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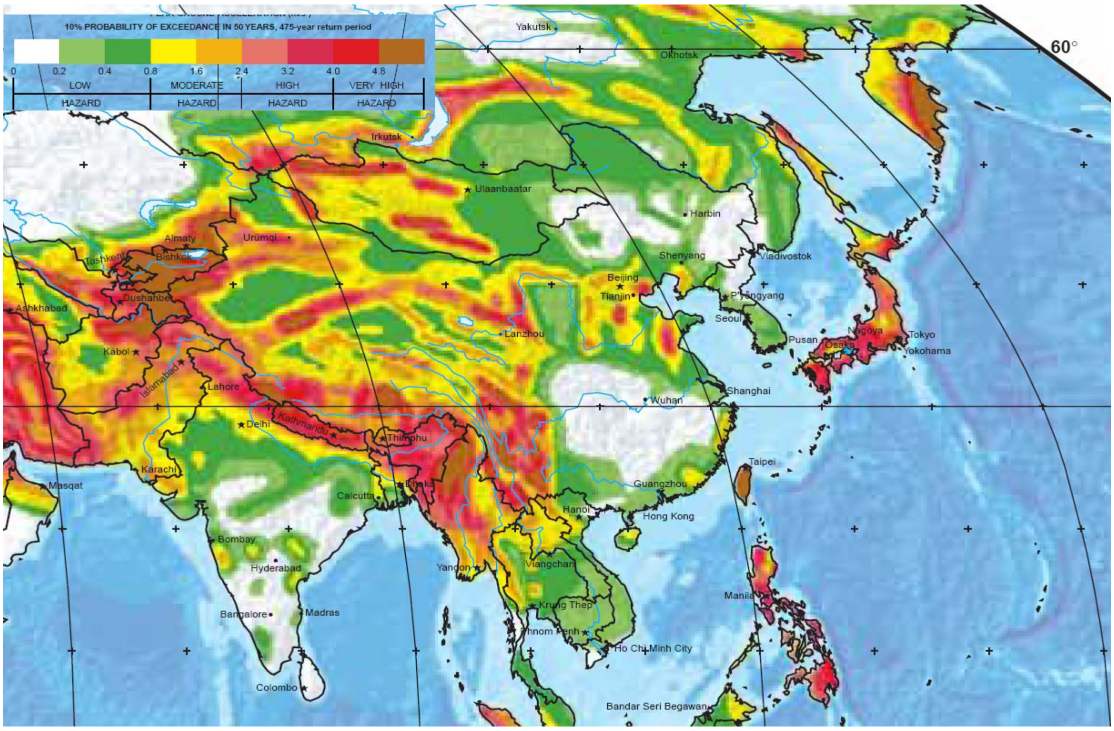
August 13, 2013
National Cheng Kung University, Tainan, Taiwan

Edited by Chjeng-Lun Shieh, Naoji Koizumi and Norio Matsumoto



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DP RC Disaster Prevention Research Center
National Cheng Kung University

No.1,Ta-Hsueh Rd. Tainan 701, Taiwan

GEOLOGICAL SURVEY OF JAPAN
NATIONAL INSTITUTE OF
ADVANCED INDUSTRIAL SCIENCE AND TECHNOLOGY（AIST）
1-1 Higashi 1-Chome, Tsukuba, Ibaraki, 305-8567 Japan
2015

12th Taiwan - Japan International Workshop on Hydrological and Geochemical Research for Earthquake Prediction

August 13, 2013
National Cheng Kung University, Tainan, Taiwan

Organizer:

Disaster Prevention Research Center, National Cheng Kung University

Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology

Sponsor：

Earth Science Research Promotion Center, National Sciences Council

Water Research and Development Center

Taiwan Disaster Prevention Society

Preface

Both of the NCKU-DPRC (the Disaster Prevention Research Center, National Cheng Kung University, Taiwan) and the IG-GSJ (Institute of Geoscience, Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology) were agree to pursue scientific and technical cooperation about hydrological and geochemical research for earthquake prediction in Taiwan in February 2002.

Follow the cooperation agreement, DPRC-NCKU and IG-GSJ intend to carry out cooperative research activities on (1) Investigation of groundwater anomalies associated with the earthquake in Taiwan; (2) Analysis of the natural groundwater level changes in correlation to the geotectonic and meteorological activities; (3) Improving methodologies in monitoring and studying the groundwater anomalies with respect to geotectonic activities and/or other aspect as well; (4) Compiling the future periodically-monitored information of groundwater chemical and physical properties, and geotectonic anomalies; and(5) Analysis of the groundwater anomalies as earthquake precursors.

The 1st International Workshop on Hydrological and Geochemical Research for Earthquake prediction had held on Sep. 24, 2002 at GSJ, AIST, Tsukuba, Japan. The workshop had good beginning to promote the research cooperation between Japan and Taiwan. The main purpose of the workshop this time is proceeded to collaborate, and provide an opportunity to share the precious experience with other researchers. In total, seventeen papers will be presented in this workshop.

Although the earthquake prediction is a hard scientific challenge in the century, keeping on study and making any kind of approach are the better way to contribute earthquake hazard mitigation. We hope that this workshop will offer the good ideas and experiences for related work. In view of these sincerely cooperation, we absolute believe that will help us to preserve more safety for our life.

August 2013
Chjeng-Lun Shieh and Naoji Koizumi

12th Taiwan - Japan International Workshop on Hydrological and Geochemical Research for Earthquake Prediction, Workshop Program

(August 13, 2013)

【 Aug.13 】 Place: International Conference Room, National Cheng Kung University

Place	Time	Program		
International Conference Room	09:10~09:30	Registration		
	09:30~09:40	Opening Ceremony		
	Time	Speaker	Title	Coordinator
	09:40~10:05	Mamoru Nakamura	Fault parameter of large historical earthquakes in the 18th century along the Ryukyu Trench from central Ryukyu to Taiwan	Director Shieh
	10:05~10:30	Jiun-Yee Yen	Introduction to E-TEC-Combination (Cocktail) Therapy for Earthquake Precursor Research in Taiwan	
	10:30~10:55	Masataka Ando	A possible tsunami source based on tsunami folklore and interview with local residents on the eastern coast of Taiwan	
	10:55~11:10	Coffee Break		
	11:10~11:35	Chih Yen Chen	Rainfall and Groundwater Effects on Borehole Strain	Prof. Ando
	11:35~12:00	Masayuki Murase	An episodic creep slip event detected by precise levelling surveys at the central part of the Longitudinal Valley Fault, eastern Taiwan, in 2011-2012	
	12:00~12:25	Kate Huihsuan Chen	Fault strengthening after the 1999 M7.6 Chi-Chi earthquake	
	12:25~13:30	Lunch Time		
	13:30~13:55	Naoji Koizumi	Detection of short-term slow slip events along the Nankai Trough by groundwater observation	Dr. Koizumi

