The 7th South China Sea Tsunami Workshop, Taiwan, 2014

第七屆南中國海海嘯研討會・台灣・2014

November 18-22, 2014
National Museum of Natural Science, Taichung, Taiwan

Graduate Institute of Hydrological and Oceanic Sciences
College of Earth Sciences, National Central University

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Welcome Message

Dear Colleagues,

On behalf of SCSTW-7 Organizing Committee, we are delighted to welcome you to the 7th South China Sea Tsunami Workshop in Taichung, Taiwan.

We are pleased to hold this workshop in this beautiful venue, National Museum of Natural Science, which is the most wonderful and popular museum in Taiwan. We hope that you will have a pleasant and memorable experience in participating in this technical conference and in visiting the scenery in and around Taichung City.

The first workshop of this workshop series was initiated and held in Taipei in 2007. The objective of the workshop series is to weave an international academic net, in which strong interactions and collaborations among coastal physical oceanographers, geophysicists, and engineers from the countries in South China Sea Region are facilitated. Through this workshop series, potential devastating tsunami disaster and hazard mitigation in this region have been profoundly discussed.

This year, 2014, marks the tenth anniversary of the devastating 2004 Indian tsunamis. It is especially meaningful to get together to review the progress we have made in the last ten years and to brain storm the challenges we face in the future. SCSTW-7 welcomes warmly not only the scientists in the fields of hydrodynamics and tsunami, but also in the fields of Seismology, Geology, Sedimentology, Disaster Management, Nuclear Energy, Museology, and Popularization Science.

The workshop includes oral presentations and field trips to the Nuclear Power Plant and 921 Earthquake Museum of Taiwan. SCSTW-7 will provide you with a plenty of opportunities to interact with the researchers from the South China Sea area as well as other parts of the world.

To complement the excellent scientific program, we also have exciting social programs for you to explore the rich local culture. The Welcome Reception and Gala Dinner will delight the SCSTW-7 participants with delicate cuisine, local culture, and warm hospitality.

We sincerely welcome you and hope that you will find the workshop and your stay in Taichung both fruitful and enjoyable. Looking forward to seeing everyone – new and old, in the SCSTW-7!

Sincerely,

Philip L.-F. Liu, Director
Class of 1912 Professor in Engineering
School of Civil and Environmental Engineering
Cornell University
USA

Tso-Ren Wu, Director
Graduate Institute of Hydrological and Oceanic Sciences
College of Earth Sciences
National Central University
TAIWAN

Committees

Honorary Conference Chair

Philip L.-F. Liu

Chair

Tso-Ren Wu

Members

Committee members (Alphabetized by last name)

- Dr. Kuo-Chun Chang
  National Center for Research on Earthquake Engineering, Taiwan
- Dr. Benjamin Fong Chao
  Institute of Earth Sciences, Academia Sinica, Taiwan
- Dr. Chia-Ren Chu
  Department of Civil Engineering, National Taiwan University, Taiwan
- Dr. Yen-Hsyang Chu
  College of Earth Sciences, National Central University, Taiwan
- Dr. Shih-Chun Hsiao
  Department of Hydraulic and Ocean Engineering, National Cheng Kung University, Taiwan
- Dr. Zhenhua Huang
  Department of Ocean and Resources Engineering, University of Hawaii, USA
- Dr. Hung-Chi Kuo
  Research Center of Climate Change and Sustainable Development, National Taiwan University, Taiwan
- Dr. Jihn-Sung Lai
  Research Center of Climate Change and Sustainable Development, National Taiwan University, Taiwan
- Dr. Lou-Chuang Lee
  Institute of Earth Sciences, Academia Sinica, Taiwan
- Dr. Charles Lin
  Department of Earth Science, National Cheng Kung University, Taiwan
- Dr. Simon C. Lin
  Academia Sinica Grid Computing Centre, Taiwan
- Dr. Yuei-An Liou
  Center for Space and Remote Sensing Research, National Central University, Taiwan
- Dr. Jann-Yenq Liu
  Graduate Institute of Space Science, National Central University, Taiwan

- Dr. Philip L.-F. Liu
  School of Civil and Environmental Engineering, Cornell University, USA
- Dr. Kuo-Fong Ma
  Department of Earth Science, National Central University, Taiwan
- Dr. Wei-Hsin Sun
  National Museum of Natural, Taiwan
- Dr. Yih-Chi Tan
  Center for Weather Climate and Disaster Research, National Taiwan University, Taiwan
- Dr. Chuen-Horng Tsai
  Atomic Energy Council, Taiwan
- Dr. Chung-Yue Wang
  Center for Bridge Engineering Research, National Taiwan University, Taiwan
- Dr. Tso-Ren Wu
  Graduate Institute of Hydrological and Oceanic Sciences, National Central University, Taiwan
- Mr. Teng Fung Yang
  Taiwan Power Company

Organizing committees and Sponsors

Organizing Committees and Sponsors (In Alphabetical Order)

- 921 Earthquake Museum of Taiwan
- Atomic Energy Council, Taiwan
- Beijing International Center for Theoretical and Applied Mechanics, China
- Center for Bridge Engineering Research, National Central University, Taiwan
- Center for Computational Geophysics, National Central University, Taiwan
- Center for Weather Climate and Disaster Research, National Taiwan University, Taiwan
- Chinese Taipei Geophysical Society, Taiwan
- College of Earth Sciences, National Central University, Taiwan
- Earth Science Research Promotion Center, Taiwan
- Graduate Institute of Hydrological and Oceanic Sciences, National Central University, Taiwan
- National Museum of Natural Science, Taiwan
- Research Center of Climate Change and Sustainable Development, National Taiwan University, Taiwan
- School of Civil and Environmental Engineering, Cornell University, USA
- Taiwan Power Company, Taiwan

Secretariat and Staff

Graduate Institute of Hydrological and Oceanic Sciences, National Central University

- Mei-Hui Chuang
- Che-Yu Cheng
- Yu-Lin Tsai
- Chun-Juei Lee
- Yu-Hong Lee
- Pei-Yu Lee
- Jun-Wei Lin
- Lin Zhang
- Han Wu

Conference Information

Website

http://tsunami.ihs.ncu.edu.tw/~scstw/2014/

Venue

National Museum of Natural, Taiwan (Workshop)

921 Earthquake Museum of Taiwan (Workshop and Field Trip)

Nuclear power plant (Field Trip)

Internet Facilities

Wireless will be provided in the Venue. No password needed.

Name Badges

While attending the Conference, please wear your name badge at all times. All attendees must register and wear their name badge while attending all SCSTW-7 functions. The name badges are color-coded as follows:

- Speaker – Red
- Participant – Blue
- Staff – Yellow

Designated Hotels

The Splendor Inn 金典商旅

Address: No. 1049, Jianxing Rd., Taichung 403 (next to Taichunggang Rd.)

台中市健行路 1049 號 (台中港路旁)

TEL: +886-4-2329-8899

Program

- **18th – 19th November, 2014**
  Workshop for Popular Science
  Conjugated with International Conference "Earthquake Disaster Reduction - bridging science, technology, and communication"
- **20th – 21th November, 2014**
  Workshop for Technical Program
- **22th November, 2014**
  921 Earthquake Museum of Taiwan and Nuclear Power Plant Field Trip

18th November, 2014 (Tue.)

Venue: Red Hall, NMNS

Time	Agenda & Speaker	Chair
08:00-09:00	Registration & Refreshment	Wei-Hsin Sun (Director-General, NMNS)
09:00-09:20	Opening Ceremony	
09:20-10:00	From Fishnet Stockings to Falling Apples: Earthquake Interaction on the Scale of a Fault to the Planet Speaker: Ross S. Stein	
10:00-10:30	Coffee Break	
SESSION 1	**Earthquake Disasters and their Implications for Disaster Risk Reduction in Japan**	Kuo-Fong Ma
10:30-11:00	Japan's Disaster Management Policy after 3.11 and New Efforts of DRI Speaker: Kenichi Oki	
11:00-11:30	Structural Inhomogeneity along Fault Strike deduced from Electrical Resistivity Distribution and Its Implication Speaker: Naoto Oshiman	
11:30-12:00	The Message from Nojima Fault Speaker: Keiji Ikemoto	
12:00-13:30	Lunch	
SESSION 2	**Tsunami Science and Disaster Reduction**	Tso-Ren Wu
13:30-14:00	Catastrophic Tsunamis and Hurricanes in the Last Decade: Is Taiwan in Danger of a Tsunami Attack in the Future? Speaker: Philip L-F. Liu	
14:00-14:30	The Pacific Tsunami Museum: Saving Lives Through Education and Awareness Speaker: Marlene Sue Murray	
14:30-15:00	Ocean Floor Networks in Japan - Towards Disaster Mitigation on Earthquakes and Tsunamis Speaker: Yoshiyuki Kaneda	
15:00-15:30	Roles of Aceh Tsunami Museum Towards Global Disaster Risk Reduction Efforts Speaker: Rahmadhani	
15:30-15:50	Coffee Break	
SESSION 3	**New Findings on Geological and Tsunami Research in Taiwan**	J. Bruce H. Shyu
15:50-16:20	The 9/21 Chi-Chi Earthquake and Its Aftermath: Episodic Growth and Erosion of the Taiwan Landscape Speaker: John Suppe	
16:20-16:50	Geological Investigation of Chelungpu Fault before and after Chi-Chi Earthquake Speaker: Jiin-Fa Lee	
16:50-17:20	The Development and Strategy for Tsunami Hazard Mitigation in Taiwan after the Event of 311 East-Japan Tsunami Speaker: Tso-Ren Wu	
17:30-18:30	Shuttle Bus to 921EMT	
18:30-21:00	Evening Reception at 921 EMT	

19th November, 2014 (Web.)

Venue: Auditorium, 921 EMT

Time	Agenda & Speaker	Chair
08:30-09:10	Registration	
09:10-09:50	Taiwan's Plate Tectonic Activities, Mountain Building and Earthquakes Speaker: Francis T. Wu	Ching-Hua Lo
09:50-10:10	Coffee Break	
10:10-10:30	The Public Communication of Earthquake Disaster Reduction in "921 Earthquake Museum of Taiwan" Speaker: Li-Hsien Lai	Liang-Chun Chen
SESSION 4	**Catastrophic Earthquakes and Post-Earthquake Recovery in Mainland China**	
10:30-12:10	Developments and Challenges of Public Education for Disaster Reduction after the Great Wenchuan Earthquake Speaker: Linsheng Gu	
	Preserving Town Ruins for Public Disaster Awareness in the "5.12 Wenchuan Earthquake Memorial Museum" Speaker: Mengyun Yang	
	Brief Introduction to 5•12 Wenchuan Earthquake Epicenter Memorial Museum Speaker: Li Cai	
	Yushu Earthquake Ruins Museum: Uniting Our Wills like a Fortress for Earthquake Disaster Relief Speaker: ZasidraMar	
12:10-13:30	Lunch	
SESSION 5	**Development of Earthquake Disaster Reduction Technologies in Taiwan**	Lee-Yaw Lin
13:30-14:00	Development of Seismic Technology for Buildings and Bridges in Taiwan Speaker: Shyh-Jiann Hwang	
14:00-14:30	The Framework and Challenge of Disaster Management System of Taiwan Speaker: Ban-Jwu Shih	
14:30-15:00	Recent Developments for Urban Seismic Disaster Risk Reduction in Taiwan Speaker: Wei-Sen Li	
15:00-15:30	An Improvement in Earthquake Monitoring – The Operation of the Earthquake Early Warning System in Taiwan Speaker: Peih-Lin Leu	
15:30-15:50	Coffee Break	
SESSION 6	**- Earthquake Risk Management and Public Education**	Wei-Hsin Sun
15:50-16:20	Taiwan Earthquake Model (TEM) Project and the Construction of the Digital 3-Dimentional Seismogenic Structure Database of Taiwan Speaker: J. Bruce H. Shyu	
16:20-16:50	Earthquake Risk Management – Residential Earthquake Insurance Speaker: Nora Chang	
16:50-17:20	Towards the Future "Earthquake" School in the Cloud: Near-Real Time Earthquake Games Competition in Taiwan Speaker: Kate Huihsuan Chen	
17:20-17:30	Round Table Discussion & Conclusion / The End Chairs: Wei-Hsin Sun, Linsheng Gu	

20th November, 2014 (Thu.)

Venue: Red Hall, NMNS

Time	Agenda & Speaker	Chair/Co-Chair
08:30-09:00	Registration	
09:00-09:30	Welcome and Opening Remarks (Page 13)	
Keynote		Tso-Ren Wu
09:30-10:00	Water Waves through Coastal Aquatic Forest Areas Speaker: Philip L.-F. Liu (Page 15)	Tso-Ren Wu
10:00-10:30	Numerical simulation of runup of undular bores on a plane beach Speaker: Hua Liu (Page 16)	Tso-Ren Wu

10:30-10:50 Coffee Break

Time	Agenda & Speaker	Chair/Co-Chair
Keynote		Yu Yao Syamsidik
10:50-11:20	Unknown desastrous event in Korea : Meteo-tsunami Speaker: Seung-Buhm Woo (Page 17)	Yu Yao Syamsidik
Sediment		Yu Yao Syamsidik
11:20-11:35	A Preliminary Investigation on Effects of the Indian Ocean tsunami on Coastal Morphology of Indrapurwa Settlement of Aceh Besar, Indonesia Speaker: Syamsidik (Page 27)	Yu Yao Syamsidik
Solid-Fluid Coupling Simulation		Yu Yao Syamsidik
11:35-11:50	Numerical study on the flow characteristics around single-row cylinders under solitary waves Speaker: Yu Yao (Page 28)	Yu Yao Syamsidik
11:50-12:05	Study of Tsunami Loadings for Low-rise Reinforced Concrete Buildings Speaker: Meng-Huang Gu (Page 29)	Yu Yao Syamsidik

12:05-13:30 Lunch

20th November, 2014 (Thu.)

Venue: Red Hall, NMNS

Time	Agenda & Speaker	Chair/Co-Chair
keynote		
13:30-14:00	Tsunami Loadings on Critical Coastal Facilities Speaker: Harry Yeh (Page 18)	Philip L.-F. Liu
14:00-14:30	Velocity Fields of Hydraulic Jumps during Run-down Motion of Solitary Waves Propagating over Different Slopes Speaker: Chang Lin (Page 19)	
Tsunami Simulation		
14:30-14:45	Investigating the influence of small islands on tsunami wave propagation in the case of March 2005 tsunami around Banyak Islands of Indonesia based on Numerical Simulations Speaker: Teuku Muhammad Rasyif (Page 30)	Philip L.-F. Liu Seung-Buhm Woo
14:45-15:00	Examining the focal mechanism of the 2009 Samoa Earthquakes by means of Tsunami Observation and Simulation Speaker: Emmy CHANG (Page 31)	
15:00-15:15	Tsunami risks to southern China from the northern segment of the Manila trench in the South China Sea Speaker: Linlin Li (Page 32)	
15:15-15:30	The Hazard Map induced by Tsunami-the case study in Gongliao District Speaker: Yong-Jun Lin (Page 33)	

15:30-15:50 Coffee Break

Tsunami Simulation		
15:50-16:05	Observations of seismo-traveling ionospheric disturbance triggered by earthquake and tsunami Speaker: Charles Lin (Page 34)	Hua Liu Linlin Li
16:05-16:20	Runup Height for Tsunami Waves of Two Humps and its Application in Eastern Japan Tsunami Speaker: Guan-Yu Chen (Page 35)	
keynote		
16:20-16:50	An overview of the recent development in tsunami research at NCU, Taiwan Speaker: Tso-Ren Wu (Page 21)	
18:00-21:00	**Welcome Dinner** (Gin Yin Room II, The Splendor Hotel)	

21th November, 2014 (Fri.)

