Proceedings World Geothermal Congress 2010
Bali, Indonesia, 25-29 April 2010

A multi-parameter measurement system at Koseto (Shizuoka, Japan) and its responses during the large earthquakes since 2003

Ömer Aydan[1], Hisataka Tano[2] and Yoshimi Ohta[3]

[1]Tokai University, Dept. of Marine Civil Eng., Shizuoka, [2]Nihon University, Dept. of Civil Eng., Koriyama, Japan ,
[3]Tokai University, Graduate School of Science and Engineering, Shizuoka, Japan

[1]aydan@scc.u-tokai.ac.jp, [2]tano@civil.ce.nihon-u.ac.jp, [3]8atad003@mail.tokai-u.jp

Keywords: multi-parameter system, earthquake prediction, temperature, AE, GPS, electric potential

ABSTRACT

The Koseto multi-parameter station is situated between Itoigawa-Shizuoka Tectonic Line (ISTL) and Sasayama Tectonic Line (STL) in Shizuoka prefecture of Japan, where. four plate boundaries exist. The prefecture may experience the anticipated Tokai earthquake in near future. The authors have continuously been measuring variations of hot-spring temperature, temperature and pressure of air, electrical field, pH, electrical resistivity and acoustic emissions as a part of their multi-parameter monitoring system. This article describes the responses of multi-parameters measured at this station during large earthquakes since 2003 and its implications in earthquake-predictions. The results indicated that there are distinct relations between measured parameters at the Koseto station and large earthquakes.

1. INTRODUCTION

When rock starts to fail, the stored mechanical energy in rock tends to transform itself into different forms of energy. Experimental studies on various rocks, which will be briefly presented in the next section, indicated distinct variations of various measurable parameters such as electric potential, magnetic field acoustic emission, resistivity etc. besides load and displacement, which are called multi-parameters, during deformation and fracturing processes. These variations may be useful in predicting the failures of rock structures as well as earthquakes in geoscience.

Temperature variations, electrical field, pH, electrical resistivity, acoustic emissions and GPS measurements are selected as the items of measurements for the crustal multi-parameter observations. Among them, variations of hot spring temperature, temperature and pressure of air, electric field and acoustic emissions are measured continuously while pH and electrical resistivity are measured at the time of data-collection from loggers. This article describes the responses of multi-parameters of this station during large earthquakes since 2003 and its implications in earthquake-predictions.

Shizuoka prefecture is situated at the junction of four plates and the Tokai earthquake with a magnitude of 8 is anticipated to occur in Suruga Bay. Extensive monitoring programs for crustal variations by various governmental institutes in relation to the anticipated Tokai earthquake have been undertaken in the prefecture. However, the monitored parameters are not often interrelated since each institute monitor certain selected parameters.

The Koseto hot spring was found through drilling a borehole to a depth of 900m (Figure 1). The spring is situated above the anticipated Tokai earthquake fault and it is an ideal place for measuring crustal multi-parameters, which may be of great value for earthquake prediction and crustal variations in the earth's crust with time. The authors describe the results of multi-parameter monitoring system installed in Koseto and its correlations with large earthquakes in Japan and worldwide since 2003.

2. GEOLOGY AND TECTONICS OF THE SHIZUOKA PREFECTURE

Figure 2 shows the geology of the Shizuoka prefecture. The eastern region and Izu Peninsula of the prefecture mainly consist of volcanic sediments and volcanic rocks, while the central region composed of Paleogenic and Neogenic sedimentary rocks. The western region consists of Paleozoic sedimentary rocks, Cretaceous Shimanto belt and metamorphic rocks. Shizuoka Prefecture is tectonically a unique prefecture in Japan where four plate boundaries, namely, Pacific plate, Eurasian plate, North American plate and Philippine Sea Plate interacts with each other and the famous Mount Fuji appears to be at the junction point of these plates boundaries. There are four well-known tectonic lines, namely, Itoikawa-Shizuoka tectonic line, Sasayama tectonic line, Akaishi tectonic line and Median tectonic line. Itoikawa-Shizuoka tectonic line constitutes the southern boundary of Fossa Magna, which is considered to be the boundary between Eurasian plate and North American plate (?). Its strike is almost NS and its deformational sense is sinistral thrust type faulting. Sasayama and Akaishi tectonic lines are the boundaries of Shimanto belt, which consists of intercalated sandstone and shale.

Figure 1: A satellite image of Shizuoka Prefecture and location of Koseto spring

The median tectonic line, which starts from Okinawa Through and disrupted at the north of the prefecture by joining the Itoikawa-Shizuoka tectonic line and it extends to Hokkaido Island in north. This tectonic line, which is more than 1000km long is considered to be associated with the interaction between Philippine Sea plate and Eurasian plate and it has the sense of dextral thrust type faulting. The sedimentary rocks sandwiched between Itoikawa-Shizuoka tectonic line and Median Tectonic line are heavily folded and the strikes of synclines and anticlines are almost NS, which implies that the region should had been subjected to high EW compressive stresses in the geological past. The Izu peninsula, which is considered to be on Philippine Sea plate, has numerous short faults, whose strikes are generally NW-SE. The other well-known faults in the prefecture are Fujikawa-Iriyama fault, Tanna fault, Inatori fault and Irozaki fault.

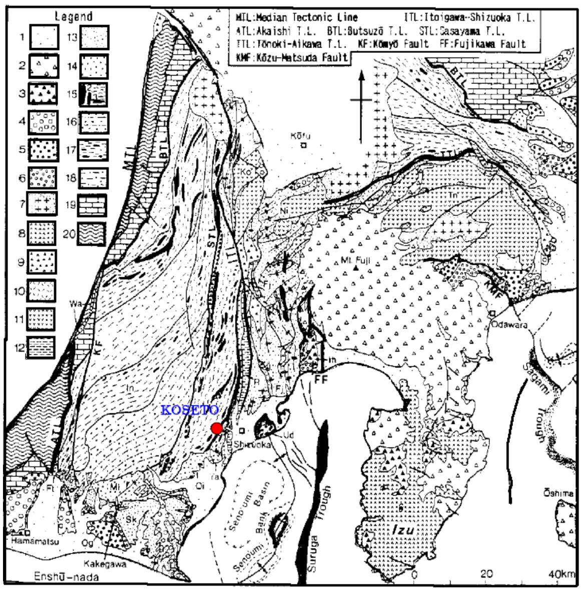

Figure 2: Geology and tectonics of Shizuoka Prefecture and location of Koseto hot spring

Koseto spring is located near the Itoigawa-Shizuoka Tectonic Line as seen in Figure 3. Rocks along the boring were mudstone, shale and sandstone mainly together with some fault gouges. The station is located over the source area of the anticipated Tokai earthquake, which may have some important implications for the area.