Place	Time	Program		
	13:55~14:20	Chieh-Hung Chen	Possible Relationships between Seismo-EM and Crustal Anomalies	
	14:20~14:45	Vivek Walia	Application of Soil Radon Monitoring for Earthquake Surveillance Studies in Taiwan	
	14:45~15:10	M. C. Tom Kuo	Earthquake precursors observed from long-term radon measurements in eastern Taiwan	
	15:10~15:30	Coffee Break		
	15:30~15:55	Kuo-Chon Hsu	The directional sensitivity of groundwater level variation to earthquake	Dr. Lai
	15:55~16:20	Mayumi Higa	Groundwater level changes by seismic ground motion of the 1999 Chi-Chi earthquake	
	16:20~16:45	Pei-Ling Wang	Studies on Mechanisms of coseismic sustained groundwater-level changes	
	16:45~17:10	Wen-Chi Lai	The Mechanism of the Pre-seismic Changes of the Tidal Deviation of Groundwater Level in Hualien City, Taiwan	
	17:10~17:35	Chjeng-Lun Shieh	Discussion & Closing Remark	

Content

Fault models of historical tsunamis between the Ryukyu Trench region and east Taiwan

Mamoru Nakamura*, Ayano Kinjou, and Yasuhisa Arashiro
Faculty of Science, University of the Ryukyus

The risk of great earthquakes and tsunamis has been assumed to be low between the Ryukyu Trench and eastern Taiwan region because the interplate coupling is weak and great interplate earthquakes (> M8.0) had not been recorded historically for about 300 years. However, recent study revealed that the 1771 Yaeyama earthquake (M8.5 from tsunami heights distribution) at south Ryukyu Trench and the 1911 Kikaijima earthquake (M 8.0) at north-central Ryukyu Trench were the interplate earthquakes. We need re-examine the great historical and pre-historical earthquakes from Ryukyu to Taiwan.

Two historical tsunamis which occurred on 1768 and 1791 in the Okinawa Island were documented in the old document “Kyuyo” (formal chronicles of Ryukyu). I investigated the source fault model of two tsunami events using numerical simulations of tsunami and earthquake shaking, and showed that their events would be the interplate earthquakes.

One earthquake occurred at noon of July 22th, 1768. The rock-walls of castle, grave of royal family were collapsed by the earthquake shaking in Shuri area, Naha, Okinawa Island. The rock-wall of temple was damaged in Urasoe. After the shaking tsunami arrived Naha port and Zamami Island. Recorded tsunami heights were about 1 m at Naha port. Nine houses and rice fields were damaged by the inundation of the tsunami in the Zamami Island. Estimated tsunami heights were 4-5 m in Zamami Island. The numerical modeling of tsunami and the estimation of earthquake shaking using empirical formula were employed, and the fault parameters of the 1768 earthquake were estimated. The faults were set to Okinawa Trough (M7.5 normal faults), Kerama Gap near Zamami Island (M7.5 normal faults), south of Zamami Island (M7.5 reverse fault), and Ryukyu Trench (M8.0 thrust faults). The computed tsunami heights and intensities of ground shaking of the M7.5 reverse fault near the Zamami Island and the M8.0 interplate earthquake models are consistent with to the recorded ones.

Another tsunami was also recorded in the “Kyuyo”. The abrupt abnormal increases of sea-level were recorded in the Okinawa Island on May 13th, 1791. The recorded tsunami heights were 1.5 m at Naha port, 2 m at Motobu (western coast of Okinawa Island), and 11 m at Yonabaru (eastern coast of Okinawa Island). Large historical earthquakes have not been reported around the Pacific Ocean in this period. The numerical simulation of tsunami was employed to estimate the fault parameters of the 1791 tsunami. The computed tsunami heights of the M8.0-8.3 interplate earthquake model, whose top is along the Ryukyu Trench, are consistent with the recorded ones. The arrivals of tsunami without earthquake shaking suggest that the 1791 tsunami would be the tsunami earthquake which occurred near the Ryukyu Trench.

Another investigation for the historical tsunami was held in the eastern Taiwan region. Although the eastern Taiwan region is convergent plate boundary where the collision of Philippine Sea plate and Eurasian plate is ongoing, occurrence of M 7.5 earthquakes are estimated from the distribution of the sea floor active faults. Few damages by historical tsunamis were reported in the old documents in Taiwan, whereas folklore about tsunami damage remains in the east part of Taiwan and Lanyu Island, southeast of Taiwan. However, large boulders, which consist of fragments of coral reef and were moved by inundation of tsunamis or storm waves, are distributed on the shore of Lanyu Island.

We surveyed the distribution of boulders in the shore of Lanyu Island, and investigated whether the boulders were moved by tsunamis or storm waves. Almost boulders are distributed in the north and east coast of the Lanyu Island. The maximum size of boulder is 6.4m x 6.1m x 2.9m. We calculated the flow velocities that can transport the boulders. The calculated flow velocities are from 3.0 m/s to 8.0 m/s. Almost boulders are distributed within 100 m apart from the shore. The inundation by the storm waves, whose wave heights (13.0 m) are estimated from the 50 years probability, is limited within 100 m from the shore. Almost boulders would have been transported by the storm waves. However, a boulder in the southeastern Lanyu Island is located on the lower terrace (altitude 7.4 m) which is 126 m apart from the shore, where the storm waves do not reach. This suggests that the boulder would have been transported by tsunami. The computed tsunami heights at the southeastern Lanyu Island are about 2.0m when we set the source fault in the east of Lanyu Island (M7.8) and southwest Ryukyu Trench (M8.2). The computed tsunami height at the southeastern Lanyu Island is 5.0 m when the source fault is in the west of Lanyu Island (M7.8). Thus, the M7.8 earthquake in the west of Lanyu Island would be the cause of the tsunami which transported the boulder at the southeast Lanyu Island.