Venue: Red Hall, NMNS

Time	Agenda & Speaker	Chair/Co-Chair
08:30-09:00	Registration	
Keynote		J. Bruce H. Shyu
09:00-09:30	Geological paleotsunami studies in Taiwan—present situation and problems Speaker: Yoko Ota (Page 22)	
09:30-10:00	Potential for Megathrust Earthquakes in Southern Ryukyu and Northern Manila Subduction Zones as Viewed from Background Seismicity Speaker: Yi-Ben Tsai (Page 23)	
Geological		
10:00-10:15	Potential paleo-tsunami records around the eastern Taiwan area Speaker: J. Bruce H. Shyu (Page 36)	
10:15-10:30	The 2013 Bohol earthquake in central Philippines: Hazards and source fault characteristics Speaker: Noelynna Ramos (Page 37)	

10:30-10:50 Coffee Break

Geophysical		Guan-Yu Chen Robert Lawson
10:50-11:05	Expansion of the Tsunami Buoy Array: Beginnings of a Global Network Speaker: Robert Lawson (Page 38)	
11:05-11:20	Traveling Ionospheric Disturbances Observed at Ground-Based GPS and HF Doppler Sounding Systems During the 2011 Tohoku Earthquake Tsunami Speaker: Ho-Fang Tsai (Page 39)	
11:20-11:35	Ionospheric disturbances resulting from tsunami effects Speaker: Charles Lin (Page 40)	
Tsunami Simulation		
11:35-11:50	Review of the 1867 Keelung, Taiwan Earthquake and Tsunami Speaker: Shih-Nan Cheng (Page 41)	
11:50-12:05	Tsunami amplification factor due to onshore topography Speaker: Shawn Yisheng Sim (Page 42)	

12:05-13:45 Lunch

21th November, 2014 (Fri.)

Venue: Red Hall, NMNS

Time	Agenda & Speaker	Chair/Co-Chair
keynote		Hermann M. Fritz Nguyen Hong Phuong
14:00-14:30	Recent Tsunami Observations in the Pacific Ocean, Experiments and their Implications Speaker: Hermann M. Fritz (Page 24)	
14:30-15:00	Risk posed by landslide generated tsunamis near southern Taiwan. Speaker: Switzer Adam (Page 26)	
Tsunami Simulation		
15:00-15:15	Assessment of tsunami hazards from Manila trench to Vietnam using a worst case scenarios Speaker: Nguyen Hong Phuong (Page 43)	
15:15-15:30	Optimization of the Number and Location of Tsunami Stations for the Tsunami Warning in South China Sea Speaker: Chao An (Page 44)	

15:30-15:50 Coffee Break

Tsunami Simulation		Philip L.-F. Liu Yu Yao
15:50-16:05	Motion of a single piece of debris in tsunami flows over a sloping beach Speaker: Yao Yao (Page 45)	
16:05-16:20	HF Radar Detects an Approaching Tsunami Wave Already in Deep Waters Speaker: Malcolm Heron (Page 46)	
Policy and Disaster prevention		
16:20-16:35	A Study on Raising Tsunami Awareness, Disaster Preparedness and Risk Reduction Among Young People in the Philippines Using Computer Simulation Games Speaker: Rafael Saldana (Page 47)	
16:35-16:50	Application of Tsunami Inundation Potential Maps on Evacuation Planning for Local Governments Speaker: Bing-Ru Wu (Page 48)	
16:50-17:05	Novel Wave Glider Based Tsunami Warning System Speaker: Matth DePetro (Page 49)	
17:05-17:20	Final Discussion Chairs: Philip L.-F. Liu	
18:00-21:00	**Gala Dinner** (Gin Yin Room II**,** The Splendor Hotel)	

22th November, 2014 (Sat.)

Earthquake Museum of Taiwan Field Trip

Time	Destination
09:00-09:40	The Splendor Inn → Earthquake Museum of Taiwan
09:40-12:00	Visit Trip
12:00-13:00	Lunch
13:00	Earthquake Museum of Taiwan → High Speed Rail Taichung Station → The Splendor Inn

Nuclear Power Plant Field Trip

Time	Destination
09:10-12:00	The Splendor Inn → Nuclear Power Plant
12:00-13:00	Lunch
13:00-16:00	Visit Trip
16:00	Nuclear Power Plant → Taipei City → The Splendor Inn

Opening remarks for SCSTW-7 by Minister Chuen-Horng Tsai

Atomic Energy Council, Taiwan

Thank you, Chairman of the organizing committee, Prof. Wu. It is my honor to be invited to address this workshop on Tsunami research. The Fukushima-Daiichi accident occurred in Japan on March 11, 2011 was triggered by an earthquake of magnitude 9 and a massive Tsunami, which were both beyond the design basis of the plant. As a nuclear safety regulator, the Atomic Energy Council (AEC) was immediately mobilized to launch a safety re-assessment program for the operating nuclear power plants in Taiwan, to not only re-evaluate the resistance of the plants to the natural disasters including earthquake and tsunami, but also enhance the defense-in-depth safety features against beyond-design-basis station blackout, and the emergency mitigation capabilities against severe accidents.

Both Taiwan and Japan are located in the Pacific rim seismic belt and some of the reactors in Taiwan have the same design as those at Fukushima-Daiichi. Therefore, after the Fukushima-Daiichi accident, people were worried about what happened in Japan might also happen in Taiwan. Actually, this is not true. Firstly, although the earthquake did result in a loss of offsite power for Fukushima-Daiichi, it did not cause major damage to the structure and safety functions, and it was the tsunami that came about 40 minutes later flooded the essential sea water pumps and all the emergency diesel and DC power of units 1, 2 and 3, which consequently resulted in prolonged station blackout and eventually caused severe core damage.

On the other hand, if you look at the map of Japan, you can easily find out that along the north-east coast there are four nuclear power plant sites. Besides Fukushima-Daiichi, there are Onagawa, Fukushima-Daini, and Tokai-Daini nuclear power stations. The Onagawa site is located 120 kilometers north of Fukushima-Daiichi, only 20 kilometers away from the epicenter of the earthquake, much closer than Fukushima-Daiichi. But the 15-meter tsunami wall built on a higher elevation at the Onagawa plant successfully prevented the 13-meter high tsunami from damaging the plant. In comparison, the reactor buildings on Fukushima-Daiichi site situated at only 5 to 7 meter elevation failed to be protected from the Tsunami of 13 meter high with a tsunami wall of only 5.7 meter, resulting in as I just mentioned the consequent station blackout and core damage. The important point here was that the tsunami wall of Onagawa was built at the initial application of its reactor establishment permit by Tohoku Electric Power Company in response to a tsunami assessment result of assumed 13.6 meter height made by the Japan Society of Civil Engineers. However, the Tokyo Electric Power Company (TEPCO) did not respond to a similar assessment in time, and the Japanese nuclear regulatory authority, NISA, at that time ignored the report and did nothing about it. The Fukushima-Daini nuclear power plant, 15 kilometers south of Daiichi site, was also flooded. Yet, the Daini nuclear power plant had an emergency diesel generator placed at high elevation, which successfully provided enough power to cool down the reactors in time, and therefore the plant survived the tsunami. Because Taiwan and Japan are located in the Pacific rim seismic belt, they all have seismic safe shutdown systems installed, so that as soon as a strong earthquake occurred, all nuclear units of the Onagawa, Fukushima-Daiichi and Daini sites were all shut down automatically. The decay heat was then successfully removed in Onagawa and Fukushima-Daini by the survived emergency power. On the contrary, Fukushima-Daiichi failed because tsunami damaged all the emergency power even if they were designed under redundancy and defense-in-depth concept. Therefore, it could be concluded that the real cause of Fukushima-Daiichi accident was tsunami, not earthquake.

In Taiwan, the safety systems, including safe shutdown function, and the elevation of the reactor buildings of all three nuclear power plants were all designed to maintain the safety functions beyond the largest historical earthquake and tsunami heights plus suitable safety margins. After the Fukushima accident, the utility was requested to re-evaluate the seismic safety margins according to newly-identified fault evidences and to install tsunami wall to the height of design values plus 6 meters. As a safety regulator in Taiwan, we are confident that, with the enhancement implemented in the foreseeable near future, the nuclear power plants in Taiwan have sufficient capabilities to resist “beyond design-basis” earthquake and Tsunami forces, and other natural disasters, so that a severe accident with massive release of radioactive materials will not occur in Taiwan.

In addition to strong interactions with USNRC (the American regulator) and JNES (now merged to the Japanese regulator NRA) on the safety re-assessment and enhancement in light of Fukushima experiences, we have also invited experts from OECD/NEA and EC/ENSREG to conduct peer review for the stress test reports of all nuclear power plants according to the specifications proposed by EC/ ENSREG. Both peer review teams had the conclusions that the stress tests were in agreement with ENSREG specifications as well as global standards, and the enhancements identified were consistent with those in European Union countries.

Ladies and gentlemen, the safety improvement of nuclear power systems has been and will continue to be a continuing process. Since the three-mile-island accident, the nuclear safety features have been drastically upgraded and the probabilistic safety assessment techniques have been developed and implemented to reduce the core melt frequency for at least one order of magnitude less. Following the Chernobyl accident, the safety culture promoted by IAEA has been implemented, and as a result, not only the number of abnormal reportable event has been dramatically reduced, the capacity factor or unit utilization factor has also been significantly increased for most of the nuclear power plants in the world. Research on severe accident management and mitigation had been emphasized since the TMI accident. As a result, the severe accident management guideline (SAMG) and full-scale off-site emergency drills have been actively implemented in all nuclear power plants, except in Japan unfortunately. As a matter of fact, I think the most crucial lesson learned from the Fukushima-Daiichi accident is that “the probability of severe accidents cannot be ignored or underestimated, no matter how small it is”. The Fukushima accident also demonstrates that if you don’t learn from lessons, the lessons will come to you. The key message I am trying to deliver in this remark is that we did learn the lessons from the tragic Fukushima accident and the capabilities of mitigating a possible beyond-design-basis accident have been obviously enhanced. But we still need to keep in mind that further safety improvement will still be needed once it is identified by an operational experience or an academic research. In other words, the academic research should always be encouraged. And through the academic research, either the effectiveness of existing safety functions might be verified, or the weakness of safety features might be discovered leading to a further improvement of degree of safety or reliability. The importance of research should therefore be acknowledged and re-iterated. I look forward to your contribution to the future research and improvement of nuclear safety, and I wish the workshop a great success!

Thanks again for your attention.

Water Waves through Coastal Aquatic Forest Areas

Philip L.-F. Liu
School of Civil and Environmental Engineering, Cornell University, USA
Institute of Oceanic and Hydrological Sciences, National Central University, Taiwan

In this talk a semi-analytical theory of water wave propagation through aquatic vegetation is presented to examine the cases where the vegetated area has a finite extent. A mathematical model for small-amplitude periodic waves propagating through a lattice-like array of vertical cylinders within a finite region is developed. Assuming periodic lattice configuration and strong contrast between the cylinder spacing and the typical wavelength, the multi-scale perturbation theory of homogenization is employed to derive the effective equations governing the macro-scale wave dynamics and the boundary-value problem of micro-scale flows within a unit cell. The constitutive coefficients in the macro-scale effective equations are computed from the solution of the micro-scale boundary-value problem, which is driven by the macro-scale pressure gradients. Furthermore, a bulk eddy viscosity is determined by balancing the time-averaged rate of dissipation and the rate of work done by wave forces on the forest, integrated over the entire forest. The wave forces are modeled by the Morison-type formula, in which the drag coefficient formula is constructed based on experimental data by Hu et al. (2014). The theory was checked with the experimental data from Hu et al. (2014) for wave decay through a forest strip, in which waves are of normal incidence. The agreement between the theory and experiment is very good. To further check the theory, a new set of experiments for periodic waves propagating through a circular shape forest was conducted. The Reynolds numbers for these experiments are in the same range as those of Hu et al. (2014). Because of the circular shape, analytical solutions of the macro-scale problem can be obtained. Again, good agreement between the theory and experimental data is observed. No additional fitting coefficient is needed in the theory/experiment comparison. Finally, a general solution approach is developed for the cases where the vegetated areas have arbitrary shape.

Tsunami waveforms and runup of undular bores in South China Sea

Xi Zhao[1], Hua Liu[1]
[1]School of Naval Architecture, Ocean and Civil Engineering,
Shanghai Jiao Tong University, Shanghai, China

Usually, the submarine earthquakes occur in the pressure zone of two plates, so a seabed deformation with an uplift zone and a subduction zone motivates an N-shape tsunami wave. This type of tsunami wave was observed in the recent tsunami events. It was shown that tsunami waves with N-shape are stable over transoceanic propagation distances in the open ocean. However, several recent literatures referred that the tsunami waves develop into undular bores when they propagate on the gentle sloping beaches. When tsunami waves transmit into a continental shelf with shallow water depth and very long gentle slope, their waveforms will change due to the gradual decrease of the water depth. It was reported that the appearance of undular bores is associated with the dispersive terms in the governing equations, grid resolution in computation and the water depth. Tsunami waves could develop into undular bores in the near shore region in some specific circumstances.

N-shape tsunami waves usually propagate long distance without deformation in the deep ocean but develop into different types of waveforms in the near shore region. When they propagate on the shallow continental shelf, solitary waves or undular bores may emerge in the wave front. In this paper, we carry out the simulation of tsunami propagation based on the fully nonlinear and highly dispersive Boussinesq model which could describe the nonlinearity and dispersion of water waves quite well. The tsunami waveforms near the shoreline are quite different on steep and mild sloping beaches, which could not be predicted by the analytical solution of the nonlinear shallow water equations. N-shape waves develop into long wave trains on the steep sloping beaches while they form undular bores on the mild sloping beaches. Due to the emergence of undulations, the wave heights increase a lot, which is quite different comparing with the linear theory. In terms of the real topographies of the South China, some typical profiles are taken to simulate the hypothetical tsunamis generated in the Manila Trench. The lengths of the gentle continental shelves in these profiles are different. So, different waveforms in the near shore regions are obtained. The N-shape tsunami waves evolve into long wave trains, undular bores or solitons in the coastal area. The circumstances of formation of different waveforms are discussed. The studies on the runup of solitary waves and N-shape waves have been carried out by many scientists for several decades. However, the investigation of the runup of undular bores is rare up to the present. In this paper, we construct a series of undular bores by sinusoidal and attenuation functions to simulate this type of tsunami waves in the near shore region. The characteristics of their runup and energy budget are investigated.