Figure 3: A view of the location and instrumentation

3. MULTI-PARAMETER RESPONSE OF ROCKS

The authors undertook an experimental studies for e understanding of multi-parameter variations including electric potential and electrical resistivity during deformation and fracturing process of geomaterials, which ranges from crystals, gouge-like materials to rocks under different loading regimes (Aydan et al. 2001, 2003). The applied load and induced displacement were automatically measured and stored on the hard disk of a laptop computer through an electronic logger. Electric potentials induced during the deformation of samples were measured through two electrodes attached to the top and bottom of samples using a voltmeter and logger unit and data were simultaneously stored on the hard-disk of the laptop computer. The electrodes were isolated from loading frame with the use of isolators. Electric potentials were measured either as DC and/or AC. When electrical resistivity is measured, a function generator was used to produce electric currency with given amplitude. In some of tests, magnetic field is also measured. In addition to the above measurement system, acoustic emissions (AE) devices and sensors and temperature sensors were used to measure the acoustic emissions as well as temperature variations during fracturing and sliding of samples. The acceleration responses of the samples during fracturing were measured accelerometer, which can measure three components of accelerations up to 10G with a frequency range of 0-160Hz. Various rock samples were tested. Although some of rock samples (i.e. granite, quartzite, sandstone etc.) contain piezo-electric minerals, some rock samples were selected such that they do not contain any piezo-electric substances such as aragonite crystal, limestone, rocksalt soapstone, marls. Various responses measured during some of experiments are shown in Figures 4-6. The detailed discussions can be found in previous articles (Aydan et al. 2001, 2003, 2005a,b, 2007; Aydan and Tano, 2003). Nevertheless, one can easily notice the distinct variations of multi-parameters during the deformation and fracturing of rocks, which are relevant to the monitoring system in this study.

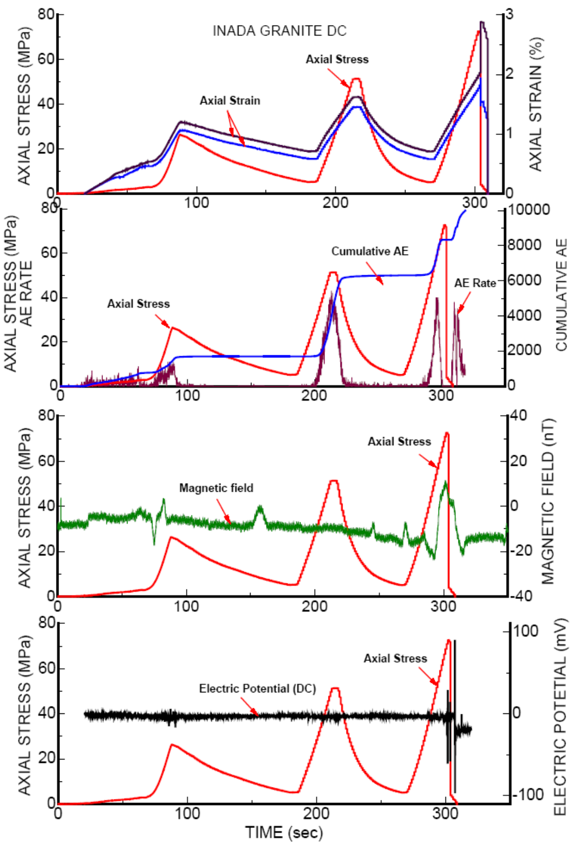

Figure 4: Multi-parameter responses of Inada granite during fracturing and deformation

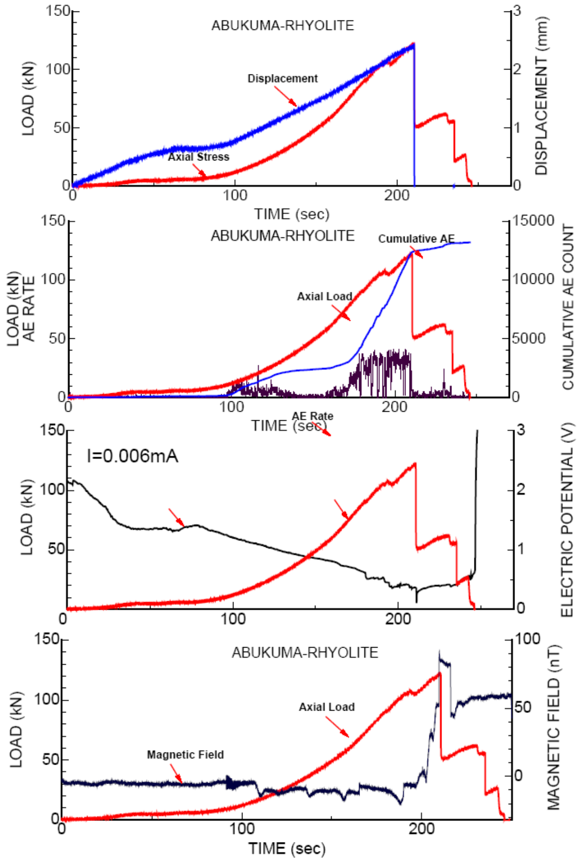

Figure 5: Multi-parameter responses of Abukuma rhyolite during fracturing and deformation