Introduction to E-TEC-Combination (Cocktail) Therapy for Earthquake Precursor Research in Taiwan

Wen-Yen Chang, Jiun-Yee Yen, Meng-Che Wu

Eastern-Taiwan Earthquake Research Center,
College of Environmental Studies, NDHU

Abstract

The island of Taiwan is located at the complicated boundary between Eurasian plate and Philippine Sea plate. Eastern part of Taiwan where strong convergence has taken place between two plates has strong seismic activity, particularly along the Longitudinal Valley that is a suture zone between both plates. Taiwan has been known as an excellent natural laboratory characterized by rapid active tectonic rate and high dense seismicity.(Fig.1)

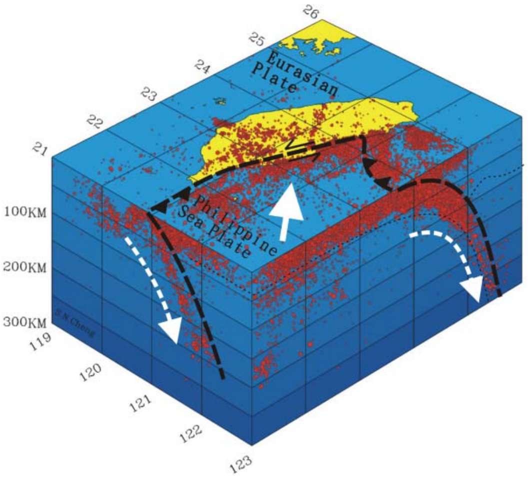
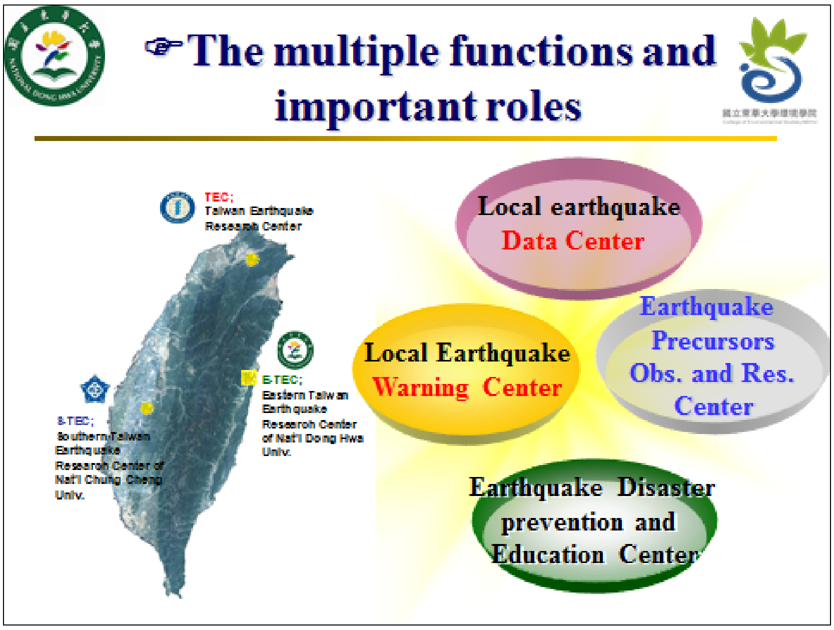


Figure1. Tectonic and seismicity of Taiwan

After Chi-Chi earthquake in 1999, Taiwan government has launched many programs of earthquake research and strengthened many kinds of observation instruments. The E-TEC aims to provide an integrated platform for researchers and scientists to conduct the new advances and researches on earthquake precursors and early warning for seismic disaster prevention in the eastern Taiwan. There are multiple functions and important roles of this center. (Fig.2)



☞The multiple functions and important roles

TEC;
Taiwan Earthquake
Research Center

S-TEC;
Southern Taiwan
Earthquake
Research Center of
Nat'l Chung Cheng
Univ.

E-TEC;
Eastern Taiwan
Earthquake
Research Center
of Nat'l Dong Hwa
Univ.

Local earthquake
Data Center

Earthquake
Precursors
Obs. and Res.
Center

Local Earthquake
Warning Center

Earthquake Disaster
prevention and
Education Center

Figure2. The multiple functions and important roles of E-TEC.

We intend to integrate the multi-disciplinary observations including seismicity, GPS, strain-meter, ground water, geochemistry, gravity, electromagnetic and ionospheric density, and infrared remote sensing etc., and to collaborate with Central Weather Bureau (CWB), National Center for Research on Earthquake Engineering (NCREE), National Science and Technology Center for Disaster Reduction (NCDR), Institute of Earth Science of Academia Sinica (IES, AS) and the other institutions (NCU, NTU, CCU). We also propose the combination observation for earthquake precursor and intend to cooperate with NCU, IES and NTU to install natural electric potential instrument in 30-meters-deep borehole, Gamma radiation detector and Radon, CO2 detectors in soil that will integrate multiple observatory experiment for earthquake precursor research in NDHU's campus. (Fig.3)

As is the case with many earthquake precursor researches, the timing is the key to success of E-TEC. The center will be established and officially inaugurated this year. From combination observation and multidisciplinary integration, E-TEC integrated platform and different instruments that are co-site will give us unparalleled opportunity to study earthquake precursors and have great opportunity to develop "Evaluate Anomaly System Automatically (EASA)" in Hualien where is strong seismic activity. Earthquake prediction may not be done by seismologist or Earth Scientist in the future, we deeply hope it will be approached, eventually by space physicist, EE, remote sensing scientist or others.

Integrated information platform and establishment of observation experiment for earthquake precursors

Figure3. The E-TEC and multiple observatory experiment in NDHU.

