 8 shows that the relationship between instrumental MMI and maximum velocity PGV almost agrees with the relationship by Bolt [9]. Therefore, validity of calculating MMI with formula (3) in realtime is verified.

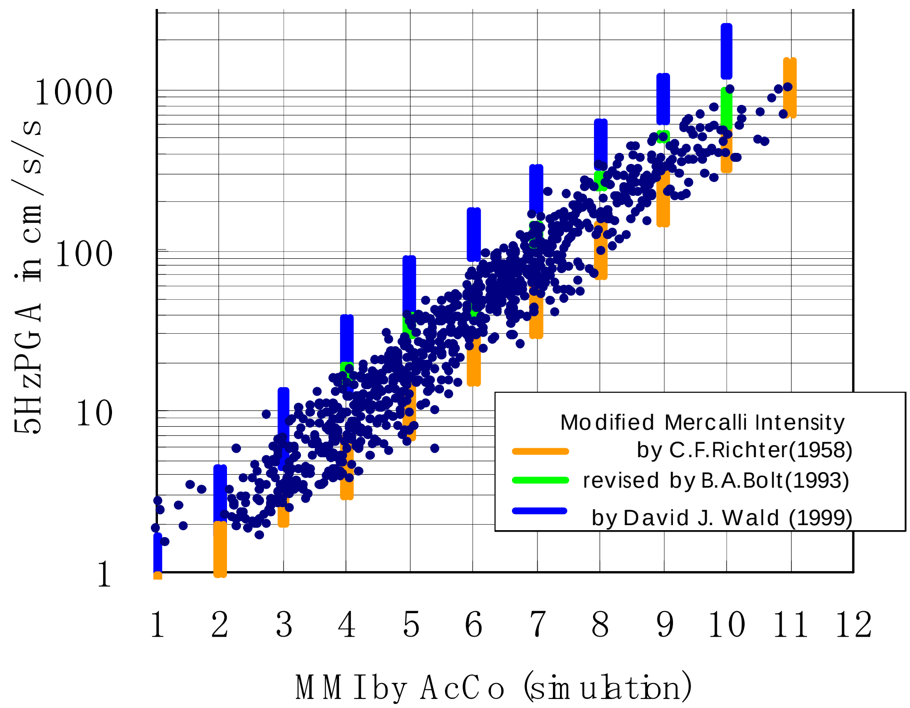


Figure 7 The relationship between instrumental MMI and 5HzPGA

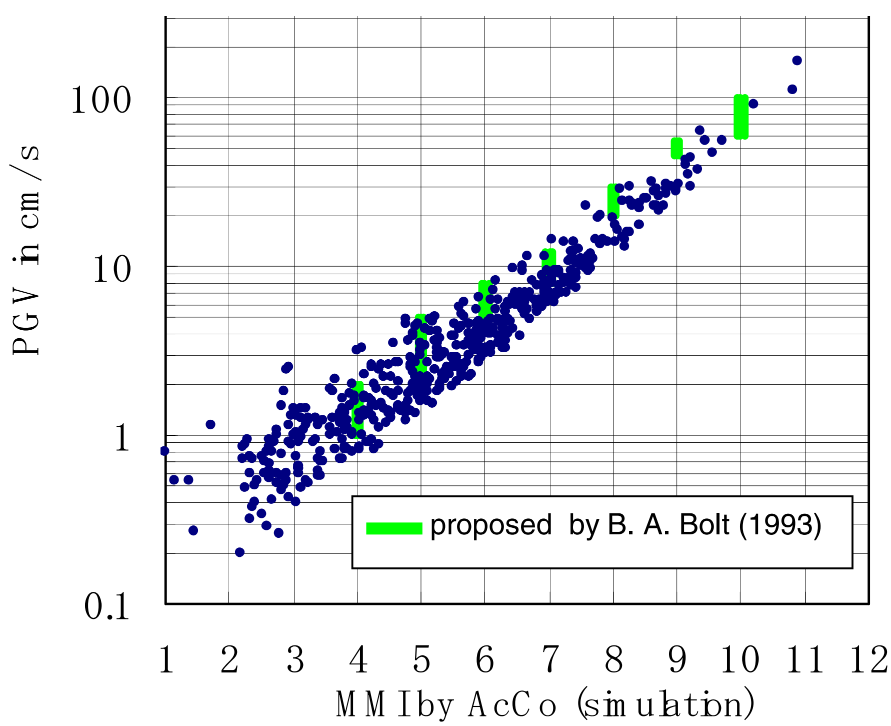
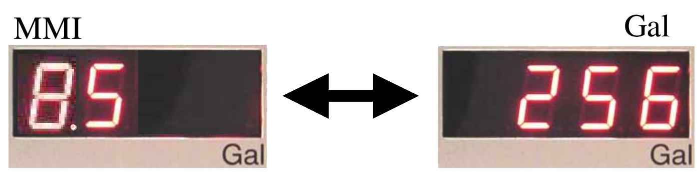