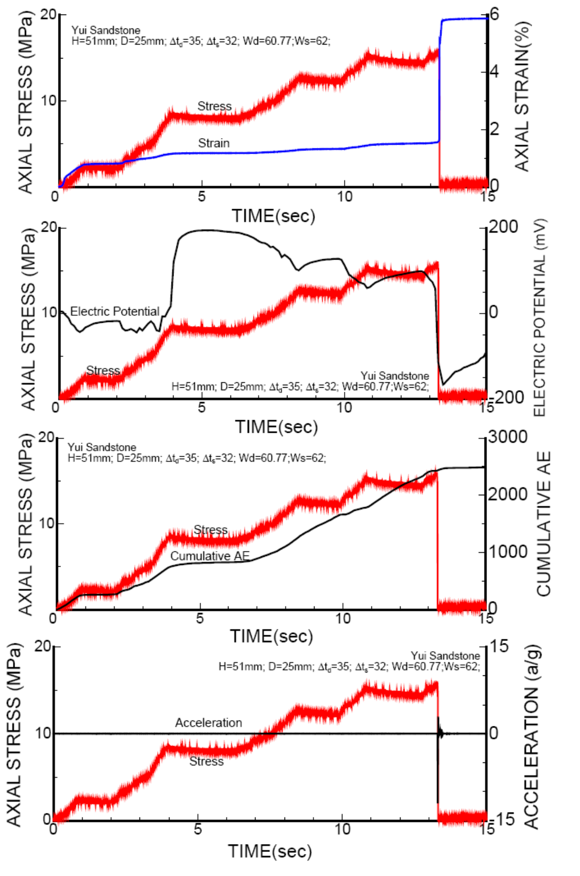

Figure 6: Multi-parameter responses of Yui sandstone

4. MEASUREMENT ITEMS AND DEVICES

The measurement items for the variations of the earth's crust may be many, depending upon the field of interests. Most of crustal multi-parameter observations involve temperature, electrical resistivity, pH, borehole strain, electro-magnetic fields. In this study, temperature variations, electrical field, pH, electrical resistivity and acoustic emissions are selected as the items of measurements for the crustal multi-parameter observations (Figure 3). Among them temperature variations, electric field and acoustic emissions are measured continuously while pH and electrical resistivity are measured at the time of data-collection from loggers.

4.1 Temperature Measurement System

Temperature measurement system is produced by T&D Corporation of Japan and the model of the system is TR-71S. The temperature sensors can measure temperatures ranging from –60 to 155 ^{o}C. The measurable temperature variation is 0.1 ^{o}C. Time interval can be selected as desired and it has two channels. One of the channels is used to measure the air temperature while the other channel is used to measure the temperature of the hot spring in a steel pipe casing at the ground level. Each channel of the TR-71S can store up to 8000 data and operates on two Alkaline (LR03) batteries of Type 4. The stored data can be transferred to computers through a RS-232C connection cable.

4.2 Electric Field Measurement System

Electric field measurement system is also produced by T&D Corporation of Japan and the model of the system is VR-71. It is a simple voltage recorder measuring voltage as DC. The measurable smallest unit by the device is 1 mV. The input impedance of the device is in the order of several Mega Ohms. Although its input impedance is low for laboratory electric field measurements, the first author obtained satisfactory performance in in-situ electric field measurements in other locations. Furthermore, the cost of device is affordable so that the wide-spread installation can be easily achieved.

4.3 Pufpuf Counting System

The second author developed pufpuf counter or acoustic emission measurement system. The system consists of three or four main components: a) stainless steel wave guide (if necessary), b) acoustic emission sensors (active and dummy sensors), c) amplifier unit, and logger unit. The wave-guide is necessary if one desires to measure acoustic emission events at deeper levels. The present system utilizes borehole steel casing as a wave-guide. This system was originally developed for Tekkehamam observation station in B. Menderes Graben nearby Denizli in Western Turkey (Aydan et al., 2001; Kumsar et al., 2003). The active acoustic emission sensor with a frequency range of 2-50KHz is attached to the top of the steel pipe casing. Another acoustic emission sensor named as DUMMY sensor is fixed to the logger box to measure acoustic emissions due to external causes in the vicinity of the station. The logger unit, which is originally developed for the AMENBO rain-fall observer produced by T&D Corporation of Japan, records the acoustic emission signals received by the amplifier unit, caused by the pulses of springing hot water for a given time interval. This system is named "pufpuf counter" as the sound generated during the explosion of bubbles resembling to the sound of "pufpuf" in Turkish.

5 MEASUREMENT RESULTS

The equipment was installed at the borehole on November 5, 2002 and the first author collected first records on November 6, 2002. As this was a second trial of the research group, the results from the pufpuf counter system as well as temperature and electric field measurement came out with a great success. As observed in Tekkehamam station in Turkey, the pufpuf count rate response is periodic. However its amplitude varies. The amplitude is particularly high after morning and it becomes smaller during the night. The overall response of pufpuf count resembles to the theoretical tidal wave height variation with time at Miho, Shizuoka. Although the saddle points are related to those of the tidal heights, a certain time lag between tidal heights and pufpuf activity exists.

The authors are particularly interested in the relation between the crustal multi-parameter variations and earthquake activity in the region. It is expected that the pufpuf count rate, temperature and electric fields should indicate some anomalous responses before-during-after the earthquakes in the region around the station. The authors obtained from the databases of the hypocenter data of the earthquakes occurred in Japan from Meteorological Agency of Japan (JMA), National Institute of Earthquake and Disaster (NIED) or NEIC. As the magnitude and distances of the earthquakes to the station varies, their effects on the observation station must attenuate. The authors defined a parameter called Magnitude-Distance Index and abbreviated as MRI and expressed as follows:

$$MRI = \frac{M}{R} \times 100 \tag{1}$$

Where M and R are magnitude and hypocenter distance of earthquake. This parameter is considered to be appropriate parameter for amplifying the nearby earthquakes. Nevertheless, the effect of large earthquakes on the multi-parameter observations of the station could not be taken into account. Therefore, a different function for MRI function is also utilized in this study as defined below:

$$MRI = A(e^{aM} - 1)e^{-bR} \tag{2}$$

where A, a and b are constants. The above function has the same form as proposed by the author for the attenuation maximum ground accelerations (Aydan et al. 1996, Aydan 2001). In this study, constants A, a and b are chosen as 1.0, 0.9 and 0.0025, respectively.