A possible tsunami source based on tsunami folklore and interview with local residents on the eastern coast of Taiwan

Masataka Ando*
Institute of Earth Sciences, Academia Sinica, Taiwan

According to folklore, a high sea wave struck the Pacific coast of Chenggong on the eastern coast of Taiwan. Because the site is 18 m above sea level. and 400 m inland from the coast, the wave is thought to have been a tsunami. This event may have happened in the middle of the 19th century. However, there is no record of such a tsunami outside of Chenggong. Numerical simulations were carried out on the basis of three tsunami source models, which are located 1) in the westernmost portion of the Ryukyu trench, 2) offshore of Chenggong and 3) at the source of the 1771 Yaeyama tsunami along the Ryukyu trench (Ando et al., 2013). Model 1 produces too large tsunami amplitudes on the islands of Ishigaki and Miyako, which is inconsistent with the written history on the islands. Model 3 generates too small tsunami heights on the western coast of Taiwan to explain the Malaulau folklore. We excluded these two models for the Malaulau event. On the other hand, Model 2 fits to the tsunami heights along the eastern coast of Taiwan, particularly around Chenggong (Fig. 1, Ando et al., 2013). However, it is still inconsistent with the written history recorded in the western half of Taiwan where it was already populated in the middle of the 19th century and oral history recorded in the eastern cost of Taiwan. This model is also excluded for the Malaulau model. Based on our recent result of interview with local residents on the islands of Lu and Lanyu and the western coast of Taiwan, we propose a new model that a local submarine slide or offshore faulting (M<7.5) occurred off Chenggong and a limited area were struck by tsunami amplitudes. However, little evidence of detailed bathymetric data supporting this idea is available. Further studies of geological tsunami deposits and the submarine topography are required to understand the future tsunami risk on the eastern cost of Taiwan.

References

Ando, M, M., Nakamura and C.-H. Lin, 2013, Tsunami folklore and possible tsunami source on the eastern coast of Taiwan, Terr. Atom. Ocean. (in press).

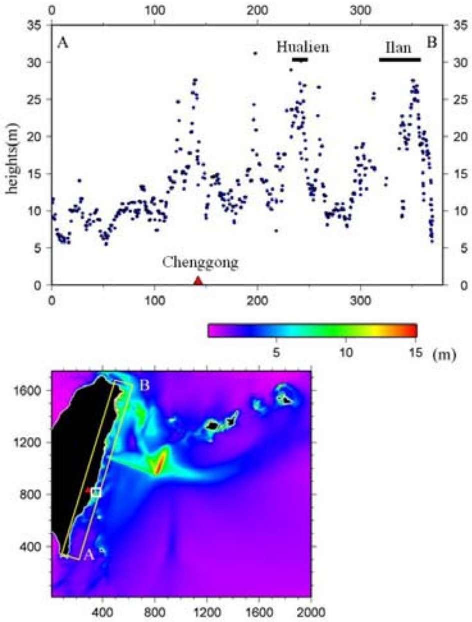


Fig. 1. The maximum tsunami height at each coastal grid point within the box A - B (top) and at each sea-bottom grid point (bottom), calculated from Model 1 for times of 0 to 3600 s with a grid interval of 250 m and using non-linear wave equations. The numerals on the frame are grid numbers counted from the southwestern corner. The small white square depicts the area, in which the nonlinear dispersive wave equations are used. The tsunami heights are given in the color bar.

An episodic creep slip event detected by precise levelling surveys at the central part of the Longitudinal Valley Fault, eastern Taiwan, in 2011-2012

Masayuki Murase*[1], Nobuhisa Matta[2], Cheng-Hong Lin[3], Wen-Shan Chen[4]，Naoji Koizumi[5]

1. Department of Geosystem, College of Humanities and Sciences, NIHON University: 3-25-40, Sakurajosui, Setagaya-ku, Tokyo 156-8550, Japan
2. Graduate School of Environmental Studies, Nagoya University: D2-1(510), Furo-cho, Chikusa-ku, Nagoya 464-8601, Japan
3. Institute of Earth Sciences, Academia Sinica: No. 128, Sec. 2, Academia Rd., Nankang, Taipei 11529, Taiwan (R.O.C.)
4. The National Taiwan University: No. 1, Sec. 4, Roosevelt Road, Taipei, 10617, Taiwan (R.O.C.)
5. The National Institute of Advanced Industrial Science and Technology, 1-1-1 Umezono, Tsukuba, Ibaraki 305-8568, Japan

Precise levelling surveys were conducted across the central Longitudinal Valley Fault, eastern Taiwan, to understand the deformation of the transition zone between the stable fault creep area and the asperity area. In order to investigate the surface relationship between the fault creep area and the geological condition of the transition zone, we established levelling routes in the Yuli, Chike-san, and Reishuei areas. The Yuli area forms the geological boundary of the Lichi Melange Formation, which is composed of chaotic mudstones containing numerous exotic blocks of various sizes and lithologies. Along the Yuli route, located on the Lichi Melange, an uplift rate of 30 mm/yr was detected during the period 2010–2012, suggesting that aseismic fault creep might be continuing with long-term stability. Along the Chike-san route, a vertical deformation rate of 8 mm/yr was detected in the period 2010–2011(Fig.1). However, a large deformation with an uplift rate of 40 mm/yr was detected in the period 2011–2012(Fig.1). Along the Reisuei route, we detected a deformation of 8 mm/yr in the period 2011–2012.

A two-dimensional single-fault model was developed to discuss the slip distributions in the periods 2010–2011 and 2011–2012 in Chike-san area (Fig.2). Relatively large slip rates were estimated at two parts of the fault plane—one at a depth of ~1.5 km and another at a depth of ~4 km—in both periods(Fig.2b). Because both parts of the fault plane show approximately the same slip distribution, we believe that the detected deformation resulted from an episodic acceleration event of creeping slip.

The northern limit of the stable creep area may be the Yuli area. The episodic creep event occurred in the transition zone between the stable fault creep area and the asperity area. The boundary between the stable creep area and the episodic creep area is consistent with the geological boundary of the Lichi Melange Formation.