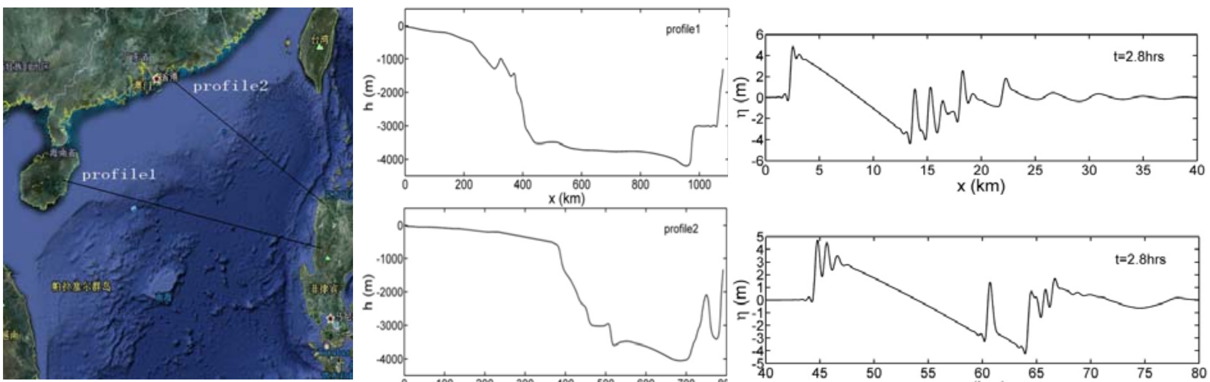

Figure 1. Wave profiles of tsunami in South China Sea

Unknown desastrous event in Korea : Meteo-tsunami

Seung-Buhm Woo[1]
[1]Department of Ocean Science, Inha University, Korea

Swell-type unexpected waves occurred along western coast of Korean at March, 2007 and it caused several deaths and heavy economic loss. Available field measurement data are collected to investigate this event, numerical model is setup to reproduce this unknown waves. We found several 1-min interval tidal elevation and sea level pressure (SLP) data along the western coast of Korea and analyzed it using wavelet technique. The wavelet power spectrum for sea water level anomalies is computed using the Morlet mother function. The high wave energy is occurred between 8 and 16 minutes during 0~2 KST 31 March 2007, and the sudden pressure jump of 3~5 hPa occurred simultaneously with high wave energy event. The numerical experiments of the abnormal wave were performed using 2-dimensional shallow water wave model (COMCOT), and air pressure forcing is made from the variation of SLP field and pressure jump from weather charts. We assume the air pressure jump of around 5 hPa is moving from Shandong of China to west coast of Korea. The sea water level by the travel of SLP field was changed all over west coast of Korea with low frequency and SLP field was not considered an original forcing of the abnormal wave. The sea level under the forcing of air pressure jump was obviously amplified by the Proudman resonant effect and it can reproduce the 2007 abnormal wave qualitatively.

Tsunami Loadings on Critical Coastal Facilities

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The 2011 Great East Japan Tsunami has altered our traditional concept on tsunami hazards. Prior to this event, we generally understood reinforced concrete structures – those often used for critical coastal facilities – could withstand tsunami actions very well. This is no longer the case. Many concrete buildings and coastal protective structures (seawalls and coastal dykes) failed by rotation: see the figure below.

We first review the existing methodologies in *Guidelines for Design of Structures for Vertical Evacuation from Tsunamis* (FEMA P646). Tsunami loadings are classified by hydrostatic forces, buoyant forces, hydrodynamic forces, impulsive forces, floating debris impact forces, damming of accumulated waterborne debris. Some of the methodologies for force estimates are physically rational, while others are not. The equations to predict hydrostatic, buoyant, and hydrodynamic forces are based on the fluid mechanics with clear assumptions. On the other hand, impulsive force is estimated with the empirical formula based on small-scale laboratory experiments. Debris impact forces are calculated by adapting the equation for a simplified and linear dynamic system that involves parameters with significant uncertainty. It is important to recognize their clear validities and limitations in the design guidelines.

Here we introduce a methodology to compute peak overturning moments with the consideration of effective buoyant force. A rise of water to a high level could float a building by buoyancy when a substantial volume of air is entrapped (Yeh et al. 2013). The buoyancy practically reduces the net structural weight; hence reduction of restoring force that resists both the sliding and rotational failure. Buoyancy force is due to net upward pressure force acting on the bottom surface of a partially or totally submerged the body. To establish the upward water pressure force under the building, pore-water pressure in the soil must increase by excess water weight on the ground surface by inundation. The pore-water pressure field is governed by the diffusion process: hence it takes a finite time to build up. We demonstrate that the effect of buoyant force depends on 1) duration and depth of tsunami inundation, and 2) the burial depth of bottom surface of the building. Due to its transient nature of tsunami, a building with the basement would be less susceptible than those without basement. We also note that if and when a building is flooded (due to breakaway walls or windows), flooded water inside the building increases the effective weight (body force); hence the building would become more stabilized. Some example computations are presented.

Figure 1 –RC building and seawall failures by overturning moment.

Velocity Fields of Hydraulic Jumps during Run-down Motion of Solitary Waves Propagating over Different Slopes

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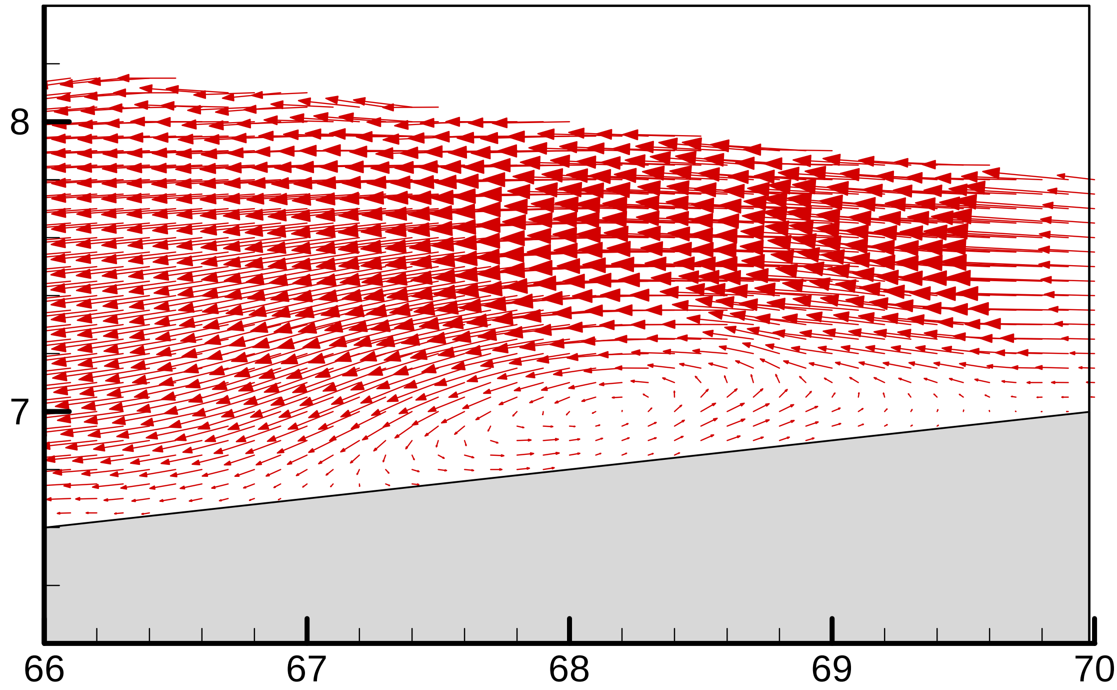
As pointed out by Russell (1838), solitary wave propagates with very stable motion over a considerable distance along a constant water-depth channel. This wave travels steadily neither steepening its wave height nor widening its effective wave length. Solitary waves are often investigated due to their simple and permanent wave form. In addition, the investigation of shoaling solitary waves can help in simulating the run-up and run-down motions as well as the shoreward inundation of a tsunami. However, the characteristics of unsteady hydraulic jump (Sumer et al., 2011) during the run-down motion of a shoaling solitary wave is still very rudimentary; and the systematical measurements has not yet been made up to now. Herein, the vortical structures and velocity fields in the unsteady hydraulic jumps during the run-down motion of shoaling solitary waves propagating over three different slopes are investigated experimentally.

The experiments were conducted in a glass-walled and glass-bottomed wave flume with dimensions of 14.0 m long, 0.25 m wide and 0.5 m deep. The wave flume was equipped with a piston-type wave maker at one of its end, which was triggered by a servo motor. The wave maker can generate ideal solitary wave forms. Two capacitance type wave gauges were employed to measure the water surface elevation. Three sloping bottoms all made of acrylic and having slopes of 1/10, 1/5 and 1/3, were used for the experiments. Two flow visualization techniques, including thin-layered fluorescent dye and neutrally suspending Titanium Dioxide particles, were both used to examine: the occurrence of unsteady hydraulic jump. A laser light sheet was used to illuminate the 2-D motion of the tracers used on a vertical plane along the longitudinal direction of the flume. A high-speed camera was used to capture images with maximum framing rate of 1200 Hz and maximum image resolution of 1,024 × 1,024 pixel. A HSPIV system was also used to measure the two-dimensional velocity fields of hydraulic jumps and the underlying vortex structures when flows retreated from different slopes.

In the present study, the temporal variations of the visualized serial images and (phase-averaged) velocity fields of the hydraulic jumps are presented, respectively. Main targets are focused on the effect of the slope on formation of the separated shear layers from the sloping bottoms and on the temporal and spatial variations of velocity fields in the vortical structures underlying the unsteady hydraulic jumps. The occurrence condition for the unsteady hydraulic jumps is elucidated by examining the variation of time-dependent Froude numbers in the vicinity of the flow separation points for different slopes. Figs. 1(a, b) show the phase-averaged velocity fields of vortical structure for T = 24.583 and 26.244, respectively, for a solitary wave (with $H_0/h_0 = 0.359$, where H_0 and h_0 are the non-shoaling wave height and still water depth) propagating over the 1:10 slope. Herein, T is the non-dimensional time defined as $T = t \times (g/h_0)^{1/2}$ where t is time and $t = 0$ (also $T = 0$) characterizes the instant as the solitary wave crest is right above the toe of the slope.

(a) T = 24.583



(b) T = 26.244

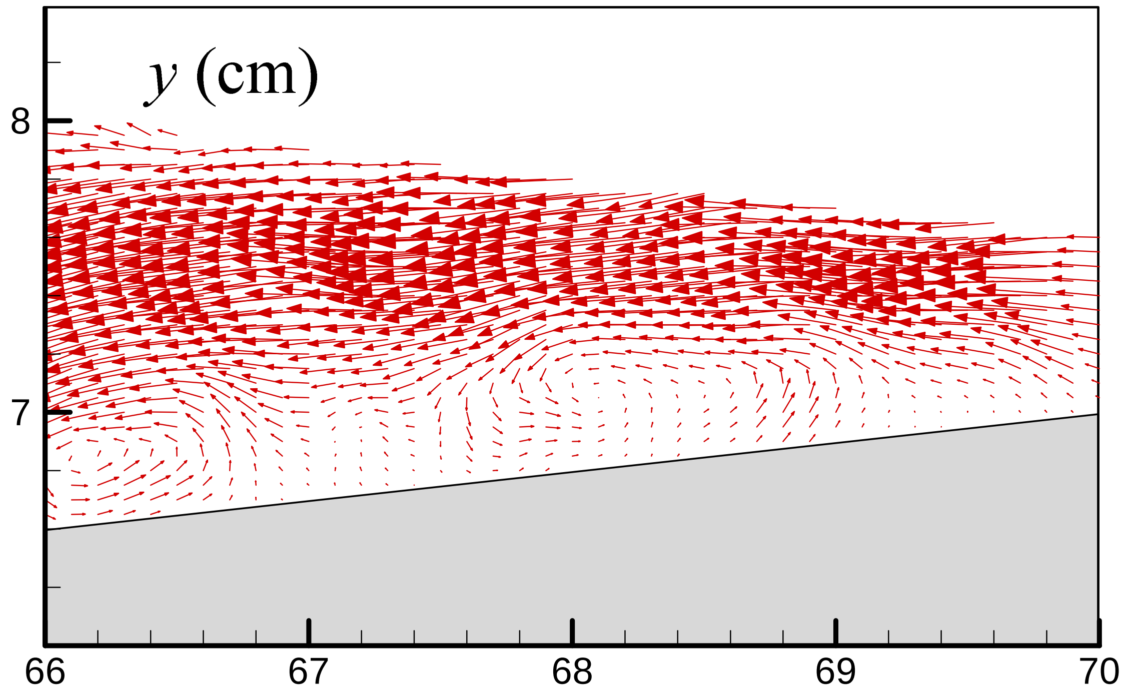


Fig. 1 Phase-averaged velocity fields of vortical structure: (a) T = 24.583, (b) T = 26.244

An overview of the recent development in tsunami research at NCU, Taiwan

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We reviewed the research development of tsunami during the past 5 years at the Tsunami Science Laboratory, National Central University, Taiwan. Categories were divided into Tsunami Simulations, Scenario Studies, Tsunami Reverse Tracing Method (TRTM), Impact Intensity Analysis (IIA), Historical Paleo-Tsunami Events, Tsunami Early Warning, and Tsunami Hazard Mitigation.

In the tsunami simulations, COMCOT and Splash3D models were coupled to simulate both deep-ocean and near-shore tsunami dynamics. Breaking waves were impinged with both stationary and moving coastal structures. Two-way fully coupled moving solid algorithm was developed for solving the boulder kinematics as well as the rock-slide generated tsunami. The algorithm was also coupled with DEM and V5 models to study the behavior of rigid and elastic materials in the breaking waves. The quadratic Bingham model was developed for solving the local scour under the violent flow condition.

To have better understanding of the potential tsunami hazard to Taiwan, scenario studies were implemented to the trench-type earthquakes around the edge of the Philippine Sea Plate. The result showed that Taiwan is under the threat from Manila, Yap trenches, and the Southern part of Ryukyu Arc. We developed TRTM and IIA methods to further realize the tsunami impact factor to the study areas. TRTM is able to find the tsunami source from the location of the study area, and IIA is able to grade the impact factor of the source. Although the history of Taiwan is shorter than 400 years, several historical records of tsunami attacks were documented and inscribed in some temples. We scientifically studied and reconstructed those historical tsunami attacks, such as the 1867 Keelung Tsunami, 1781 Kaohsiung-Pingtung tsunami, and 1894 Donggan tsunami. In the past two years, we have also found tsunami boulders at the Southern East of Taiwan as well as the Green Island. TRTM and IIA methods, and moving-solid method were applied to analyze the tsunami sources.

For hazard mitigation and early warning, we paralyzed the COMCOT source code and improved the simulation speed at least 20 times fast. For example, a simulation covers Japan, Taiwan, South China Sea, and Philippine Sea Plate can be finished in 3 minutes with a resolution up to 200 meters and 10 hours simulation time. The paralyzed COMCOT is currently adopted by Central Weather Bureau in Taiwan for tsunami early warning.

Detailed results and discussions will be presented in the SCSTW-7 conference.