5.1 Responses in Relation to 2003 Tokachi-oki Earthquake

Tokachi-oki earthquake with a magnitude of 8.3 occurred at 4:50 AM (JST) on Sept. 26, 2003 (NIED, 2003; USGS, 2003 (Figure 7). The earthquake was caused by the subduction of Pacific Plate beneath North American plate. The fault plane dips NW with an inclination of 15^o and it has the sense of dextral-thrust type faulting.

The measured responses of multi-parameters such as pufpuf, electric potential, tidal wave height, temperatures of hot spring, air and ground, humidity and MRI computed for formula 1 and 2 are shown in Figure 8. It is of great interest that the pufpuf count, electric potential, temperature and humidity start to show very large variance following an earthquake of 51km deep with a magnitude Mw of 5.7 nearby the southern tip of Boso Peninsula (150km away from Koseto). The decreases of pufpuf count, electric potential, temperature stops on September 23 and then they start to increase. Just before the earthquake, very large electric potential variations, which may be interpreted as seismic electric signals (SES), occurred on September 24 and 25 about 12-30 hours before the main shock. The fluctuations are in the order of 150-350 mV for the 20cm spacing of electrodes. The response of the pufpuf count observed at Koseto before the Tokachi-oki earthquake resembles to those observed in Buldan earthquakes in July 2003 in Western Turkey. While the ground temperature and air temperature decreased for about 4-5 days before the earthquake, the variation of temperature of hot spring is not distinct. Nevertheless, the high temperature fluctuations of the hot spring may be easily inferred from the responses shown in Figure 8.

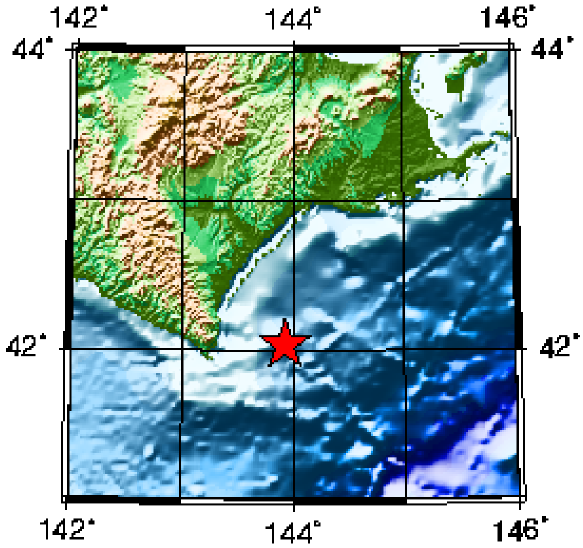

Figure 7: Location of Mw8.3 Tokachi-oki earthquake

The alternative function (Eq. 2) for RMI seems to be capable of representing the effect of distant large earthquakes such as the effect of 2003 Tokachi-oki earthquake. Since this form of the RMI function was tested and its suitability was confirmed for estimating the attenuation of peak ground acceleration, this functional form would be preferred in further studies. Figure 9 shows the epicenters of earthquakes in/around Japan together with the trace of electric fields in the tangential plane to the earth's crust. It is of great interest that the electric field variations are dominant in NE direction, which clearly points out the direction and location of anomalous electric signals caused by the potential earthquake. This conclusion could be of great significance in further utilization of the electric potential variations in earthquake predictions. Figure 10 shows the computed variations of moon-phase and the distance of the moon from the earth. It is of great interest that the earthquake occurred when the moon was at the new-moon phase and the distance was the minimum. As discussed by Aydan and Ulusay (2000), the effect of the moon should be seen as a triggering effect. It is of great to notice that the large thrust type faulting occur when the attraction of the moon is greatest if we consider the timing of 2003 Tokachi-oki earthquake in Japan and 2001 Kutch earthquake in India (Hamada et al. 2001).

5.2 Responses in Relation to 2004 Aceh and 2005 Nias (Off-Sumatra) Earthquakes

Figure 11 shows the responses of pufpuf counts at Koseto station during December 2004 in relation M9.3 Aceh earthquake. It is of great interest that 2004 December 26 earthquake occurred when the pufpuf counts become minimum following a peak. This was a common pattern observed in earthquakes observed in Turkey and Japan previously (Kumsar et al. 2003, Aydan & Tano 2003, Aydan et al. 2005).