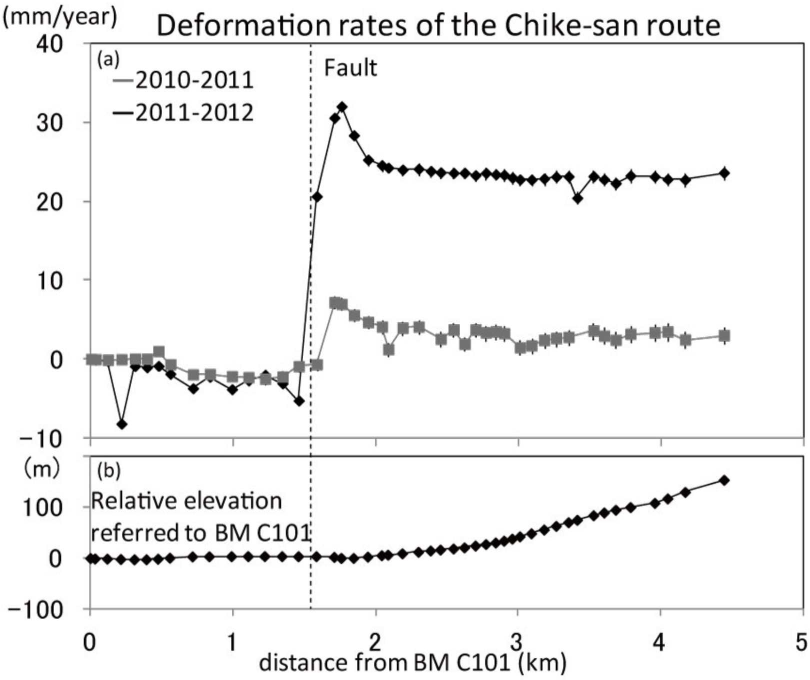


Fig. 1. (a): Vertical deformation of the Chike-san route detected by precise levelling. Gray and black lines denote vertical deformations from 2010 to 2011 and from 2011 to 2012, respectively. The reference point is BM C101. Error bars denote the accumulated closing errors from BM C101. The dashed line denotes the location of LVF in the Chike-san route. (b): The route profile by the precise levelling survey. Relative elevations of the benchmarks in the Chike-san route are referred to BM C101.

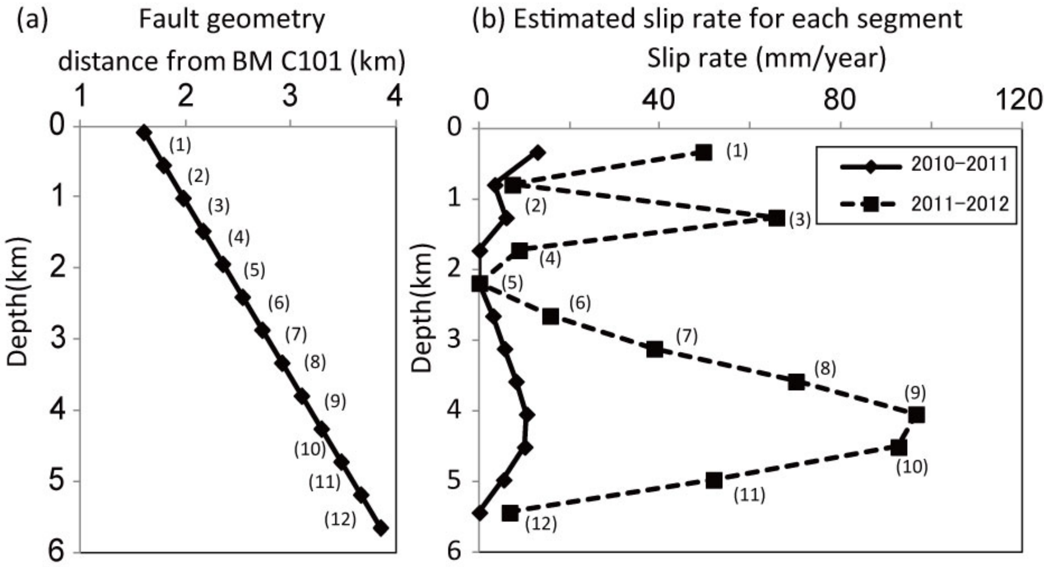


Fig. 2. (a) Depth profile of the 12 sub-faults. The black line denotes the geometry of the optimal fault model. The diamonds denote the breakpoints of sub-faults. The sub-faults are numbered from 1 to 12. (b) Slip distribution of the 12 sub-faults for the periods from 2010 to 2011 and from 2011 to 2012. The solid line denotes the estimated slip distribution of the 12 sub-faults in the period from 2010 to 2011, and the dashed line denotes the estimated slip distribution of the 12 sub-fault in the period from 2011 to 2012.

Detection of short-term slow slip events along the Nankai Trough by groundwater observation

Yuichi Kitagawa[1] and Naoji Koizumi*[1]
1.AIST, Geological Survey of Japan, Active Fault and Earthquake Research Center

Nonvolcanic deep low-frequency (DLF) tremors are detected on plate boundaries along many subduction zones around the world. Episodic slow slip events (ESSEs), which cause small crustal deformation with no seismic waves, are also detected in the subduction zones. There is a spatial and temporal correlation between DLF tremors and ESSEs. However ESSEs do not always occur in the areas where the DLF tremors occur and vice versa. Therefore it is important to clarify the detailed spatial and temporal correlation in order to know what occurs on the plate boundaries along the subduction zones. It will contribute to predicting large earthquakes in the areas. In general, detection capability of ESSEs by crustal deformation is much smaller than that of DLF tremors by seismogram. One of the reasons is that decay of crustal deformation by distance is much larger than that of seismic waves. Therefore it is necessary to develop tools or techniques for detecting ESSEs. ESSEs are generally detected by strainmeter or tilt meter and large ESSEs also can be detected by GNSS observation. However those observation tools for monitoring crustal deformation are generally expensive and are not always popular in the areas and countries near the subduction zones. On the other hand groundwater observation is popular in those areas and countries. If it is possible to detect ESSEs by groundwater observation, it will be useful for knowing the plate boundary situations and predicting the large earthquakes. Groundwater pressure or level is coupled with strain according to poro-elastic theory. It is known that groundwater pressure change is proportional to volumetric strain change under the undrained condition. In other words, we can estimate volumetric strain changes through observation of groundwater pressure or level.

The Active Fault and Earthquake Research Center, the Geological Survey of Japan, AIST, has a network composed of approximately 50 groundwater observation stations in and around the Tokai, Kinki, and Shikoku regions in Japan (Fig.1). At these stations, groundwater levels or pressures are continuously monitored. At 17 of the stations (N1-N16 and TYE in Fig.1), which are located in the areas faced to the Nankai trough, borehole strainmeters are also equipped. We have been monitoring ESSEs mainly using the data of the borehole strainmeters since 2007. Observation at ANO station (N14 in Fig.1) started in February, 2010. ANO has three observation wells (Fig.2). Two of them (Borehole 1 and Borehole 2) are artesian wells and the heads of the waters are higher than the surface. Therefore we sealed the two wells and monitor the groundwater pressures in the wells. Borehole 1 also has a borehole starinmeter at the depth of approximately 600m.