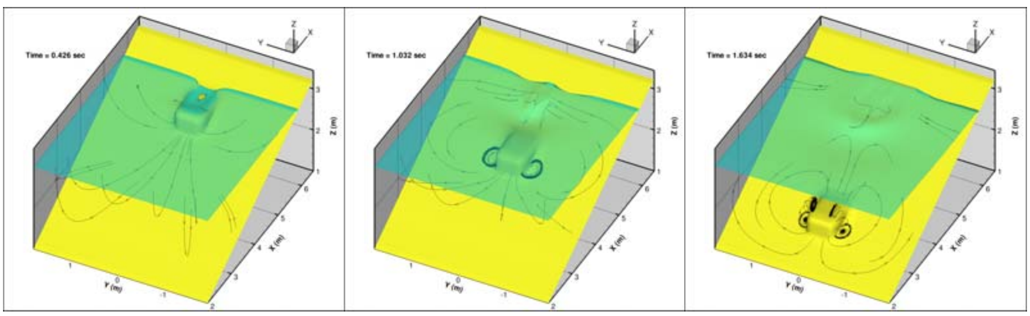

Figure 1. Snapshots of the free-surface elevation with streamlines for the rockslide tsunami simulation.

Geological paleotsunami studies in Taiwan—present situation and problems

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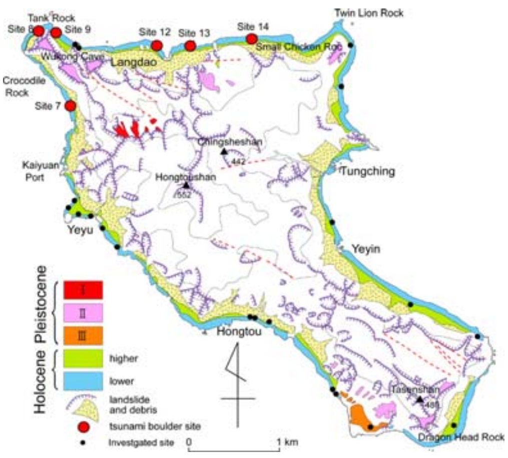
In the last decade, several disastrous tsunamis hit a large area of coastal Asia, and produced numerous casualties and economic losses. As a country that is also prone to tsunami hazards, Taiwan is in urgent need for more knowledge of past tsunami records and potential tsunamigenic source. However, In Taiwan, paleotsunami was not studied until recently, even though many geological evidences of paleotsunami have been found in the Ryukyu Islands which are close to Taiwan. We expect that the east coast of Taiwan has a large potential for paleotsumani research.

Coral boulders are visible indicator for recognition of paleotsunami. The first finding of coral boulders are from the Jiupeng coast on the southern east coast of Taiwan (Fig.1, inset) by Matta et al., 2013). Here we provide more evidence from our recent results from the coast of Lanyu Island, offshore southeastern Taiwan (Fig.1, inset). On the basis of detailed geomorphic mapping and field investigations, we identified six sites (Fig. 1) in the northern part of the Lanyu Island, where nine large coral boulders rests on Holocene uplifted coral terraces. We mapped their location and measured their profiles and took samples for 14C and U series dating. All the boulders likely moved by extremely strong waves, and four sites (8, 9, 12 and 14) have better constraints to suggest that the boulders may indeed be transported during a paleotsunami event, based o large size an their occurrence (Fig. 2). The ages of the boulders range from 100 to 200 ears ago to ca. 7000 yBP, suggest that the extremely strong wave events occurred at least several times since the mid-Holocene high stand of sea level, and the youngest event may correlate with the 1771 Meiwa tsunami of the southern Ryukyu Islands, or alternatively some undocumented event along the eastern coast of Taiwan. Moreover, the locations of the coral boulder sites along the northern coast of the Lanyu Island suggest that the sources of the events are located to the north of the island. We hope our results would provide further information for future tsunami hazard assessments along the eastern coastal area of Taiwan.



Fig, 1. Geomorphic map of the Lanyu Island with location map. Solid dots are the surveyed sites.

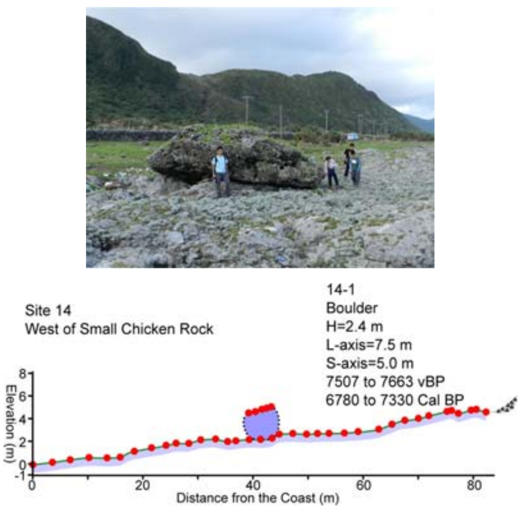


Fig. 2. Profile across Site 14 where the largest (long axis is 7.5m) boulder is found

Potential for Megathrust Earthquakes in Southern Ryukyu and Northern Manila Subduction Zones as Viewed from Background Seismicity

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In this study the potential for megathrust earthquakes in Southern Ryukyu and Northern Manila subduction zones near Taiwan are assessed by comparing their background seismicity rates with that of five M $\geq$ 8.5 earthquakes since 2004. The selected events include the 20041226 M9.1 Northern Sumatra, 20050328 M8.6 Northern Sumatra, 20070912 M8.5 Southern Sumatra, 20100227 M8.8 Chile, and 20110311 M9.0 Tohoku earthquakes.

The background seismicity rate is represented by the number of M $\geq$ 5.0 earthquakes shallower than 70 km occurred from 1974 to 2003 that are listed in NEIC catalog. The areas for counting the background seismicity rates of the five megathrust earthquakes are defined by the aftershock activity in the first three months. Comparable sized areas are adopted for the two subduction zones near Taiwan.

The results, as summarized in the table, show that both Southern Ryukyu and Northern Manila subduction zones have comparable background seismicity rates as the five recent megathrust earthquakes. As pointed out by other researchers, our results also suggest that similar sized megathrust earthquakes could occur in these subduction zones. Potential seismic, tsunami and submarine landslide hazards to the surrounding regions need to be taken seriously.

Background Seismicity and Aftershock Activity of Recent Megathrust Earthquakes (1974-2003, H<70 km)

M>=	5.0	6.0	7.0	8.0	9.0
20110311 M9.0	680 (655)	68 (66)	6 (4)	0 (1)	0 (1)
20100227 M8.8	252 (313)	32 (24)	6 (1)	0 (1)	0 (0)
20070912 M8.5	252 (114)	22 (11)	4 (3)	0 (1)	0 (0)
20050328 M8.6	190 (159)	21 (15)	4 (1)	0 (1)	0 (0)
20041226 M9.1	350 (492)	26 (26)	2 (2)	0 (1)	0 (1)
S.Ryukyu M?	217	12	1	0	0
N. Luzon M?	326	26	2	0	0

Recent Tsunami Observations in the Pacific Ocean, Experiments and their Implications

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This presentation covers selected aspects and implications of the following recent tsunami events around the world: Japan (2011), Solomon Islands (2013) and Chile (2014). In addition an overview on multiple phases of large scale landslide tsunami experiments will be given.

The 2004 Indian Ocean tsunami marked the advent of survivor videos mainly from tourist areas in Thailand and basin-wide locations. Near-field video recordings on Sumatra's north tip at Banda Aceh were limited to inland areas a few kilometers off the beach (Fritz et al., 2006). The March 11, 2011, magnitude Mw 9.0 earthquake off the Tohoku coast of Japan caused catastrophic damage and loss of life resulting in the costliest natural disaster in recorded history (Shimozono et al., 2012; Liu et al., 2013). The mid-afternoon tsunami arrival combined with survivors equipped with cameras on top of vertical evacuation buildings provided numerous inundation recordings with unprecedented spatial and temporal resolution. High quality tsunami video recording sites at Yoriisohama, Kesennuma, Kamaishi and Miyako along Japan's Sanriku coast were surveyed, eyewitnesses interviewed and precise topographic data recorded using terrestrial laser scanning (TLS). Measured overland flow velocities during tsunami runup exceed 13 m/s at Yoriisohama. The runup hydrograph at Yoriisohama highlights the under sampling at the Onagawa Nuclear Power Plant (NPP) pressure gauge, which skips the shorter period second crest. Combined tsunami and runup hydrographs are derived from the videos based on water surface elevations at surface piercing objects and along slopes identified in the acquired topographic TLS data. Several hydrographs reveal a draw down to minus 10 m after a first wave crest exposing harbor bottoms at Yoriisohama and Kamaishi. A multi-hour ship track for the Asia Symphony with the vessels complete tsunami drifting motion in Kamaishi Bay is recovered from the universal ship borne AIS (Automatic Identification System). Multiple hydrographs corroborate the tsunami propagation through Miyako Bay and up the Hei River. Tsunami outflow currents up to 11 m/s were measured in Kesennuma Bay making navigation impossible (Fritz et al., 2012). Further we discuss the complex effects of coastal structures on inundation and outflow hydrographs as well as associated flow velocities.

On February 6, 2013 a magnitude M_w 8.0 earthquake occurred 70 km to the west of Ndendo Island (Santa Cruz Island) in the Solomon Islands. The under-thrusting earthquake near a 90° bend, where the Australian plate subducts beneath the Pacific plate generated a locally focused tsunami in the Coral Sea and the South Pacific Ocean. The tsunami claimed the lives of 10 people and injured 15, destroyed 588 houses and partially damaged 478 houses, affecting 4,509 people in 1,066 households corresponding to an estimated 37% of the population of Santa Cruz Island. The 19 to 23 February 2013 ITST covered 30 locations on 4 Islands: Ndendo (Santa Cruz), Tomotu Noi (Lord Howe), Nea Tomotu (Trevanion, Malo) and Tinakula. The tsunami impact peaked at Manoputi on Ndendo's densely populated west coast with maximum tsunami height exceeding 11 m and local flow depths above ground exceeding 7 m. A fast tide-like positive amplitude of 1 m was recorded at Lata wharf inside Graciosa Bay on Ndendo Island and misleadingly reported in the media as representative tsunami height. The stark contrast between the field observations on exposed coastlines and the Lata tide gauge recording highlights the importance of rapid tsunami reconnaissance surveys. Observations from the 2013 Santa Cruz tsunami are compared against the 2007 and 2010 Solomon Islands tsunamis (Fritz and Kalligeris, 2008; Newman et al., 2011).

On 1 April, 2014 a magnitude Mw 8.2 earthquake occurred off the coast of northern Chile less than 100 km NW of Iquique within a region of historic quiescence termed the northern Chile seismic gap. The ensuing tsunami inundation caused mostly minor damage centered in Iquique and neighbouring stretches of coastline. Fortunately, ancestral knowledge from the past 1868 and 1877 tsunamis in the region along with the recent 2010 Maule tsunami (Fritz et al., 2011), as well as tsunami education and evacuation exercises prompted most coastal residents to spontaneously evacuate to high ground after the earthquake. There were no tsunami victims, while a handful of fatalities were associated to the earthquake and the tsunami evacuation. The April 2014 ITST covered a 700 km stretch of coastline from the Mejillones Peninsula north of Antofagasta in Chile up to Vila Vila in southern Peru. The tsunami impact peaked in the vicinity of Iquique exceeding 4 m in tsunami height.

Tsunamis generated by landslides and volcanic island collapses account for some of the most catastrophic events. Major tsunamis caused by landslides or volcanic island collapse were recorded at Oshima-Oshima in 1741, Unzen in 1792, Krakatoa in 1883, Lituya Bay, Alaska in 1958 (Fritz et al., 2009), Papua New Guinea in 1998, Java in 2006 and Haiti in 2010 (Fritz et al., 2013). Source and runup scenarios based on real world events are physically modeled in the three dimensional NEES tsunami wave basin (TWB) at Oregon State University (OSU). A novel pneumatic landslide tsunami generator (LTG) was deployed to simulate landslides with varying geometry and kinematics (Mohammed and Fritz, 2012). Source and runup scenarios based on real world events are physically modeled using generalized Froude similarity in the three dimensional NEES tsunami wave basin at Oregon State University. A novel pneumatic landslide tsunami generator (LTG) was deployed to simulate landslides with varying geometry and kinematics. The bathymetric and topographic scenarios tested with the LTG are the basin-wide propagation and runup, fjord, curved headland fjord and a conical island setting representing a landslide off an island or a volcano flank collapse. The LTG consists of a sliding box filled with 1,350 kg of landslide material which is accelerated by means of four pneumatic pistons down a 2H:1V slope. The landslide is launched from the sliding box and continues to accelerate by gravitational forces up to velocities of 5 m/s. The landslide Froude number at impact with the water is in the range $1 < F < 4$. Two different materials are used to simulate landslides to study the granulometry effects: naturally rounded river gravel and cobble mixtures. Water surface elevations are recorded by an array of resistance wave gauges. The landslide deformation is measured from above and underwater camera recordings. The landslide deposit is measured on the basin floor with a multiple transducer acoustic array (MTA). Landslide surface reconstruction and kinematics are determined with a stereo particle image velocimetry (PIV) system. Wave runup is recorded with resistance wave gauges along the slope and verified with video image processing. The measured landslide and wave parameters are compared between the planar hill slope used in various scenarios and the convex hill slope of the conical island. The energy conversion rates from the landslide motion to the wave train is quantified for the planar and convex hill slopes. The wave runup data on the opposing headland is analyzed and evaluated with wave theories. A method to predict the maximum wave runup on an opposing headland using nondimensional landslide, water body and bathymetric parameters is derived. The measured landslide and tsunami data serve to validate and advance three-dimensional numerical landslide tsunami prediction models.

Risk posed by landslide generated tsunamis near southern Taiwan

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The late 18th century tsunami event that struck southwestern Taiwan coast sometime in 1781-83 maybe the most devastating tsunami ever reported in the South China Sea. However, a plausible source for this tsunami has never been identified. Based on numerous modeled scenarios we find that large megathrust earthquakes from the northern segment of the Manila trench, nor the submarine volcanic eruption from the northern Luzon Arc can adequately explain the relatively limited impact area, nor the geographical extent of notable tsunami waves in the historical records. The lack of seismic or volcanic mechanism focuses in on the possibility that a submarine-mass-failure on the upper portion of the continental slope offshore southwestern Taiwan may provide the best match to the historical records and present evidence of an underestimated local threat to Kaohsiung, Kenting and the Taiwan Nuclear Power Plant No. 3, at the southern tip of Taiwan.