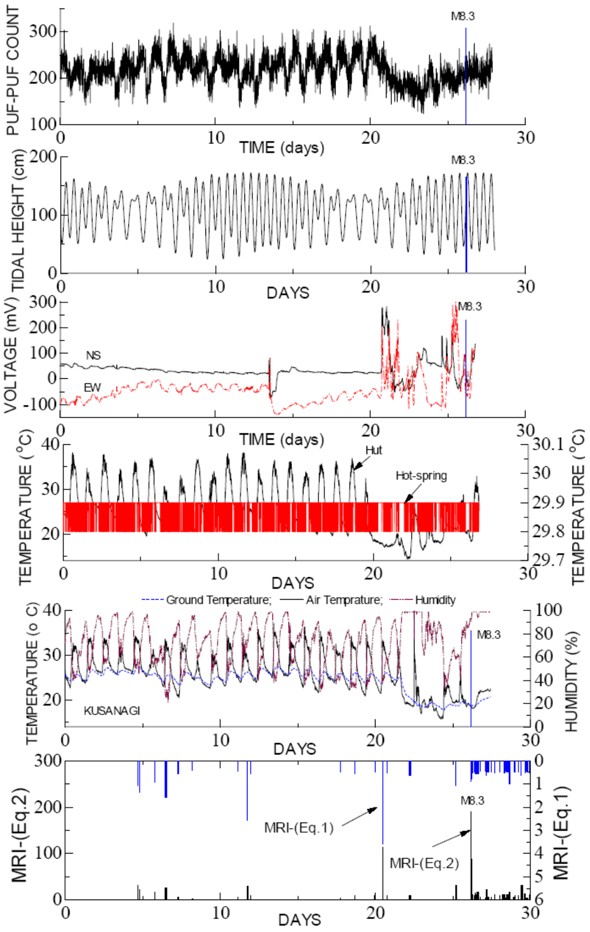

Figure 8: Responses of various parameters during September 2003

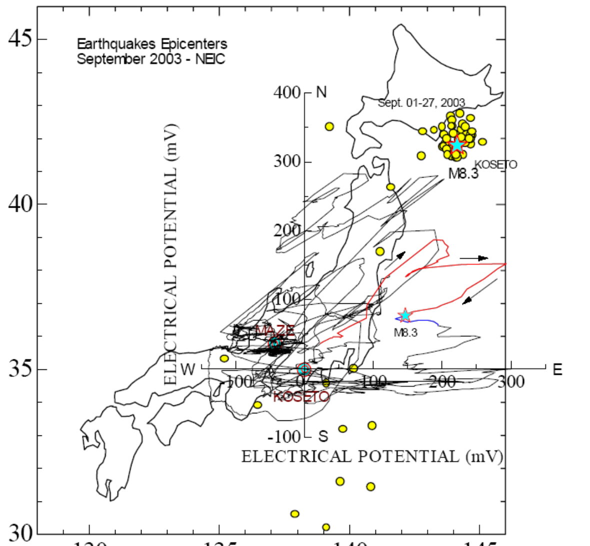

Figure 9: Epicenters of earthquakes in/around Japan and the trace of electric field variations during September 1-27, 2003

Figure 12 shows the electric potential variations at the Kusanagi station in Shizuoka and Denizli station in Turkey. It is of great interest that there is a remarkable fluctuation approximately one week before the 2004 December 26 earthquake. The laboratory experiments indicated that depending upon the size of the samples, the time becomes longer with the increase of the volume. Therefore, the period between the precursory electric potential variations (Seismic Electric Signals–SES) and the earthquake are expected to be longer for larger events. For example, the SES appeared about 2.5 hours before the M4.8 aftershock on March 31, 2001 of the M8 2001 Kutch earthquake in India, 2-3 days before M5.2 and M5.6 Buldan (Turkey) earthquakes on July 23 and 26, 2003 (Kumsar et al. 2003) and 5 days before M8.3 Tokachi-oki (Japan) earthquake on Sep. 26, 2003 as seen in Figure 12. Furthermore, the vectors of the SES clearly indicated the epicenter of the earthquakes.

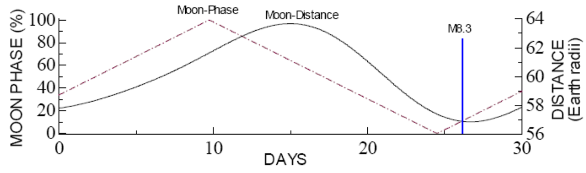

Figure 10: Variations of moon-phase and distance between the Moon and Earth

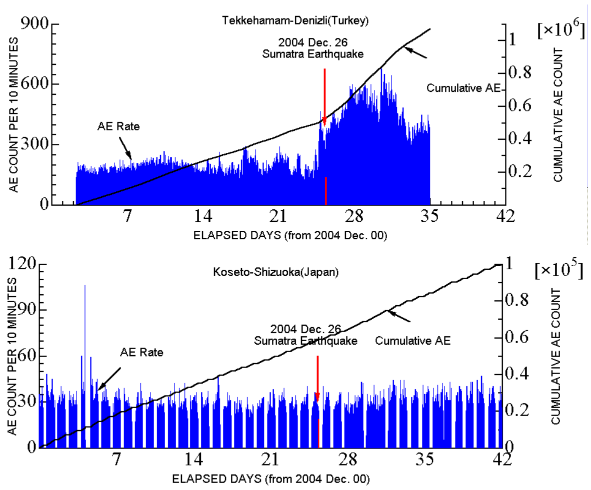

Figure 11: Pufpuf counts at Tekkehamam (Turkey) and Koseto stations

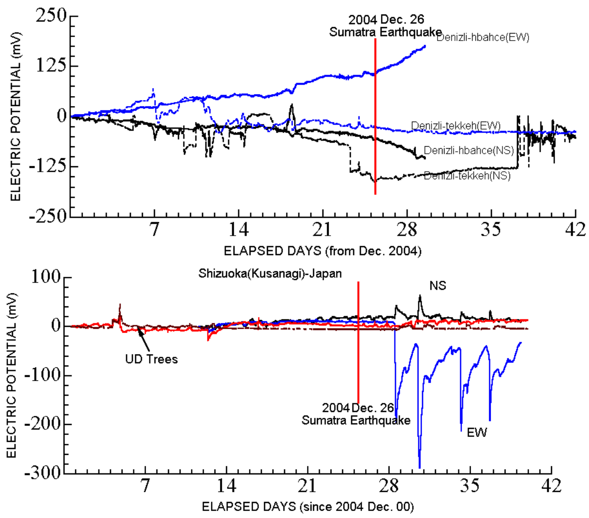

Figure 12: Electric potential variations at stations in Shizuoka and Denizli (Turkey)

Figure 13 shows the pufpuf counts in Koseto station during March 2005 in relation to M8.6 Nias earthquake. The time variation patterns of pufpuf counts are remarkably similar. Once again it is noted that the 2005 March 28 earthquake occurred when the pufpuf counts become minimum following a large peak. Since the pufpuf activity is much stronger at Tekkehamam station, counts per 10 minutes are much higher at Tekkehamam compared with that at Koseto station.