The active DLF tremors occurred near ANO on June 28, 2011. It continued several days. At ANO, crustal strains and groundwater pressures were changed from June 28 to July 1 in 2011 (Fig.3). At the same time, strains at the other stations near ANO were also changed. Based on those strain changes, the fault model for the ESSE was estimated under ANO. The fault model quantitatively explained the volumetric strain changes which were calculated from the groundwater pressure changes at Borehole 1 and 2. In other words, it shows that groundwater pressures at ANO can detect ESSEs . In the presentation we will also introduce the other examples and discuss about what are the conditions for detecting ESSEs by observation of groundwater pressure or level .

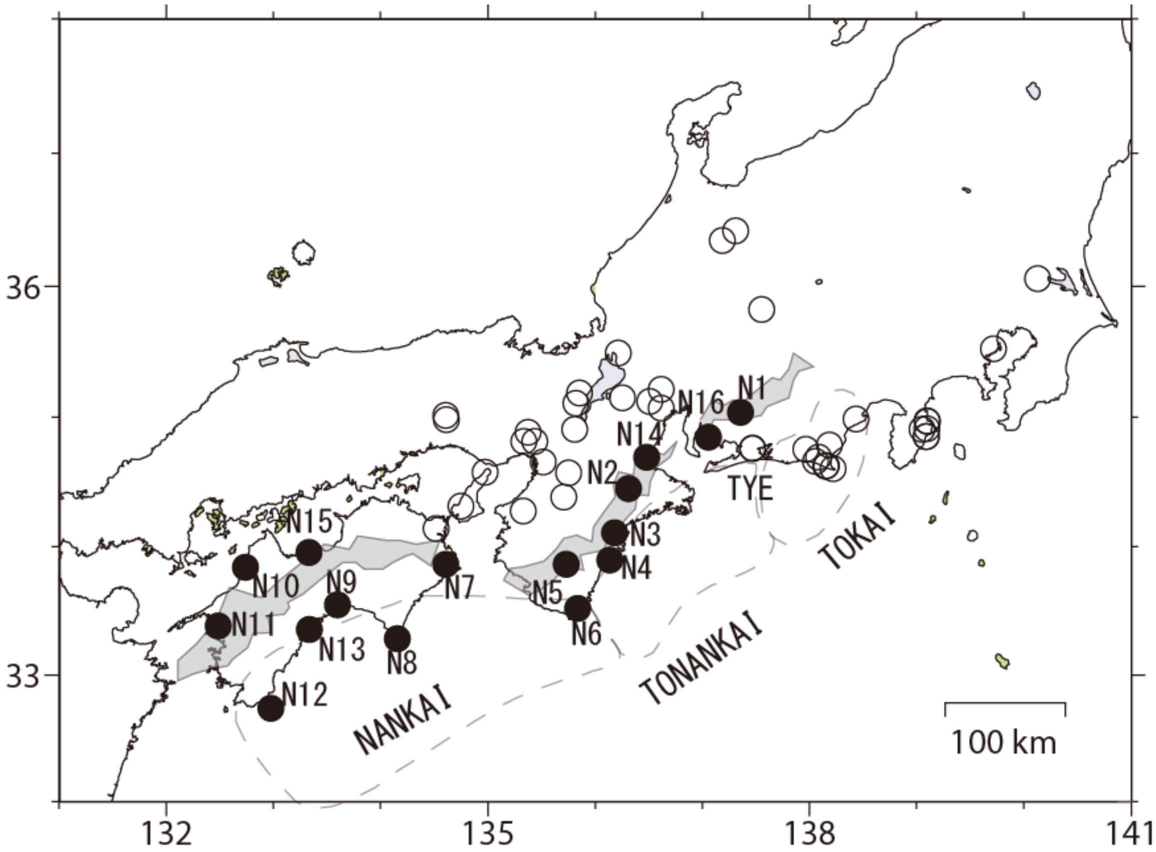


Fig. 1. Assumed focal region (dashed line) of the Tokai, Tonankai, and Nankai earthquakes along the Nankai trough and the AIST groundwater observation network for earthquake prediction research. Open circles are observation stations constructed before FY 2004. Solid circles are new observation stations N1-N16 constructed after FY 2006. N1-N16 and TYE also have a borehole strainmeter. The grey area in the inland area shows the region where the ESSEs and DLF tremors occur regularly. N14 is ANO station.

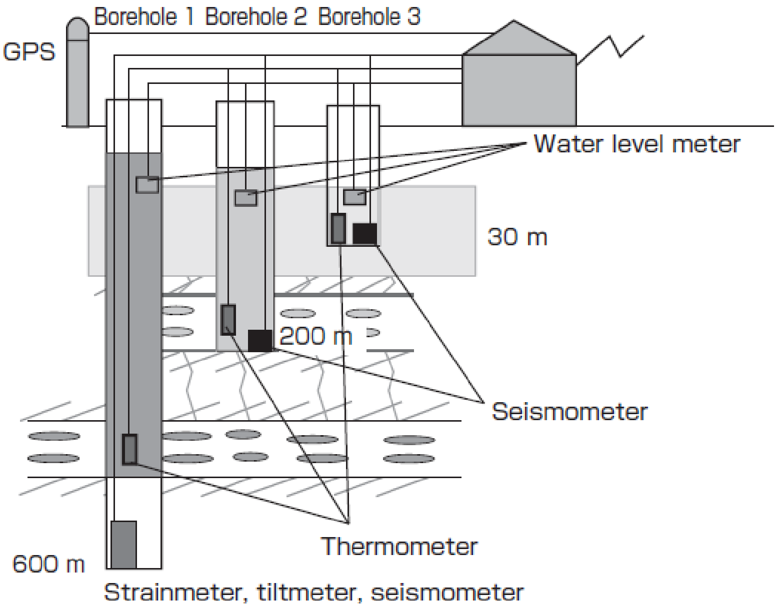


Fig.2 Schematic figure of the observation system at ANO. It is a typical observation system at N1-N16 stations.