A Preliminary Investigation on Effects of the Indian Ocean tsunami on Coastal Morphology of Indrapurwa Settlement of Aceh Besar, Indonesia

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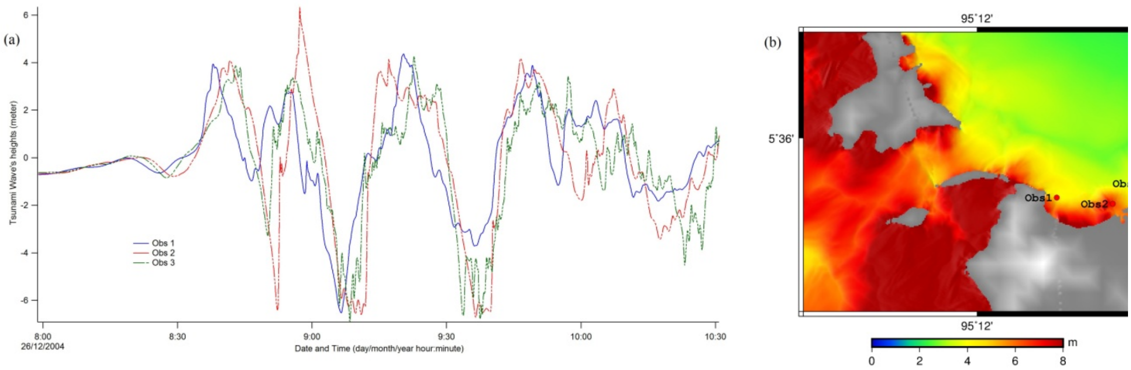
A series of tsunamis are believed to attack the Ujong Pancu Coast of Aceh Besar, which is located about 10 km to the west of Banda Aceh. The coast was a place where an old Hindu settlement of Indrapurwa was situated around 960 AC. A series of tsunamis, there were 960 AC, 1390 AC, and 1450 AC struck this area forcing the settlement to move and to abandon the area. In 2004, another giant tsunami generated around the Indian Ocean repeated the attack. This study is aimed at investigating the effects of tsunamis to deform the coastal morphology that later drove the change of the settlement of Indrapurwa. A field survey to map the bathymetry and coastal line of this area was performed in 2011. A time series of maps were used to show the changes of this area from early 1800s to recently. Furthermore, COMCOT was used to reconstruct the tsunami waves runup to this area. A number of tsunami poles were used to validate the tsunami waves heights for the Indian Ocean tsunami case. Distribution of maximum tsunami wave heights based on COMCOT numerical simulation using the 2004 Indian Ocean tsunami can be seen in Figure 1. The results show that maximum wave heights around this area were about 6 m around the near shore zone of the study area. A tsunami pole around the Ujong Pancu, based on local people witness, shows that the maximum tsunami wave heights was about 7 m. Bed Shear stress distribution, sediment transport due to the wave forces, and other further results are presented in full paper version. This study reveals the relation of tsunamis to the history of the Indrapurwa settlement. It is expected that the study will also compliment historical studies to explain previus process contributing to the demolishing of old settlement of Indrapurwa.



(a) (b)

Figure 1 (a) Tsunami wave's elevation at three observation points based on numerical simulations. (b) Distribution of maximum tsunami wave heights based on the 2004 Indian Ocean Tsunami case around the former Indrapurwa settlement.

Numerical Investigation of Tsunami-like Solitary Wave Interaction with the Pile Breakwater

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Pile breakwaters are sometimes preferred to provide protection from waves owing to their relatively low cost and capability of both safeguarding the landscape and preserving the quality of coastal water environment. The interactions between regular (sinusoidal) waves and vertical slotted barriers have been extensively studied by many researchers. However, the study of interactions between tsunami-like solitary waves and pile breakwaters are rare in the literature. Modeling the non-linear interaction between waves and a group of cylindrical piles faces multiple challenges similar to other wave-structure interaction problems. The free surface runs up and down on the piles, and flow separation occurs on the leeside of pile. Local but strong turbulence in the vicinity of the pile and near the free surface need to be considered, thus a three-dimensional model which can solve the rotational flow should be employed.

This study numerically investigated tsunami-like solitary waves propagating over a row of vertical slotted cylindrical piles. An alternative three-dimensional numerical model based on the well-known open-source CFD tool OpenFOAM® was developed in this study. The Navier-Stokes equations for two-phase incompressible flow, combining with methods of Large Eddy Simulation (LES) for turbulence closure and Volume of Fluid (VOF) for tracking the free surface, were solved.

Laboratory experiments were performed regarding to measurements of flow near the piles and the dynamic pressure on the pile surface. The model was then validated by the laboratory data as well as the data in the literature, and good agreements were found for wave, flow and dynamic pressure in the vicinity of the slotted piles.

Finally, a set of numerical experiments was conducted to examine evolutionary behaviors of wave runup, vortex generation as well as the vertical structure of dynamic pressure around the row of slotted piles and around a single pile.

Discussions were given to the comparisons of total force between the row of slotted piles and a single pile in view of the Morison equation. It is found that the interactions between adjacent slotted piles exerted increased drag on the surrounding waters compared to the single pile.

The detailed laboratory settings and numerical settings, model validation, and result analysis will be presented in the full paper.

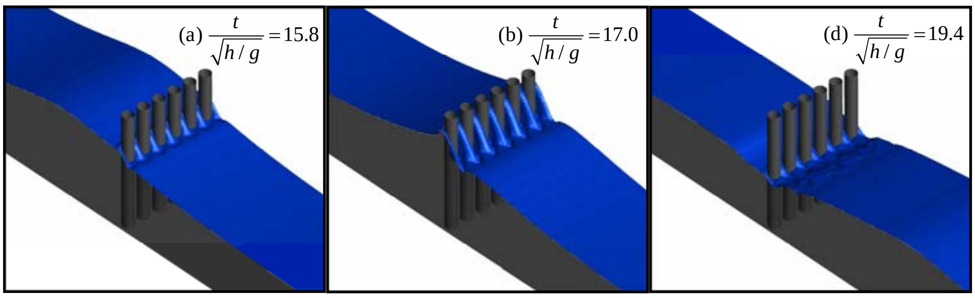

Figure 1. Snapshots of the free-surface elevations for solitary wave interaction with a row of piles

Study of Tsunami Loadings for Low-rise Reinforced Concrete Buildings

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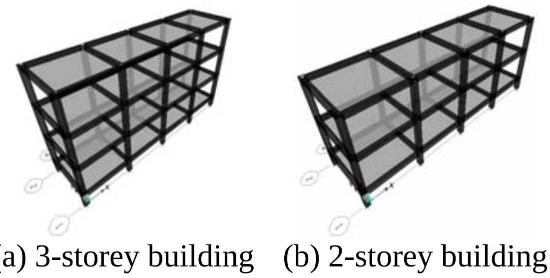
On Friday 11 March 2011, a magnitude 9.0 (Mw) earthquake occurred in Tohoku area (called 311 earthquakes). The 311 earthquakes were the most powerful earthquakes ever recorded which have inflicted serious damages to Japan area. Besides, the 311 earthquakes not only lead to large ground motions, but also triggered formidable tsunami waves to assault the coast area of Japan. Furthermore, the tsunami waves also caused the Fukushima Daiichi nuclear disasters.

The 311 earthquakes and related tsunami disasters were considered as the multi-hazard caused over 20,000 people injuries, deaths and wrecked infrastructure destruction along the Tohuko coasts. According to the experiences of multi-hazard from 311 earthquakes for serious considering, Taiwan is also a high potential area under risk of tsunami hazards. Therefore, a well preparation to develop the methodology of designing and checking the safety of building is necessary for preventing Taiwan from the tsunami disasters.

In this study, the low-rise reinforced concrete buildings were selected to investigate (Figure 1), the hydraulic parameters such as inundation depth, flow velocity, momentum flux and structural dimensions, etc were considered to simulate the run-up behavior by the shallow water approach. The results of tsunami simulation were applied to estimate the loading effects of tsunami, and defined the demands of tsunami resistance for designing and checking the safety of buildings. Besides, the nonlinear static analysis was also used to obtain the capacity of tsunami resistance. According to the demand and capacity of tsunami resistances, a simple methodology for analysis the safety of vertical evacuation building was proposed in this study.

A pseudo event was also applied to explain the details of proposed methodology for estimation the targeted buildings. The numerical techniques were used for tsunami simulation to obtain the essential parameters. Then the loadings of tsunami can be easily obtained to define the demands of targeted building for tsunami resistance. Finally the nonlinear static analysis was applied to estimate the capacity of targeted building for tsunami resistances. On the other words, the hydraulic parameters can be used for qualitative analysis on checking the safety of targeted buildings. According to the results of proposed methodology, the direction of tsunami wave propagation highly influences the analysis results.

In this study, a simple methodology based on nonlinear static analysis for checking the safety of the low-rise reinforced concrete building was proposed. The analysis results display the consistency and suitability. From those results, it is convinced that the proposed methodology and related experiences can be easily introduced for engineers.



(a) 3-storey building (b) 2-storey building
Figure 1: 3-dimensional numerical models of low-rise reinforced concrete buildings

Investigating the influence of small islands on tsunami wave propagation in the case of March 2005 tsunami around Banyak Islands of Indonesia based on Numerical Simulations

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Tapaktuan and Singkil are two cities located along southwestern coast of Aceh, Indonesia. Both of the cities indirectly face the Indian Ocean. There are several small islands situated between 40 and 60 km to the west of the cities, shading the cities from direct impacts of the sea-climate generated around the Indian Ocean. Several studies previously revealed the influence of small islands in tsunami wave propagation towards the city behind. They were conducted by post-tsunami survey data and numerical simulation. The studies indicated that tsunami waves were significantly higher at the city located behind the small islands. Tapaktuan, however, was not significantly destroyed by tsunami waves in March 2005. On the other hand, the tsunami in 2005 gave adverse impacts on Singkil city. Both of the cities located near the earthquake's epicenter in 2005 but the tsunami impacts on the cities were different. These contradictory findings lead to different tsunami mitigation facilities in the cities. Singkil is prepared by several tsunami escape facilities such as escape route while the similar facilities were found minimum in Tapaktuan. This research is aimed at investigating the influence of small islands by conducting tsunami numerical simulation and comparing the results based on three parameters of small islands, i.e. the island dimension, the bathymetry around it, and a distance between it and the main island. The COMCOT model was used in this research to simulate tsunami waves propagation process toward the cities based on scenario in 2005 which the multi fault model was developed by (Banerjee et al., 2005).The nested grid system also was used in this research to obtain the detail tsunami waves propagation process in near shore area where the near shore was updated by digitizing the nautical chart with scale about 1:250,000 measured by Dishidros of TNI AL Indonesia.The results are show that tsunami waves height were significantly lower to about 1 m at Tapaktuan city located behind the Simeulu island. However, tsunami waves were higher with value about 5.5 m at Singkil city located behind Banyak islands as can be seen in Figure 1.

(a)

(b)

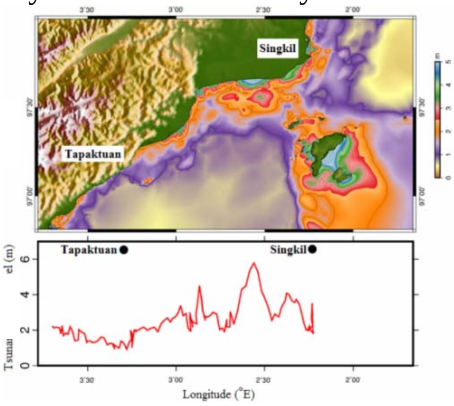

Figure 1. (a) Distribution of maximum tsunami waves' amplitudes and (b) Maximum values of the amplitude around near shore where water depth is about 10 m.

Examining the focal mechanism of the 2009 Samoa Earthquakes by means of Tsunami Observation and Simulation

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A major earthquake event occurred in the Samoa-Tonga region on September 29, 2009 generated a significant tsunami waves across the Pacific ocean, which was later recognized as a multiple-source event as the Pacific plate subducts westward beneath the Australia plate along the Tonga trench. Differing from the typical subduction-zone earthquake caused by sudden slip on the plate interface, the main earthquake visible in seismic records is resulted from extensional faulting at the outer rise, where the descending plate begins to bend into the trench. Two distinct mechanisms have been proposed by Lay et al. (2010) and Beaven et al (2010) for this event. Lay et al. deduced from teleseismic observation and proposed an initiation of an outer-rise normal faulting (Mw8.1) triggering two underthrusting subevents (both Mw7.8) at the subduction plate interface. Beaven et al. determined from tsunami waves and GPS data to propose that the outer-rise normal fault (Mw7.9) was triggered by a preceding slow thrusting of the interplate motion (Mw8.0) of subduction. These two studies describe the varied mechanical regimes within the lithosphere for the tectonic stress transferring between the outer-rise and the subducting plate. The fault plane solutions of the earthquakes determined in these two studies are dissimilar as well. All the discrepancies between these two studies shall be examined by the geodetic and tsunami observations neighboring to the seismic foci to verify the focal mechanisms of this event.

The onland coseismic dislocations detected by GPS in the Samoa island (Stations ASPA, SAMO) cannot discriminate the two mechanisms because they are used to infer the latter in the first place. We therefore examine the tsunami waves observed at three nearby DART ocean-bottom pressure stations (51425, 51426, and 54401), and compare them with those simulated by the computer program COMCOT given the different seismic source mechanism solutions and the high-resolution seafloor bathymetry model GEBCO. Based on the comparison between the simulated and observed tsunami waves, both normal and thrust mechanisms are indeed required for this event, in agreement with Lay et al. and Beaven et al. However, we find that the thrust mechanism dominates the tsunami waves at stations 51426 and 54401, whereas the normal fault mechanism is more prominent at 51425. This can explain why the automated inversion of the tsunami wave assumed a thrust-fault source for this event, especially in the consideration of a single seismic source for the tsunami waves (NOAA, 2010). Our simulation can furthermore discriminate the actual fault plane of the great outer-rise normal faulting, which should be the one dipping to the northeast. Thus, examining the tsunami waves close to the seismic source can shed light on the focal mechanism of the seismic source, which is particularly constructive for earthquakes lacking seismic records in the near field.

Tsunami risks to southern China from the northern segment of the Manila trench in the South China Sea

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The northern Manila Trench offshore Southwestern Taiwan is capable to generate a Mw ≥ 7.7 earthquake (Shyu et al., 2005). In this study we investigate the tsunami hazard in the southern China coast posed by the northern segment of the Manila Trench in the South China Sea. Our fault-slip model conforms to the structural geology of the trench and the fault-rupture length and width is constrained by the empirical fault scaling relationship for the subduction zone earthquakes. For the slip distribution in the synthetic fault models, we considered uniform slip distribution, non-uniform slip distribution and tsunami earthquakes. Our simulation results reveal that earthquakes above Mw 8.2 are capable of generating ~5 m tsunami waves on the southwest Taiwan coast, and would likely generate 2m + waves on the Chinese coast between Macau and Shantou only 300-600 km from the source area. Modelling also indicates that the combined effect of source directivity and lateral depth heterogeneity between the Manila trench and the east China coast focuses most of the wave energy towards the Pearl River Delta region including regional centers such as Hong Kong, Macau and Shenzhen. Secondly, the orientation of Manila trench means that any tsunami waves generated by fault models, which rupture along the trench, generate much smaller tsunami waves on the Tainan coast where devastating waves were as yet unexplained tsunamis were reported in historical records.