Figure 8 The relationship between instrumental MMI and maximum velocity PGV

DEVELOPMENT OF PALM-TOP DIGITAL ALARM SEISMOMETER

Maximum acceleration is important to estimate the seismic force. DI, basis of RI value and instrumental MMI, relates power of earthquake motion, which is important to estimate destructive energy of earthquake motion. Based on this technique, digital alarm seismometer AcCo, Acceleration Collector, is developed. **Figure 9** shows the exterior view of AcCo. Table 1 is main specifications for AcCo. AcCo gives realtime display of 5HzPGA and instrumental seismic intensity RI or MMI. Applying that accurate DI value can be calculated without using vertical component, it made saving in cost. AcCo has palm-top body weighs below 1kg. AcCo has RS232C port to output digital waveform. Also it can record the waveforms for two events, maximum and next, with pre-event-memory.



Gal and MMI, or RI, will be displayed with alternation every 0.5 seconds

Figure 9 Photo of AcCo and illustration its display manner

Table 1 The main specifications for AcCo

PHYSICAL SPECIFICATIONS	
Dimension	17cm(w) x 12cm(h) x 6.5cm(d) (not including projections)
Weight	0.8 kg (not including a battery)
Power Supply	AC100V-240V, 50/60Hz, and 4VA (AC adapter attached, battery back up (*1)
Operating temperature	0-50 C
Operating humidity	Less than 80% (not dew)
Measurement	
Sensor type	Acceleration 2 direction
Measurement range	Each direction up to 2g (2 x 980Gal)
Noise level	Less than 1Gal-rms
Resolution	Approximately 1/6Gal
Sampling rate	1/100 seconds
Frequency range	DC-10Hz
Event Memory (option)	Record length 108 sec within pre-event memory 30 sec for max and next events
Display	
Frequency range	0.1-5Hz
Contents of a display	The maximum acceleration, RI or MMI(option)
Display type	4 characters of high luminosity 7 segment Light Emitting Diode
Alarm output	
Frequency range	0.1-5Hz
Alarm conditions	Exceeding preset level (*2)
Output method	Red LED luminescence, buzzer and output via RS-232C
Output	
Contents of an output	Waveform and other information
Output method	The original protocol using RS-232C (D-SUB 9 pin socket). (Separately optional software and optional cable are required to communication with PC.)

* The characteristics above-mentioned changes not with a guaranteed value but with observation conditions.

(*1) 006P(9V) battery are required for back up.
(*2) selectable from 12 stages of 10, 15, 20, 25, 30, 40, 50, 80,100,120,150 and 200Gal.

CONCLUDING REMARKS

This paper considered of rational index value of earthquake motion and proposed new index; RI value, Realtime seismic Intensity, that becomes almost the same with Ijma. Also proposed concrete method to measure MMI, which is standard seismic intensity among the world and verified its validity. Furthermore palm top digital alarm seismometer which can display seismic intensity and acceleration in realtime was developed.
It is expected that this inexpensive digital alarm seismometer contributes to develop rational vulnerable design and also leads the change of earthquake disaster prevention, with making strong motion index common sense to public or making record strong motion easier for various structures.

ACKNOLEDGEMENTS

In this paper, the waveform data was mainly provided by K-KET and KIK-net of NIED, National Research Institute for Earth Science and Disaster Prevention, and the Meteorological Agency of Taiwan. Dr. K. T. Shabestari, former researcher of Earthquake Disaster Mitigation Research Center, calculated Ijma and SI value of the 1995 Hyogoken-Nanbu Earthquake, the 2000 Tottori Earthquake and the 2001 Geiyo Earthquake. Midorikawa laboratory of Tokyo Institute of Technology, http://www.enveng.titech.ac.jp/midorikawa/, calculated Ijma of the 1999 Chi-Chi Earthquake. Ijma of Other earthquakes calculated by CUE, Conference on Usage of Earthquakes, http://www.sdr.co.jp/cue/cuemainjn.html, are used. I would like to sincerely express my highest appreciation and gratitude to people and organizations above mentioned.

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