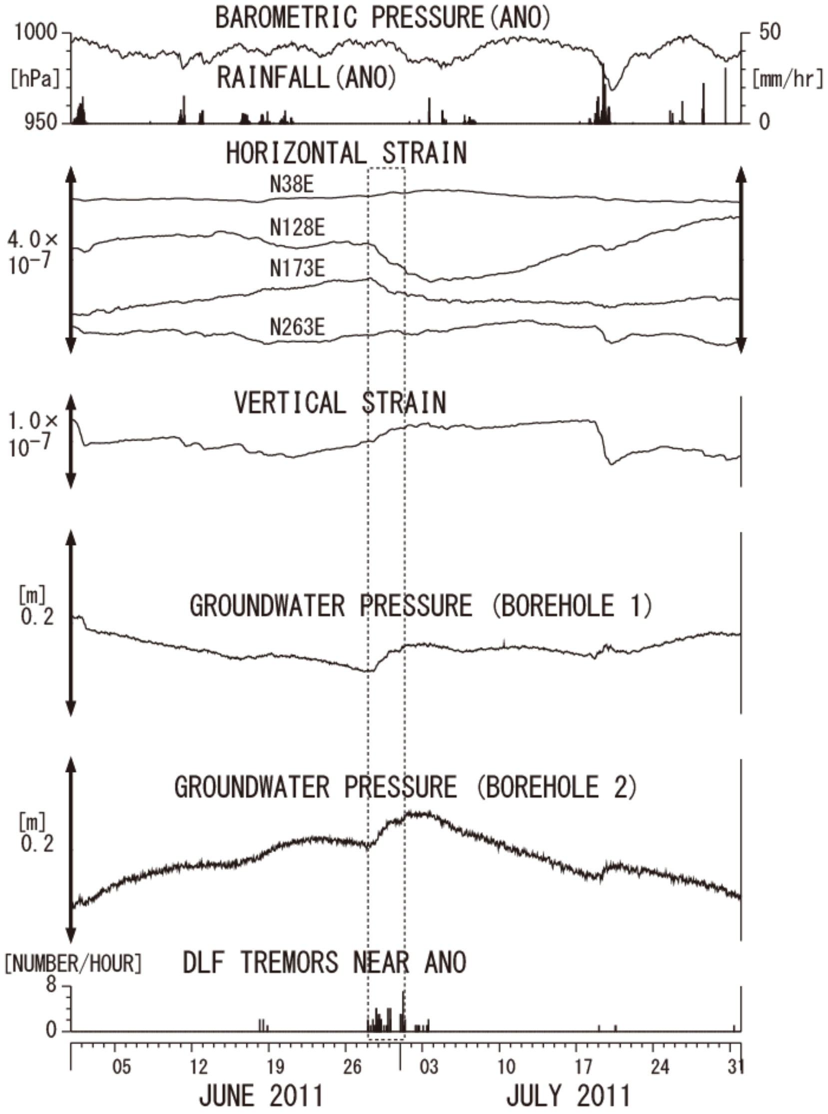


Fig.3 Groundwater pressures and crustal strains observed at ANO during the period from June 2011 to July 2011. DLF tremors near ANO are also shown. The tidal changes and barometric effects were eliminated from both of the groundwater pressures and the strains. In addition linear trends were eliminated from the strains and the rainfall effects were eliminated from the groundwater pressures.

Possible Relationships between Seismo-EM and Crustal Anomalies

Chieh-Hung Chen

Department of Earth and Environmental Sciences,
National Chung Cheng University, Chiayi 621, Taiwan

This study examines the relationships between surface displacements and conductivity changes during two M6 earthquakes (on 27 March and 2 June 20123) in Taiwan. Hilbert-Huang Transform is applied on surface displacement data to filter responses of noise, semi-annual and annual cycles as well as the long-term plate movements. Orientations of the residual displacements are oriented toward a similar direction as loadings of earthquake-related stress. When the loading stress approaches the threshold of the fault rupture, the orientations of the residual displacements generally become random in order, expect for small regions near the epicenters. It is interesting that high conductivity anomalies, which are detected by using the 3-component magnetic data via magnetic transfer function, appear in areas nearby the small regions. Agreements between high conductivity anomalies and surface displacements in the temporal and spatial domains suggest that electric charges would migrate toward and be trapped within the small regions due to discrepancy of the stress accumulation. Meanwhile, the gathered electric charges would form high conductivity materials affecting the geomagnetic field.

The directional sensitivity of groundwater level variation to earthquake

Yen-Ming Pan[1], Feng-Sheng Chiu[1], Wen-Chi Lai[2], Kuo-Chon Hsu[1]

[1] Department of Resources Engineering, National Cheng University
[2] Center of Disaster Prevention, National Cheng University

Abstract

Groundwater well response to earthquake is important to the research of earthquake hydrology. Understanding well sensitivity to earthquake improves the correct interpretation of groundwater fluctuation measurements. This research develops a procedure for the anisotropic analysis of well response to earthquakes. Donher well is located at southern Taiwan and is one of the most sensitive groundwater wells to earthquakes. Observation data of Donher groundwater well were used with a sampling rate of one data per second. Step-like groundwater level change was analyzed for near-field earthquakes. Earthquakes with magnitude greater than 4 occurring in April and December, 2006, January, 2007, October to December, 2009 and March, 2010 with epicenters located around Donher groundwater well within 150 kilometers and with depths from 0 kilometer to 30 kilometers were analyzed. A total of 34 earthquake events were used. Two-step analysis was adopted for studying the well response to earthquake. Step one constructs the correlation of the local energy to groundwater level. Step two relates source energy to local energy. Well sensitivity to earthquake is defined and anisotropic analysis is performed to detect the sensitive direction of the monitoring well. Results show that Donher groundwater well is sensitive to earthquake in the direction of N45°E using either empirical local energy relation or strain energy estimation. There is slight difference in the effective detection range. For the empirical approach is 119 kilometers in N45°E and 65 kilometers in S45°E . For the strain energy estimation, DonHer groundwater well is with an effective detection range of 117 kilometers in N45°E and of 56 kilometers in S45°E .

Key words: Earthquake, Step-like Groundwater level change, Earthquake sensitivity, Two-step analysis, Anisotropic analysis.