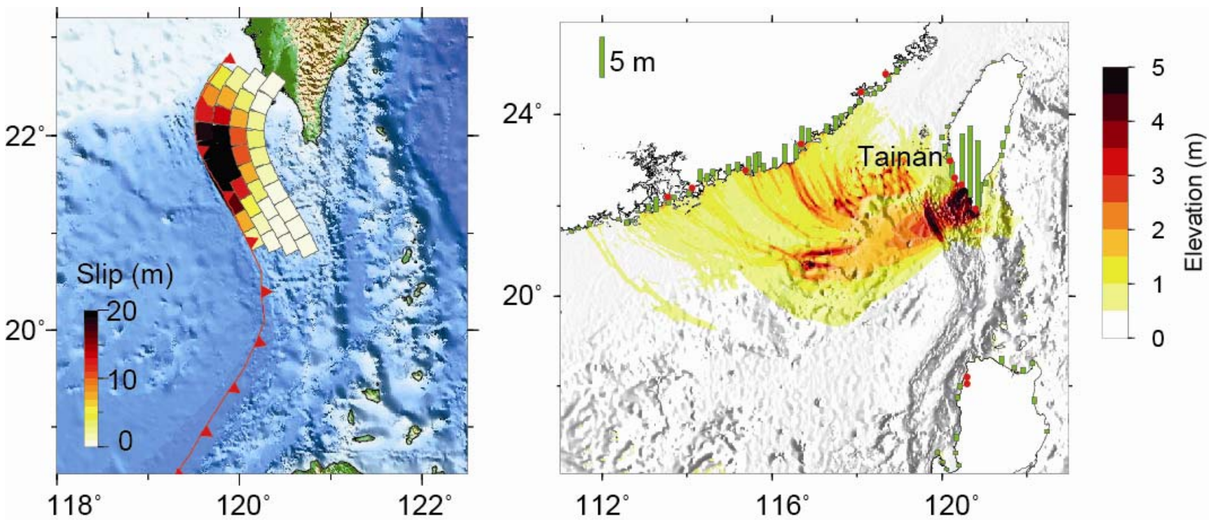

Figure 1. Left: slip distribution of a tsunami earthquake with magnitude 8.2; right: Maximum surface elevation, green vertical bars show the tsunami wave height at 5 m water depth contour near coastal line.

The Hazard Map induced by Tsunami-the case study in Gongliao District

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The casualties and damages brought by the South Asia Tsunami in 2004 and the East Japan Tsunami in 2011 have been noted by the whole world. A great tsunami had stroke the northern coast of Taiwan in 1867. The study area is focused on Gongliao District, New Taipei City. The assumed earthquake scenario originated from Yap Trench is used for Cornell University tsunami model (COMCOT model) which simulates the wave height and wave speed of the tsunami triggered by the earthquake. The wave heights of the northern coast of Taiwan are then used as boundary conditions for overland flow simulation.

The area of flood inundation of 0.3 ~ 0.5m depth is 8.57 ha., that of 0.5 ~ 1.0m is 12.98 ha., that of 1.0 ~ 2.0m of 19.35 ha., that of 2.0 ~ 3.0m is 11.41 ha., and that of 3m or above is 10.61 ha (Fig. 1). The maximum inundation depth, the maximum velocity of the tsunami wave and rate of water level rise are gotten and used for production of tsunami hazard map. The area of very high hazard is 13.53 ha., that of high hazard is 18.56 ha., that of medium hazard is 13.53 13.90 ha., that of low hazard is 16.63 ha., and that of very low hazard is 12.38 ha (Fig. 2). The hot spots of assumed scenario can be read from this map and used to take suitable measures to reduce the social impact, the loss of life, and properties.

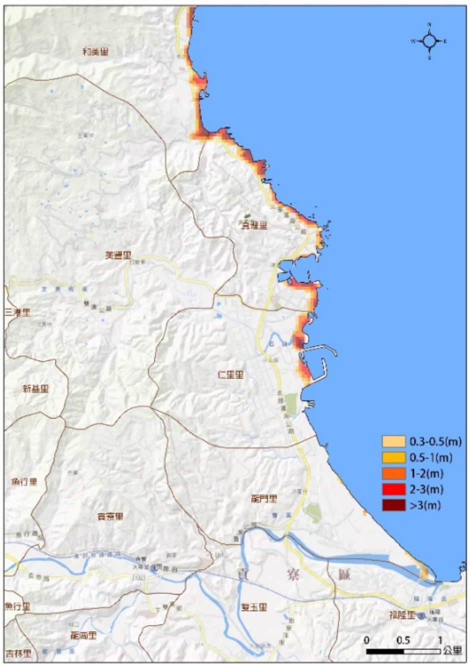

Figure 1 Inundation depth map due to tsunami

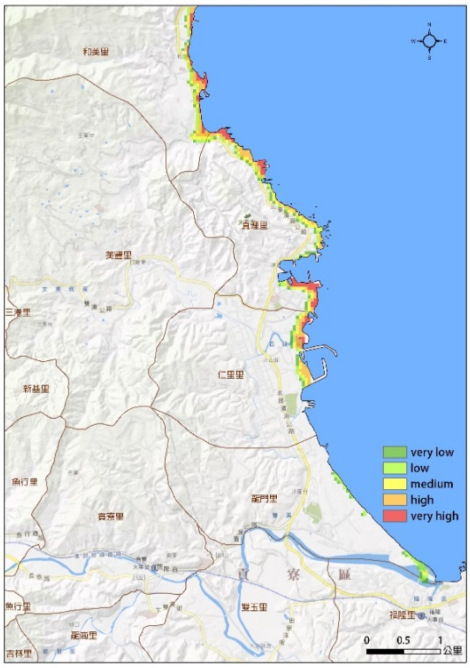

Figure 2 Hazard map due to tsunami

Observations of seismo-traveling ionospheric disturbance triggered by earthquake and tsunami

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In this study, the seismo-traveling ionospheric disturbances (STIDs) in total electron content (TEC) generated by the 2011 Mw9.0 Great Tohoku earthquake at 05:46:23 UT on March 11, 2011, are investigated by using ground-based Global Positioning System (GPS) receiver networks. Not only triggered by seismic surface waves the STIDs formed by tsunami waves are clearly seen during the Tohoku earthquake event.

A method of wavelet analysis is applied to investigate the spectral characters of STIDs induced by the seismic surface waves and the tsunami waves. Results show that the spectrum of STID resulting by surface waves reveals a single short period enhancement, while those by tsunami waves show multiple long-period responses. Additional events, including 2004 Sumatra(Mw 9.1), 2010 Chile(Mw 8.8) and 2013 Solomon(Mw 8.0) earthquakes, are investigated for the general spectral characteristics of seismic surface and tsunami waves.

The occurred time of disturbance can also find on spectra. The velocity of the tsunami is calculated by using DART (Deep-ocean Assessment and Reporting of Tsunami) stations, therefore the propagable area of tsunami can be calculated. Those two information shown the occurred time of disturbances is earlier than tsunami at far GPS station from the epicenter.

This results shows that the arrival time of STID induced by surface waves is earlier than that by tsunami waves, which could be applied as the short-term tsunami warnings.

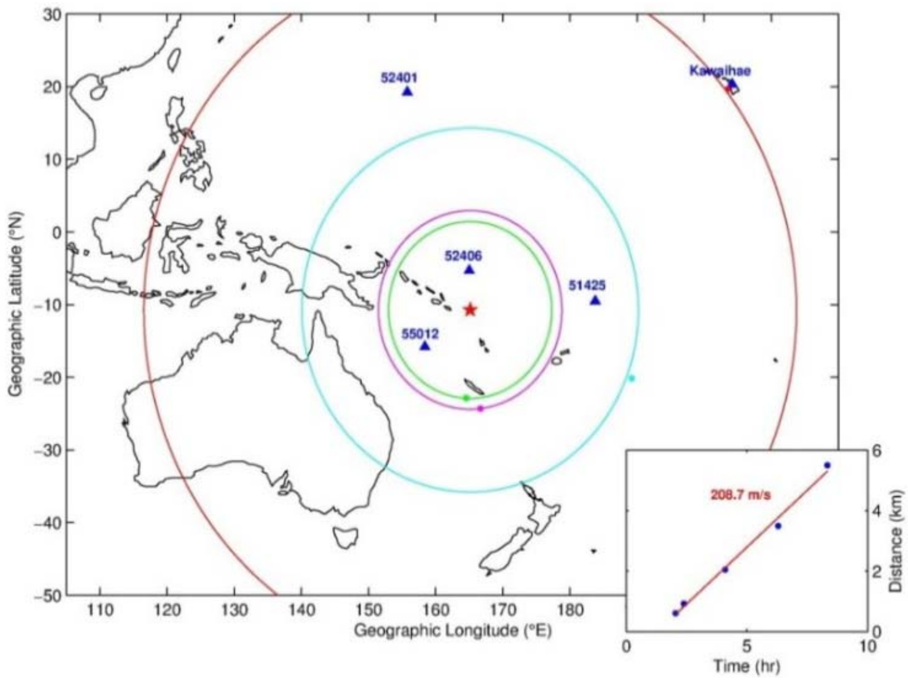

Figure 1. the occurred time of disturbances is earlier than tsunami at far GPS station from the epicenter.

Runup Height for Tsunami Waves of Two Humps and its Application in Eastern Japan Tsunami

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To construct a tsunami inundation map is very complicated because the runup height in the coastal zone, which is defined as the highest altitude the tsunami wave can reach as it propagates toward shore, depends on the incident waveform. For a uniform constant slope, we assume the following waveform for the first few waves

$$\eta = A_1 \exp\{-k_1(x-x_1)^2\} - rA_2 \exp\{-r^2 k_2 (x-x_2)^2\} \qquad (1)$$

where x is the nondimensionalized offshore distance, parameters A_1 and A_2 represent wave height, k_1 and k_2 represent "wavenumber," and r is the ratio of the amplitude at x_1 to that at x_2 according to Green's law and is defined by

$$r = \sqrt[4]{\frac{x_1}{x_2}} \qquad (2)$$

as for a uniform slope, the water depth is proportional to the distance to the shoreline. This ratio is to adjust the wave height of the second peak due to shoaling effect so that all waveforms used in the study have the same wave height. The factor r^2 before the "wavenumber" of the second peak is the modification due to celerity. Note that both factors r and r^2 are introduced to ensure when the first and the second peaks are of the same waveform, they will look alike at location x_1. The difference between x_1 and x_2 is the distance between two successive peaks of the waveform.

The waveform of eq. (1) is the combination of a few parameters and hence many simulation cases are required. To save the computer time, the Carrier, Wu and Yeh (CWY) algorithm of 1D fully nonlinear shallow water equations over a uniform constant slope is used. The results show that the M-shaped wave has the highest runup height compared with other waveforms. The first hump of the most hazardous M wave is a little bit larger than the second hump, and the second hump is much wider than the first hump, no matter how the bottom slope changes. This waveform is dubbed M1 wave, as the left panel of Fig. 1 show.

It is natural to ask if this two-humped waveform can exist in a real tsunami. In Eastern Japan (Tohoku) tsunami, the waveform off the coast of Iwate also has two humps: narrower hump rides on a wider hump, as shown in the right panel of Fig. 1. Tsunami source inversion suggests this waveform is related to the asperity distribution; the fault rupture is nonuniform with very high slippage (larger than 50) occurs in a narrow zone. This asperity distribution may occur in other subduction zones and hence the runup characteristics of two-hump waveform should be further discussed.

Extensive investigation shows runup height of two-humped waveforms similar to that in Iwate can be higher than a bell-shaped wave. Tsunami model COMCOT is compared with the CWY algorithm and satisfactory agreement is obtained.

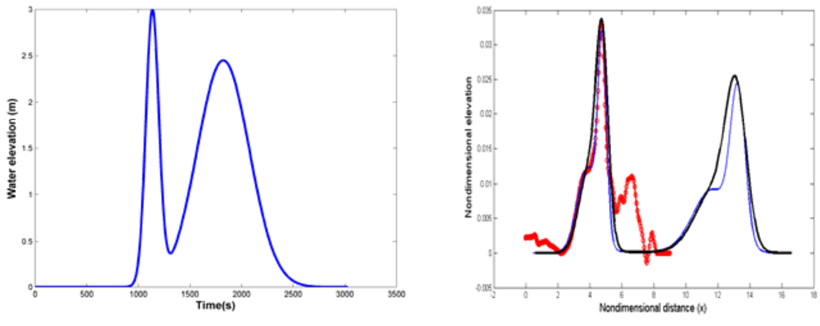

Figure 1. M1 waveform (left) and the waveform measured at Iwate (right).

Potential paleo-tsunami records around the eastern Taiwan area

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Since the 2011 Tohoku-Oki earthquake of Japan, tsunami hazards along the western Pacific have become one of the most important research topics in Earth sciences. As a country regularly hit by tsunamis in the history, Japan probably has the most wealth of paleotsunami studies among all nations of the world. Many of these studies are based on stratigraphic evidence within Holocene deposits. Some historical records of paleotsunamis were confirmed by facies changes of Holocene deposits and dating results of many drilling records in coastal areas of Japan. One well-known example is the confirmation of the great AD 869 Jogan tsunami, which attacked a wide area on the Pacific side of Japan's Tohoku region.

However, such paleotsunami studies have not been emphasized traditionally in Taiwan, albeit the island has a similar tectonic setting as Japan. This is partly due to the fact that disasters caused by storms associated with typhoons occur more frequently in Taiwan and produce more serious damages. In order to look for potential paleo-tsunami records, we have been conducting aerial photo mapping and field investigations in eastern Taiwan. Geological evidence such as multiple sudden facies changes within Holocene deposits are considered as records of possible paleotsunamis at Chenggong, on the eastern coast of Taiwan. Two, maybe three, potential tsunami boulders have also been identified at a site near Jiupeng, at the southeastern corner of Taiwan.

For the past a couple of years, we have also been focused on two small islands, Lutao (Green Island) and Lanyu (Orchid Island), offshore Taiwan's southeastern coast. Potential tsunami boulders on Lanyu are all composed by coral reef blocks, and their sizes indicate that they can only be transported by extremely high-energy waves from the ocean. Although some of the blocks are middle Holocene in age, same as the age of the uplifted coral terraces they are sitting upon, other boulders are only a few hundred years old and their age indicate the event occurred recently. Since all sites are located along the northern coast of Lanyu, directly facing the Ryukyu trench, the young ages of the boulders suggest that they might have been transported during the 1771 Yaeyama earthquake. If so, our results may be the first report of the 1771 tsunami record in the Taiwan area, and would provide significant constrains for future earthquake and tsunami hazard mitigations for Taiwan and the surrounding regions.

The 2013 Bohol earthquake in central Philippines: Hazards and source fault characteristics

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A *Mw*7.2 earthquake shook Bohol Island and central Philippines last 15 October 2013. The earthquake, with an epicenter located 6 km S24°W of Sagbayan (09.97°N, 123.14°E) and a focal depth of 12 km, reportedly originated from the NNE-trending North Bohol Fault. Centroid moment tensor solutions of the main shock and associated aftershocks indicate reverse faults that generally strike northeast. Proximal to the earthquake epicenter, fissures, lateral spreads, tension cracks and karst collapse were prevalent. Sinkholes and slope failures generally occurred in the interbedded clastic and carbonate rocks of the Maribojoc Formation which are relatively less indurated compared to the underlying igneous and metamorphic rocks. Vertical displacement measured along the fault scarp in Inabanga ranges from 1.5 m to 2.9 m while coastal uplift measured from emerged modern coral reef platforms in Loon and Maribojoc ranges from 1.2 to 2 m (Figure 1). A southeast-dipping source fault with reverse slip of not more than 5 meters is modeled based on focal mechanism parameters, aftershock distribution and observed surface deformation (Figure 2).