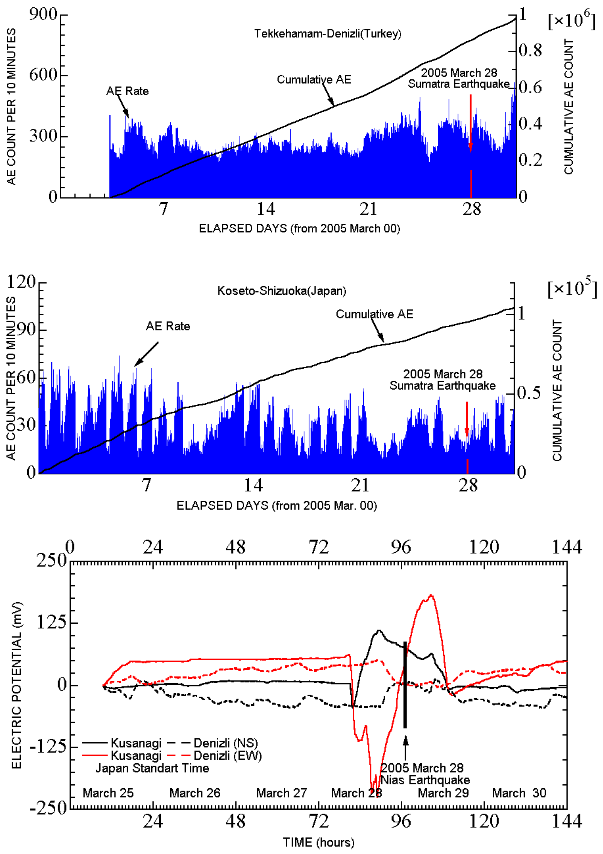

Figure 13: Pufpuf counts and electric potential variations in Shizuoka (Japan) and Denizli (Turkey) stations

5.3 Responses in Relation to 2004 Tokaido-oki Earthquake

On September 5, 2009, Two earthquakes with a magnitude of 7.2 and 7.5 occurred off Tokaido area, which is in the source area of anticipated Tonankai earthquake. Figure 14 shows the variations of several parameters with time before and after the 2004 Tokaido-oki earthquake. Temperature variations are very small and there was no remarkable anomaly before and after the earthquake. However, the pufpuf count and electric potential variations show distinct anomalous response before and after the earthquake. The pufpuf count starts to increase monotonically about 36 hours before the earthquake and then to decrease about 3 hrs just before the earthquake. Furthermore, a very large pufpuf activity occurs 19 hrs before the earthquake. The electric potential has distinct anomalous response, which is similar to the pufpuf count. The electric shows a bay-like response starting about 11 hrs before the earthquake. Figure 15 shows the projection of electric potential on the horizontal space. The vectorial response clearly indicated the anomalous signal was originating from a region southwest to the Koseto station. This is also a very remarkable observation.

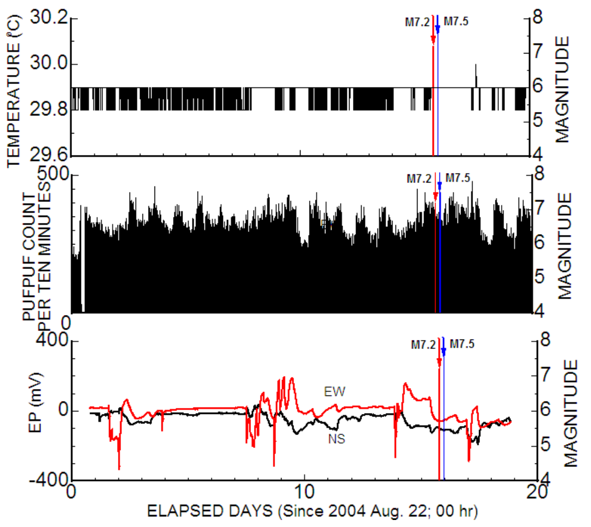

Figure 14: Multi-parameter variations at Koseto station

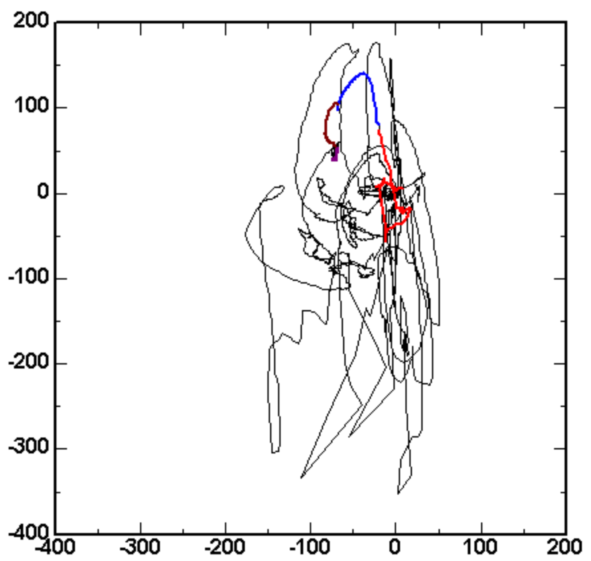

Figure 15: Projection of electric potential variation in horizontal space

5.4 Responses in Relation to 2007 Noto-hanto and Kameyama Earthquakes

2007 Noto-hanto earthquake occurred in The Noto Peninsula (Noto-Hanto) earthquake occurred at 9:42 on JST on March 25, 2007 and it had a magnitude (Mj) of 6.9 (Mw 6.7) on the magnitude scale of Japan Meteorological Agency. The earthquake killed one person and injured more than 250 people. This earthquake is about 150km north-west of the Koseto Station.

The Kameyama earthquake earthquake occurred at 12:19 on JST on April 15, 2007 and it had a magnitude (Mj) of 5.3 (Mw 5.0) on the magnitude scale of Japan Meteorological Agency. The earthquake injured 12 people and caused some structural damage. This earthquake is about 120km south-west of Koseto station.

Figure 16 shows the variations of air pressure, pufpuf count and electric potential at Koseto station together with that air pressure variation measured at Mitake. Regarding the air pressure, it is of great interest that the earthquakes occurred during or just after a great reduction of air pressure. It is well known that there are some speculative observations about the anomalous feeling of people and animals before the earthquakes. Although it is early to draw any conclusion about this observation, this monitoring result might be a quantitative explanation to this phenomenon.