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Geochemical Research for Earthquake Prediction

Groundwater level changes by seismic ground motion of the 1999 Chi-Chi earthquake

Mayumi Higa*[1], Mamoru Nakamura*[2], Naoji Koizumi*[3]

1. Graduate School of Engineering and Science, University of the Ryukyus, Japan
2. Faculty of science, University of the Ryukyus, Japan
3. AIST, Geological Survey of Japan, Active Fault and Earthquake Research Center

The water level change during and after earthquake has been reported. However, there are some unknown factors about the causes of coseismic water level changes. One of the causes of coseismic water level change is static seismic changes (static strain change and vertical displacement). The other is dynamic seismic changes(dynamic strain changes and seismic ground motion). The static strain change is assumed as one of the main factor of the water level change from the comparison of water level change with static strain change in the earthquakes. However, the relation between water level change and dynamic strain change or seismic ground motion has not been known yet. Wang et al. (2003) compared the coseismic water level change of well with seismic ground motion. However, they used all well without taking account for these sensitivity to the Earth's tide. The sensitivity of well against the Earth's tide would be related to the sensitivity against the seismic ground motion. The comparison between the sensitivity and degree of water level change against the seismic ground motion is not known. We investigated the relation between coseismic water level change of well and seismic ground motion of the 1999 Chi-Chi earthquake (Mw7.6). We used the waveform records of strong-motion seismograph which are managed by Central Weather Bureau, and the water level data which is managed by Water Resources Agency around the middle part of Taiwan (from January 1. 1994 to December 31. 2000).

I decomposed the tide components from the groundwater level data with Baytap-G (Tamura, 1995), and selected the observation wells which show the Earth tide response. Total wells we used were 183. The water level data at 20 wells contain the Earth's tide (M_2tide amplitude > S_2 and K_2, P_1, S_1, K_1, O_1). Second, I measured the degree of coseismic groundwater level change. The groundwater level change was observed at 163 observation well. Then we compared the amount of water level change with the degree of seismic ground motion. First, slightly high correlation was observed between the water level change and peak ground velocity (PGV). Similar correlation was also observed between water level change and spectral response of ground motion. For example correlation coefficient between it the water level change and the vertical PGV in 0.1-0.2Hz is 0.68, and the correlation coefficient between it and vertical motion spectral velocity in 0.1Hz is 0.65. The high sensitive wells against the Earth' tide can respond strongly to strain change than the response of insensitive ones. This suggests that the sensitive wells can respond accurately to the pressure change by the ground motion or dynamic strain. Second, the correlations are higher in a low frequency ground motions than a high frequency ones. For example the correlation coefficient between it and spectral velocity in 0.1Hz and 1Hz is 0.57 and 0.31, respectively. Since the corner frequency of the 1999 Chi-Chi earthquakes was between 0.17 Hz and 0.037Hz (Wang 2006, Mayeda and Malagnini, 2009), the spectral amplitude in 0.1 Hz is larger in than that in 1Hz. Therefore the water pressure in the aquifer would have responded to large amplitude of low frequency ground motion.

Studies on Mechanisms of Coseismic Sustained Groundwater-level Changes

Pei-Ling Wang, Yeeping Chia, Jyr-Ching Hu
Geosciences, National Taiwan University

Abstract

Base on high sampling rate records of three monitoring wells in Taiwan, we analyze the relation between coseismic water-level change and earthquake magnitude, hypocentral distance and distribution, and compare the calculated volumetric strain change with observed coseismic water-level change, in order to discuss possible mechanisms to sustained water-level change. Between 2004 and 2009, the Hualien, Zhuagnwei-2 and Chishan-3 wells recorded 280, 97, 47 oscillatory water-level changes, and 18, 25, 5 sustained water-level changes, respectively. Those earthquakes, which caused sustained water-level change, were located near the Hualien well. While the Zhuangwei-2 well recorded earthquakes as far as the 2008 Wenchuan earthquake 1935 km away from the well. And the Chishan-3 well recorded earthquakes located in the southern and eastern Taiwan. Geology and structure as well as hypocentral distance and earthquake magnitude affect coseismic water-level changes. There are earthquakes that induced large water level oscillations with no sustained water-level change, but some earthquakes induced small water level oscillations with induced sustained water-level change. To the Hualien, Zhuangwei-2 and Chishan-3 wells, the square correlation coefficient between sustained water-level change and oscillation range are 0.51, 0.53 and 0.48, respectively. Therefore, seismic shaking may not account for sustained water-level change. Liquefaction can account for coseismic rises. However, only 17% of sustained water-level changes at the Hualien well, 16% at the Zhuangwei-2 well, and 0% at the Chishan-3 well showed coseismic rises. Enhanced permeability may not account for the coseismic changes in the three wells, because it can’t apply to the Hualien and Zhuangwei-2 well that recorded coseismic rises and falls, and the different rates in sustained water-level changes at the Chishan-3 well. Static strain change can account for 83% of coseismic changes at the Hualien well, 60% at the Zhuangwei-2 well, and 80% at the Chishan-3 well. The inconsistency between calculated strains and observations could be caused by different physical properties of aquifers and the complexity of stress redistribution. Therefore, coseismic sustained water-level changes at the three wells may due to static strain changes, but a simple dislocation model may be insufficient to predict pore pressure change at a specific site.

The Mechanism of the Pre-seismic Changes of the Tidal Deviation of Groundwater Level in Hualien City, Taiwan

Wen-Chi Lai[1], Shih-Jung Wang[2], Naoji Koizumi[3] and Norio Matsumoto[3]

[1]*Disaster Prevention Research Center, National Cheng-Kung University, Tainan, Taiwan*

[2]*Georesources Research Center, National Cheng-Kung University, Tainan, Taiwan*

[3]*Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology ,Tsukuba, Japan*

The different response by various natural stimuli and processes (tidal force, barometric loading, ground shaking and crustal strain) were used as the elements of the hydraulic information in the earthquake induced groundwater level changes. Using the ocean tidal force to act as naturally recurring stimuli to provide a sufficiently varied distribution of excitations in time and space, and represented the hydro-geological changes responses to the earthquake processes.

The purposes of this study are to analyze the recently observation results of the earthquake induced tidal deviation of groundwater level in observation wells around Hualien city, eastern Taiwan. The analysis of the tidal responses and the atmospheric pressure responses also will be used to estimate the mechanical properties of the aquifer. Comparison the observation between the sea level and the groundwater level changes in the each event, offers the opportunity to discussion the possible mechanism of the hydrologic response to earthquake. Curiously pre-seismic groundwater level changes in the pattern of tidal deviation occurred repeatedly in several local seismic events nearby the Hualien City. The Wave Propagation Model and Structural-Sensitive Zone were issued from the observation results. The results support the “Predictable” groundwater level responses except to other non-structural factors.