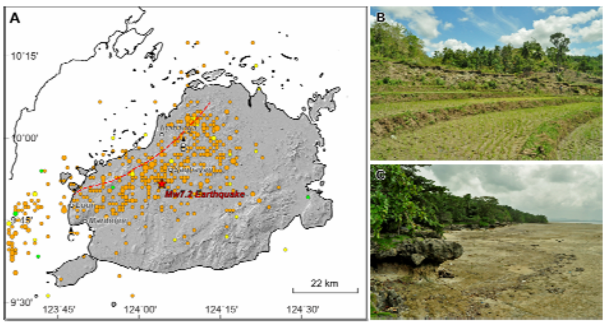

Figure 1. A) Seismicity map of Bohol Island (2013-2014) showing the epicenter (red star) of the 2013 *Mw*7.2 earthquake and the inferred trace of the North Bohol Fault (red dashed line) based on observed surface deformation. Earthquake data is from the Philippine Institute of Volcanology and Seismology (PHIVOLCS). B) Surface rupture in Inabanga showing a 2.5-m-high scarp. C) Uplifted coral reef platform in Maribojoc.

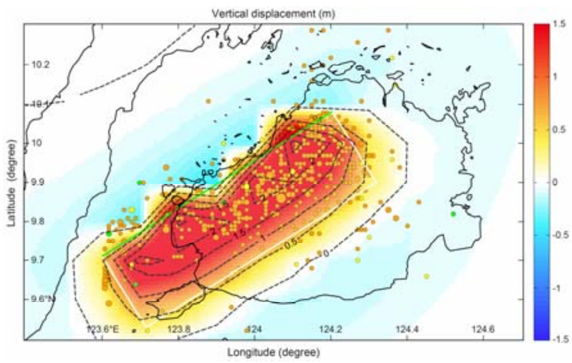

Figure 2. Ideal and simple source fault model of the 2013 Bohol Earthquake based on focal mechanism characteristics, aftershock distribution, height of fault scarp and uplifted modern coral platform. Earthquakes are shown as solid circles.

Expansion of the Tsunami Buoy Array: Beginnings of a Global Network

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Long-Lih Huang, All-Star Technology Corporation, Taipei, Taiwan

The development and growth of commercial tsunami buoy systems have laid the groundwork for the beginnings of a global tsunami buoy network. The proliferation of these systems are providing the foundation for an ever growing integrated operational environment where data, information, and forecasts are openly shared between countries, greatly enhancing real-time, world-wide tsunami threat awareness.

Subsequent to the devastation of the December 26, 2004, Indian Ocean tsunami that killed more than 230,000 people, the global requirement for a reliable commercial system became an international high priority. As a result, Science Applications International Corporation (SAIC) invested internal research and development funds to develop a commercial version of the National Oceanic and Atmospheric Administration (NOAA) Deep-ocean Assessment and Reporting of Tsunamis (DART®) system in late 2006. After a one year test off the coast of California with a DART® system, NOAA evaluated the SAIC Tsunami Buoy (STB) system as having met or exceeded its DART® operational standards.

In 2008, an agreement was signed between SAIC and NOAA’s Pacific Marine Environmental Laboratory (PMEL) licensing SAIC to use DART Technology® in its tsunami buoy systems. In a further expansion of this agreement in late 2009, SAIC began to build a commercial version of the PMEL developed next-generation Easy-to-Deploy (ETD) DART® system. In 2014, SAIC and PMEL signed another technology agreement making PMEL’s newly developed near-field capability available in SAIC’s STB and ETD DART Tsunami Buoy systems.

There has been in exponential growth of tsunami assessment capability since 2004 with the expanding deployment of commercial systems. SAIC has produced over 30 systems for countries including Australia, Chile, China, India, Japan, Russia and Thailand. Where there was previously little or no data in the Indian and Pacific Oceans, reliable systems are now being deployed and maintained in greater numbers, greatly improving the world’s ability to respond to tsunamis through direct measurement made to common data and capability standards. With the significant potential for tsunami generation along the Manila Trench and Ryukyu Islands subduction zones and no deep-ocean reporting stations in the South China Sea and western Philippine Sea, now may be an opportune time for Taiwan to strengthen its capability through the deployment of several tsunami buoy systems. These systems would not only provide much needed data to build upon Taiwan’s existing tsunami assessment capability but could also be a valuable asset to other countries in the region through the open sharing of data.

A thorough review of these systems and potential deployment locations will be presented.

Traveling Ionospheric Disturbances Observed at Ground-Based GPS and HF Doppler Sounding Systems During the 2011 Tohoku Earthquake Tsunami

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Tsunami waves propagating across long distances in the open ocean can induce atmospheric gravity waves by dynamic coupling at the surface. Several studies since 70s suggested that a tsunami may generate atmospheric internal gravity waves (IGWs) and then induce ionospheric anomalies (Hines, 1972; Peltier and Hines, 1976). The first tsunami-related perturbation in ionosphere was observed after the tsunamigenic quake in Peru in 2001 (Artru et al., 2005). The three-dimensional numerical modeling of the ocean-atmosphere-ionosphere coupling for the Sumatra tsunami signature in ionosphere was reproduced in Occhipinti et al. (2006). Furthermore evidence was reported in Okal et al. (1999), Gower (2005), Blewitt et al. (2006), Liu et al. (2006), Occhipinti et al. (2008), and Galvan et al. (2011). The tsunamigenic traveling ionospheric disturbances (TIDs) are due to chemical process such as the recombination of ions and electrons in the lower thermosphere (Kakinami et al., 2012).

A megathrust earthquake with a magnitude of 9.0 occurred off the Pacific coast of the Japanese Tohoku area on 11 March 2011 and the following tsunami propagated through the Pacific Ocean afterward. Although the tsunami and the associated TIDs have been reported, the relationship between them and how to distinguish seismo-induced and tsunami-induced TIDs have not been clarified yet. In this study, both of the seismo-related and tsunami-related ionospheric perturbations have been detected in the ionospheric total electron content (TEC) by means of ground-based GPS measurements. Meanwhile, related ionospheric disturbances are also observed with two networks of HF Doppler sounding systems in Japan and Taiwan. After various data analyses with Hilbert-Huang Transform (HHT), circle method, ray-tracing and beam-forming methods, the characteristics of the tsunami waves in the ionosphere are revealed and discussed (Fig. 1).

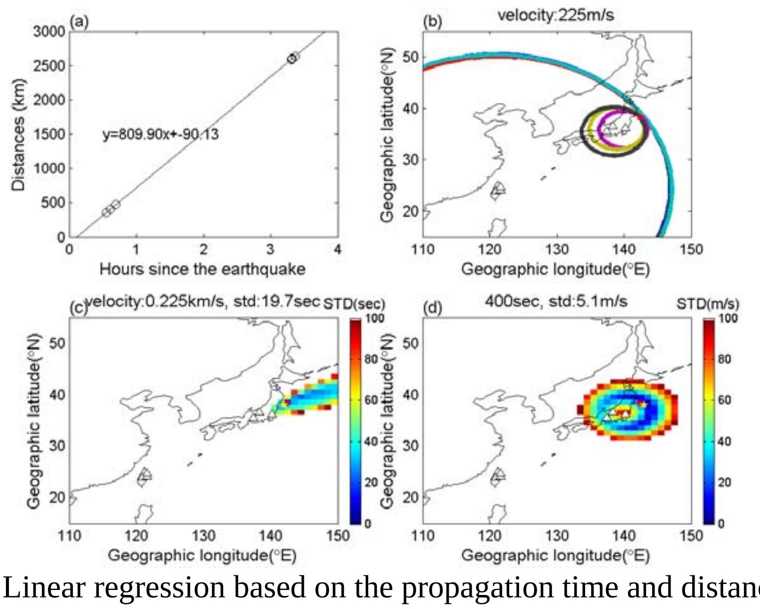

Figure 1. (a) Linear regression based on the propagation time and distances from the epicenter to the ionospheric reflection points after the earthquake; (b) the result of the circle method; (c) the result of the ray-tracing method; (d) the result of beam-forming.

Ionospheric disturbances resulting from tsunami effects

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Recent observations of the GPS total electron contents (TECs) variations indicate that the tsunami effect could result in disturbances in the ionosphere. The tsunami related ionospheric disturbances could travel with a much higher velocity varying from 500 to 1000 m/s, several times faster than the tsunami propagation velocity of ~200 m/s on the sea surface, providing a potential application of tsunami warning. In this study, a whole atmosphere disturbance model (WADM) is utilized to study the tsunami effect in the atmosphere and ionosphere. The model couples the atmosphere and ionosphere and the tsunami effect can be modeled by specifying the lower boundary condition according to sea surface displacement simulated by the tsunami model. The characteristics of tsunami related atmospheric and ionospheric disturbance waves will be examined for its applications of realistic observations.

A tsunami-ionosphere coupling simulation is carried out by assuming over-simplified circular tsunami waves with sea surface displacement of 10 m height and a horizontal propagation velocity of 212 m/s. The results indicate that the tsunami effect to the ionospheric TEC disturbances is prominent. The ionospheric TEC disturbances in the north-south direction (along magnetic field line) propagate much faster than tsunami wave, whereas the TEC disturbances in east-west direction have slower velocity than tsunami. The preliminary simulation result illustrate potential application of the tsunami warning by observing ionospheric TEC disturbances.

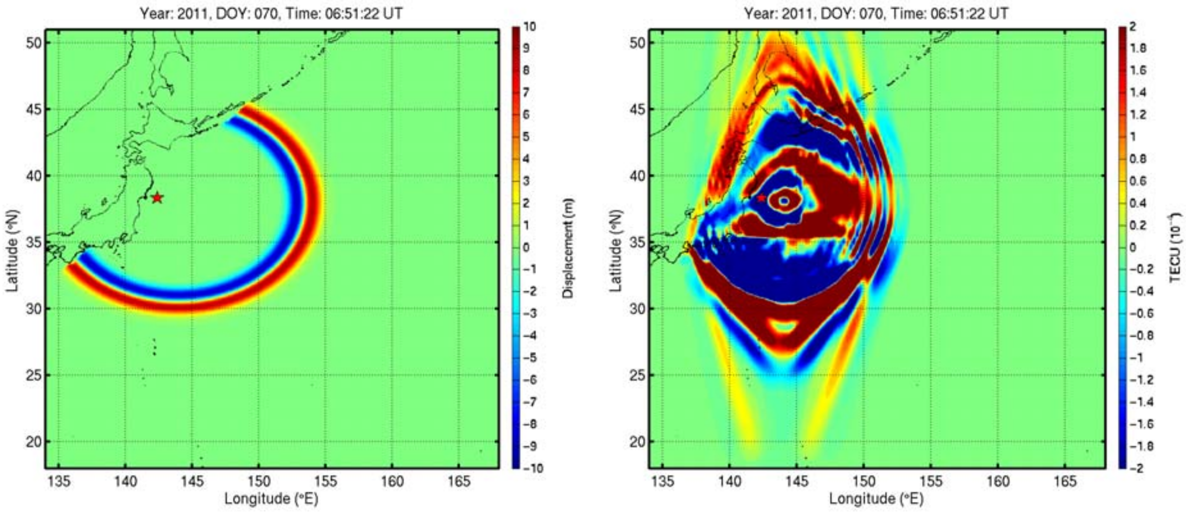

Figure. Simplified tsunami waves with sea surface displacement of 10 m height and unified horizontal propagation velocity of 212 m/s as the perturbation source to tsunami-ionosphere modeling (Left), and the resulting ionospheric total electron content (TEC) disturbances (Right).

Review of the 1867 Keelung, Taiwan Earthquake and Tsunami

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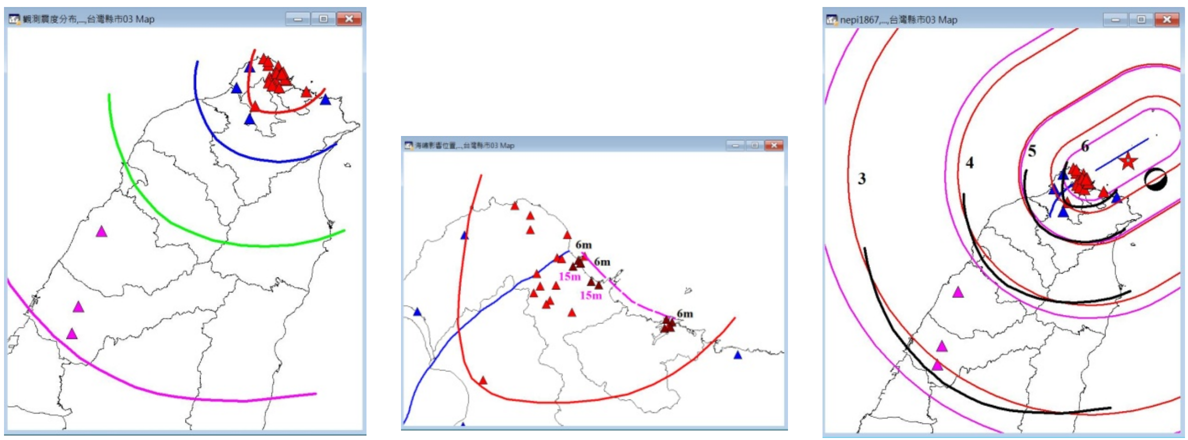
Chien Hsin University of Science and Technology, Taiwan, ROC,

On December 18, 1867, a disastrous earthquake occurred in northern Taiwan, and triggered tsunami, caused hundreds deaths. Because of the age, the lack of relevant information, for this limited understanding of the 1867 Keelung earthquake and tsunami. In this paper, we re-collected and collated historical document begin, and try to build situation of the 1867 Keelung earthquake and tsunami.

According to historical records, this event caused more than 580 deaths: include 400 deaths in Jinshan area, 150 deaths in Shilin area, 30 deaths in Tamsui area, and hundreds deaths in Keelung area. There were tsunami reports observed in Huang-Kang, Shuei-wei, Pa-tao-chi, Bush Island, Heping Island, and Keelung harbor. The height of tsunami is about 6 meters In Huang-Kang and Shuei-wei region. The elevation of flooding area, Jinshan and Pa-tao-chi, are about 15 meters. The results of archeological trench on Heping Island shows that the maximum height of tsunami layer is about 6 meters.

The attenuation law is used to simulate the distribution of intensity. Compare intensity distribution and disaster distribution to discuss the reasonableness of the source parameters. The results showed that the 1867 Keelung earthquake and offshore extension of Shanchiao fault are closely related, the fault length is about 40 km, epicenter: 25.34N, 121.91E, Depth=10 km, the magnitude Mw = 7.0, strike, dip, and rake of possible fault plane are 60, 62, -90.



(a) (b) (c)

Figure 1. (a). The intensity distribution of the 1867 Keelung earthquake. (b). The influence are for the 1867 Keelung earthquake. (c). The simulation results: fault length:40 km, M_W=7.0, epicenter: 25.34N, 121.91E, Depth=10 km (60, 62, -90).

Tsunami amplification factor due to onshore topography

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Watermarks left on trees, buildings and other structures serve as an indicator to the extent of tsunami run-up after an inundation event. However, attempts to reconstruct the same event using numerical models often do not produce similar results to the observed data. As most numerical models utilise the shallow water equations to simulate the entire tsunami propagation from source to shore; the accuracy of the model results are highly linked to the limitations of the model's governing equations. These models could only produce best-fitting results in the offshore domain but as the tsunami moves closer to shore, the results start to deviate. Furthermore, the presence of undulating onshore topography in real-life scenarios means that the results derived from the shallow water equations based numerical model would most probably deviate from post tsunami measured data.