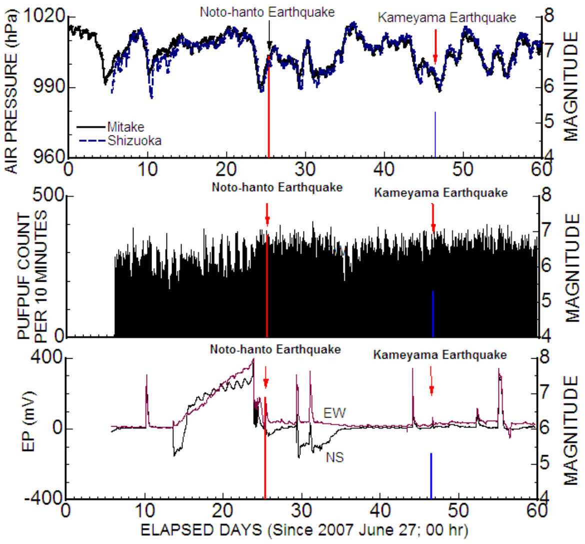

Figure 16: Multi-parameter variations at Mitake and Koseto stations

The pufpuf count and electric potential variations show very similar responses to those presented before. The increase of pufpuf count before the earthquake and subsequent decrease just before the earthquake are clearly distinguished. The rapid variation of electric potential is very distinct 38 hours before the Noto-hanto earthquake. Nevertheless, the variation before the Kameyama earthquake is not apparent. This may be associated with the magnitude of the respective earthquakes. Furthermore, the co-seismic electrical potential variations were noted during the both earthquakes.

5.5 Responses in Relation to 2007 Chuetsu-oki Earthquake

The earthquake with a local magnitude of 6.8 (Mw 6.6) occurred near the off-shore of Kashiwazaki City in Niigata Prefecture. The nuclear power plant of Kariwa-Kashiwazaki is the largest one in the world and it received great attention worldwide.

There was well-marked relations between the main shock and the variations of the multi-parameters measured as seen in Figure 17. Large variations took place before the event. These variations started approximately 4-5 days before the main shock. One of the most striking feature was the variation of air pressure simultaneously at stations in Shizuoka and Gifu Prefectures, which are about 300km away from each other. The temperature variations at Koseto hot-spring of Shizuoka Prefecture was quite small and no remarkable change was noticed at this station. The electric potential variation also indicated that the signals were originating from a location north-east of the Koseto station.

5.6 Responses in Relation to 2008 Wenchuan (China) Earthquake and 2008 Iwate-Miyagi Intraplate (Japan) Earthquake

2008 Wenchuan earthquake with an estimated magnitude of 7.9 struck Wenchuan county in Tibet at 2:28 p.m. local time (06:28 UTC) on May 12, 2008. The quake was felt throughout much of Asia, as well as parts of Taiwan, Thailand, and Vietnam. The earthquake caused widespread damage to buildings, transportation facilities, industrial plants and large-scale slope failures in the earthquake-affected area as well as huge number of casualties. Approximately after one month, 2008 Iwate-Miyagi intraplate earthquake with a magnitude of 7.2 took place in Japan. This earthquake also caused heavy damage in mountainous areas.

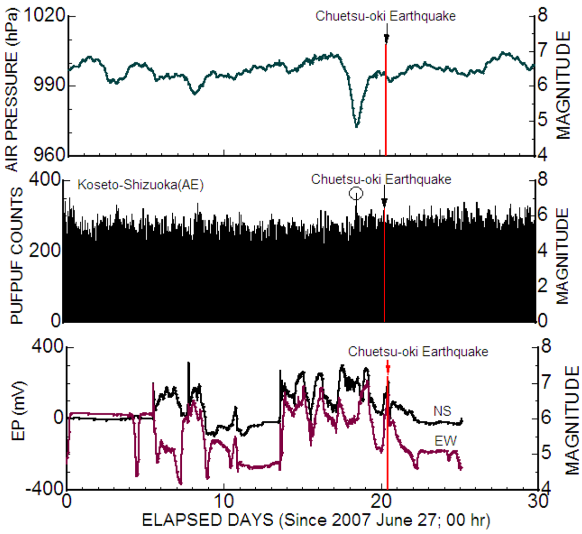

Figure 17: Multi-parameter variations at Koseto station

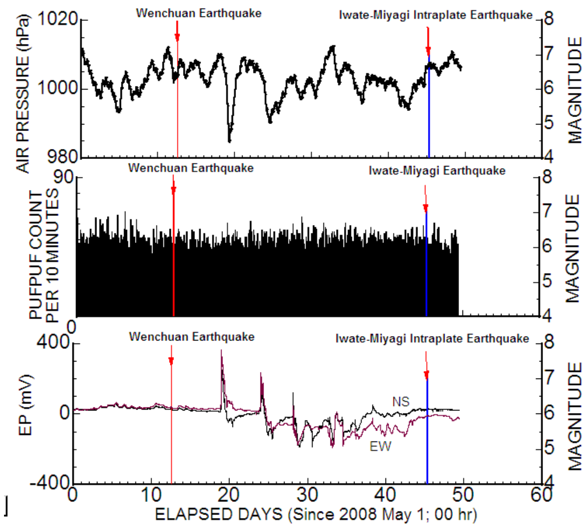

Figure 18: Multi-parameter variations at Koseto station

Figure 18 shows the multi-parameter responses at Koseto station during a period of 60 days. It is also great interest that air pressure shows bay-like reduction before the earthquakes and then attains its original value. The pufpuf counts show a similar response observed during other earthquakes. Nevertheless, the amplitudes of variations are much smaller. This may be related to the magnitude as well as the distance of the earthquakes with respect to the location of Koseto station.

No distinct variation of parameters shown in Figure 18 in relation to the 2008 Wenchuan earthquake was observed. Nevertheless, some variations were observed in relation to the 2008 Iwate-Miyagi intra-plate earthquake. There are multiple variations of electric potential before the Iwate-Miyagi intra-plate earthquake. These variations are related to other earthquakes nearby. In addition, some co-seismic electric potential variations were observed during the both earthquakes although their amplitudes were small.

CONCLUSIONS

The authors first described the installation of a crustal multi-parameter measurement station at Koseto hot spring in Shizuoka and its characteristics following a brief presentation of multi-parameter responses of rocks in laboratory experiments. Then the measurements taken before, during and after large earthquakes in Japan and worldwide were presented and their interrelations with these large earthquakes and other small earthquake activities were discussed. There were distinct variations pufpuf count, electric potential, and temperature in relation to earthquakes. Bay-like large electric potential variations did occur before each earthquake mentioned in this article. Furthermore, some of electric potential variations may be interpreted as seismic electric signals (SES), occurred several hours before the main shocks. The fluctuations are in the order of 150-350 mV for the 20cm spacing of electrodes. The response of the pufpuf count at Koseto station before earthquakes resembles to those observed in Tekkehamam station in Western Turkey (Kumsar et al., 2003). The variation of temperature of Koseto hot spring station is not distinct. The reason may be associated with the source of temperature of the hot spring, which mainly results from the temperature gradient of crustal rock rather than natural rock fractures in communication with the hot spots of the earth's crust. The triggering of earthquakes is closely associated with moon phase and the distance from the earth. The large thrust type faulting occurs when the attraction of the moon is greatest. Although the number of earthquakes and measurement period are still limited, a fairly good correlation exist with the crustal multi-parameter observations and earthquake activities and these preliminary results are very promising.

ACKNOWLEDGEMENTS

The authors would like to sincerely thank Bijinyu Spa Corporation (Shizuoka) for allowing the authors to establish the station at their Koseto hot spring site and Prof. Y. Kim for informing the first author of the existence of Koseto hot-spring. The authors also would like to acknowledge Japan Highway Public Corporation, in particular, former chief engineer K. Ohkubo for generous supports and graduate students Mr. Y. Ogura, M. Daido and Y. Ohta of Tokai University for the help during the installation and operation of the equipments. Prof. H. Kumsar (Vice Rector of Pamukkale University) is sincerely acknowledged for his long-term collaboration with authors and providing data from Tekkehamam station in Denizli province of Turkey.

REFERENCES

Aydan, Ö. (1997). The seismic characteristics and the occurence pattern of Turkish earthquakes. Turkish Earthquake Foundation, Report No.: TDV/TR 97-007, 41p.

Aydan (2001). Comparison of suitability of submerged tunnel and shield tunnel for subsea passage of Bosphorus (in Turkish). Geological Engineering Journal, 25(1), 1-17.

Aydan, Ö. ve Ulusay, R. (2000). Is it possible to predict earthquake? Anomalous phenona. (in Turkish). Mavi Gezegen, No.3, 78-90.

Aydan, Ö., Sezaki, M., and Yarar, R., (1996). The sesimic characteristics of Turkish Earthquakes. 11th World Conference on Earthquake Engineering, Acapulco, Mexico, CD-2, Paper No. 1025.

Aydan, Ö, H. Kumsar, R. Ulusay, H. Tano (2001): Is there a relation between the temperature changes of thermal waters in Denizli region and the earth crust at the Denizli fault zone. *Jeoteknik III : İzmir ve Çevresinin Jeoteknik-Deprem Sempozyumu*, Bildiriler CD'si, 14s. ISBN 975-395-491-3.

Aydan, Ö., T. Minato & M. Fukue (2001). An experimental study on the electrical potential of geomaterials during deformation and its implications in Geomechanics. 38th US Rock Mechanics Symposium, Washington, Vol.2, 1199-1206.

Aydan, Ö., N. Tokashiki, T. Ito, T. Akagi, R. Ulusay, H.A. Bilgin (2003). An experimental study on the electrical potential of non-piezoelectric geomaterials during fracturing and sliding, 9th ISRM Congress, South Africa, 73-78.

Aydan, Ö. and Tano, H. (2003). Multi-parameter measurement system at Koseto (Shizuoka) and its response during the M8.3 Tokachi-oki earthquake of 2003. Int. Colloquium on Instrumentation and Monitoring of Landslides and earthquakes in Japan and Turkey, Koriyama, (Edited by H. Tano and Ö. Aydan), 101-110.

Aydan, Ö., Kumsar, H., Tano, H. (2005a). Multi-parameter Changes in the Earth's Crust and Their Relation to Earthquakes in Denizli Region of Turkey. World Geothermal Congress 2005, Antalya, Paper No.1804.

Aydan, Ö., Daido, M., Tano, H., Tokashiki, N., Ohkubo, K., (2005b). A real-time multi-parameter monitoring system for assessing the stability of tunnels during excavation. *ITA Conference*, Istanbul, 1253-1259.

Aydan, Ö., Daido, M., Tokashiki, N., Bilgin, A. and Kawamoto, T. (2007). Acceleration response of rocks during fracturing and its implications in earthquake engineering. 11th ISRM Congress, Lisbon, Vol.2, 1095-1100.

Hamada, M., Hakuno, M., Iwatate, T., Enomoto, J., Kiyono, J., Aydan, Ö, Shimo, K, Kapoor, C.M. (2001): The 2001 Kutch Earthquake, Gujarat State, India: Investigation into Damage to Civil Engineering Structures. Earthquake Damage Investigation Series 7, Earthquake Engineering Committee, Japan Society of Civil Engineers, June.

Kumsar, H., Aydan, Ö., Tano, H. and Ulusay, R. (2003): A multi-parameter measurement system in Denizli and its response during July 2003 Buldan earthquakes. Int. Colloquium on Instrumentation and Monitoring of Landslides and earthquakes in Japan and Turkey, Koriyama, 69-81.

NIED (2003): http://www.bosai.go.jp/

USGS-NEIC (2003): http://neic.usgs.gov/.