To eliminate such problems, scientists came up with a tsunami amplification factor. This factor is the ratio of the measured onshore run-up to the numerically computed flow depth near shore or on the shoreline. Using this factor, scientists can then attempt to numerically derive an onshore run-up value. Using this definition of the tsunami amplification factor, scientists have came up with different amplification factor values based on their individual study. For example, based on the case of the 1993 Nicaragua earthquake and tsunami event, three different researchers used three different values.

The main motivation of this study is to quantify an amplification factor for different scenarios. In this study, five different onshore cliffs and four different incident wave heights were tested. However, rather than measuring the maximum run-up, six different onshore locations were measured. We found that a steeper onshore slope does in fact amplify the flow depth around the region and the resulting flow pattern is highly turbulent as well. Moreover, using a piecewise linear regression analysis on the data set, we concluded that if the onshore cliff angle is greater than a critical value, the amplification factor becomes rather constant. Another important detail that has to be considered in utilising the amplification factor is the choice of the reference near shore location for flow depth measurement. We managed to show that a simple shoaling relationship from offshore to onshore can be used to link these two locations. This elucidates two points; one, the reference point should not be influenced by wave reflection from the cliff and secondly, further offshore tide gauges or buoys could be used as reference locations if the shoaling criteria can be fulfilled.

Assessment of tsunami hazards from Manila trench to Vietnam using a worst case scenarios

Nguyen Hong Phuong[1], Bui Cong Que, Vu Ha Phuong, Pham The Truyen
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In less than a decade, two massive earthquakes have produced destructive tsunamis in the Indian and Pacific Oceans. The Indian Ocean tsunami of December 26, 2004, generated by the M 9.1 Sumatra-Andaman Earthquake, was one of the deadliest natural disasters in recorded history. The Japan tsunami was generated by the M 9.0 2011 Tohoku earthquake. These two earthquakes were, respectively, the third and fourth largest ever recorded.

Vietnam was spared damage from these tsunamis, because of its sheltered location. These recent tragic events, however, remind us that the Vietnamese coast would be threatened by tsunamis sources in the East Vietnam Sea.

This paper assesses the impact of tsunamis in the East Vietnam Sea potentially originated from a giant rupture along the Manila Trench to the Vietnamese coast. Tsunami heights and arrival times to the major forecast points along the Vietnamese coast are computed using COMCOT model. The results of the worst case scenario (M_w=9.3) and two extreme scenarios were used to assess the tsunami hazards. The simulation results show that Vietnamese coast can be divided into three parts with different levels of tsunami hazard. The highest threat exists along the coasts of Central and North-Central Vietnam, from Quang Binh to Ba Ria – Vung Tau provinces, with maximum wave height of 18 m observed near Quang Ngai coast, and a tsunami would reach this coastline in two hours at the earliest. The northern coastal zone of Vietnam has lower tsunami hazard. In the worst case scenario, maximum amplitudes of tsunami waves at Hai Phong sea port and Nam Dinh city, North Vietnam, are 3.5 m and 3.7 m, respectively, while the travel times to these sites are much longer, over 8 hours. The southern coastal zone of Vietnam has very low tsunami hazard. In the worst case scenario, the maximum amplitude at Ca Mau is 0.12 m, while the travel time is over 10 hours.

While a very large earthquake in the Manila Trench seems improbable, the lesson from recent giant earthquakes is that every subduction zone should be regarded as dangerous. Since the consequences are so dire, it is important to consider such extreme events.

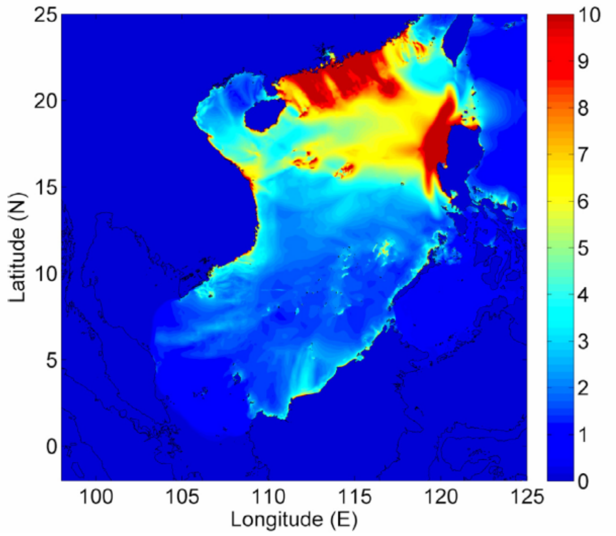

Figure 1. Maximum free-surface elevation in the East Vietnam Sea (m) according to a worst case scenario, M_w=9.3.

Optimization of the Number and Location of Tsunami Stations for the Tsunami Warning in South China Sea

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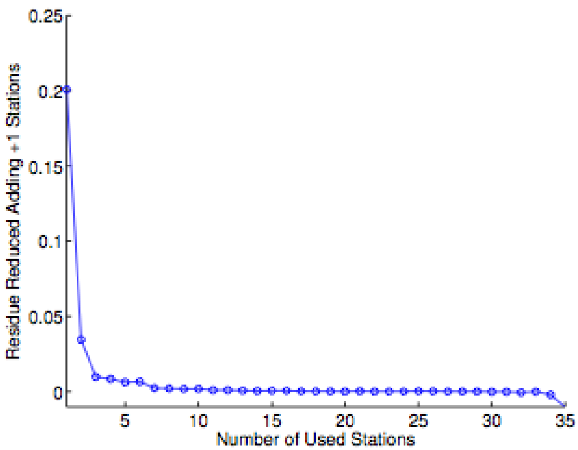
In studies of inversion of tsunami data, it is always good to use as much data as possible. However, limited by the size of computational domain due to computational cost, far-field data is seldom included. Thus, it is desirable to investigate the minimum number of tsunami stations that can provide sufficient data for a valid inversion. In addition, such investigations lead to valuable guidance for the deployment of new tsunami buoys for tsunami warning in a region, e.g., the South China Sea.

During the 2011 Tohoku tsunami event, 28 coastal gauges and DART buoys in the near- to middle-field recorded the tsunami waves. To evaluated their effectiveness in identifying the earthquake parameters, we conducted inversions of tsunami data from various number (1~28) and locations of the stations. Based on the inverse residue, results show that, if the stations are optimally located, 2~4 stations are sufficient to constrain the source parameters. Adding more data from more stations into the inversion does not significant improve the results. It is also found that stations within the source region generally have worse constraint of the earthquake source than stations farther from source, which is due to the exaggeration of model error in matching large amplitude waves at near-source stations. Quantitative discussions on these findings will be given in the talk.

Similar analysis is applied to the Manila Trench based on artificial scenarios of earthquakes and tsunamis. On each of the three main faults of the Manila Trench, an earthquake of Mw 9.0 is triggered and generates tsunamis. Tsunami waves are recorded by 36 artificial surrounding buoys. Again, inversions using various number (1~36) and locations of stations are conducted. In the inversions of tsunami data, slightly different fault geometry and subdivision are used to mimic model errors. Based on the inverse residue, results confirm that only 2~4 stations are needed to well constrain the earthquake source parameters if they are optimally located. Optimal location of tsunami stations is also obtained for each of the three faults and for the average of all the three faults. The two realistic buoys HX1 and HX2 operated by China are also included in the analysis and they give small but not the least residue compared to other buoys.



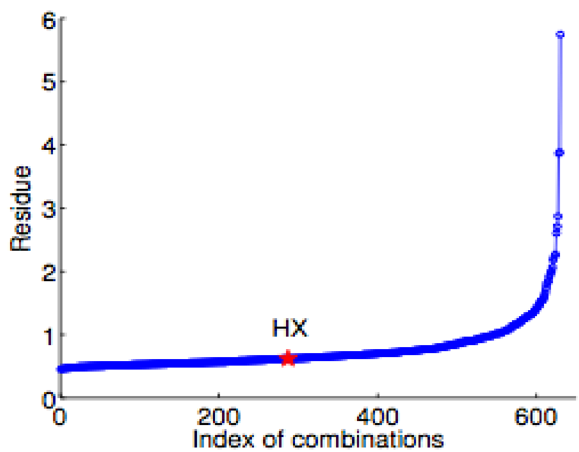


Figure 1. Residue v.s. Number of tsunami buoys; residue from HXs compared to others.

Motion of a single piece of debris in tsunami flows over a sloping beach

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Tsunami induced debris-laden flow is a destructive factor in a tsunami event, since the high speed and energy tsunami waves could destroy and carry anything they could move. A key limitation in understanding tsunami debris-laden flows is lack of both quantitative experimental data and numerical models. Our preliminary results have shown a large difference between the final location and the tsunami inundation limit. In addition to translational motion, the debris model may also have significant rotational motion, which can affect the impact force between debris and coastal structures. In this talk, we will discuss the behavior of a single piece of debris in tsunami flow under different incoming wave conditions. The set of experiments was conducted in a wave flume (34m long, 0.55m wide, and 0.6m height) in the Hydraulic Laboratory, Nanyang Technological University. A slope model is made of PVC and consists of three slopes angle with the corresponding dimension (see Figure 1.) is used to represent the beach profile. One piece of polyethylene block is representing the presence of debris in a tsunami event. This is important for designing tsunami-resistant coastal structures. We will present at the meeting the following results of the motion of a single piece of debris under the following conditions: 1) different magnitudes of the incoming solitary wave, 2) different dimensions of the debris model.

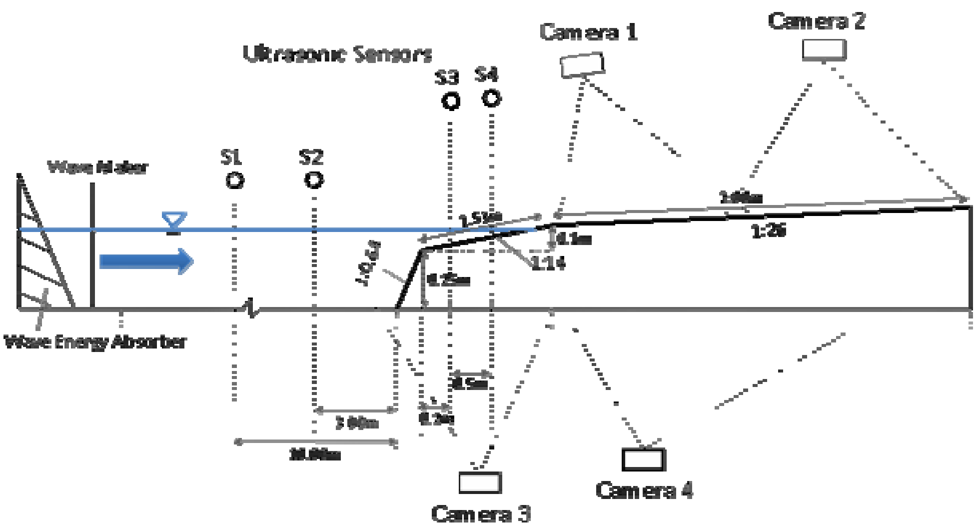

Figure 1 Experimental Setup

HF Radar Detects an Approaching Tsunami Wave Already in Deep Waters

Long-Lih Huang[1], Anna Dzvonkovskaya[2], Malcom Heron[3]
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[2] Helzel Messtechnik GmbH, Kaltenkirchen, Germany
[3] James Cook University, Townswille, Australia

The ocean high-frequency (HF) radar, which is based on electromagnetic wave propagation along the salty and good conducting ocean surface, provides a unique capability for continuously monitoring large areas of ocean. This type of radar is usually operated at a radio frequency between 3 and 30 MHz to measure ocean surface currents over long range that could extend more than 250 km off the coast.

One WERA radar system (**W**av**E** **RA**dar) was in operation on March 11, 2011, when the Great 2011 Japan tsunami waves hit the Chilean coast after 22 hours of propagation time throughout the Pacific Ocean. The radar was located near Rumena, Chile and supplied ocean surface monitoring in that region. The radar measurements were recording during several hours while the tsunami wave train was arriving at the coast. Bragg-resonant backscattering by ocean waves with a half of the electromagnetic radar wavelength allows measuring the ocean surface current velocity. The ocean surface current field changes due to a tsunami event were evaluated using the measured HF radar backscatter spectra. The unique chance to observe a natural tsunami event by means of WERA radar showed that such radars are capable to measure tsunami surface current velocity with a resolution of a few cm/s. Significant deviations in ocean current measurements were observed by the radar system at distances up to 40 km off the coast. It was also observed that as soon as the tsunami waves were moving into shallower water, the surface velocity was increasing. To identify a tsunami induced signature in a measured current field, a moving-average filtering technique to remove regional surface currents was used. After applying this technique the unique tsunami wave train was clearly seen in radar measurements. These tsunami induced were found up to a water depth of more than 800 meters, as displayed in figure 1. The observed results were compared with water level measurements by the tide gauge located 50 km to the south from the radar site. The tsunami wave periodicity was estimated for measurement data. It showed agreement estimating two tsunami wave periods of 14 min and 32 min for both tide gauge and radar measurements.

Installed along the coastal regions at tsunami risk the ocean HF radars can contribute to tsunami early warning systems.

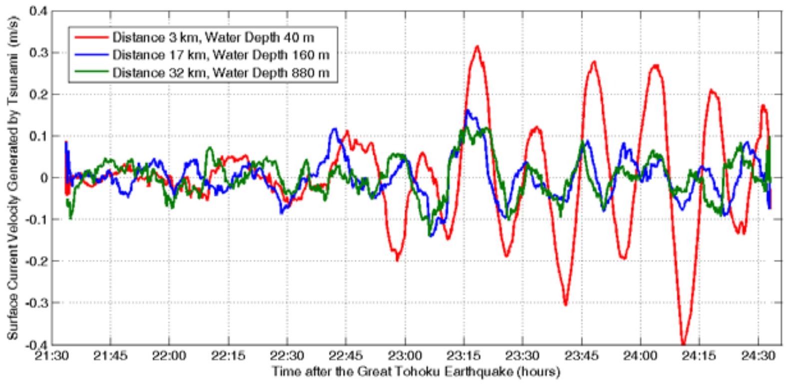

Figure 1. Radial surface currents measured by the WERA HF radar at different distances off the coast of Chile as the tsunami disturbance propagated towards the coast following the earthquake in Japan in 2011.

A Study on Raising Tsunami Awareness, Disaster Preparedness and Risk Reduction Among Young People in the Philippines Using Computer Simulation Games

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The Philippines is one of the most hazard-prone countries in the world. This is due mainly to its geographic and geologic location and physical characteristics. The country is situated in the “Pacific Ring of Fire”, between two tectonic plates (Eurasian and Pacific), an area encircling the Pacific Ocean where frequent earthquakes and volcanic activity result from the movements of said tectonic plates. Recent statistics show that worldwide the Philippines has one of the highest number of people affected by natural disasters and has one of the highest disaster risk index. The country is exposed to a variety of hazards such as floods, earthquakes, typhoons, storm surges, tsunamis, volcanic eruptions, landslides, droughts, etc.

To increase awareness on tsunamis and other natural hazards in the Philippines and to promote disaster preparedness, risk reduction and management we conducted a study among young people in the country using computer simulation games developed by the United Nations/International Strategy for Disaster Risk Reduction. Called “STOP DISASTERS”, this online game features five natural hazards: (1) tsunami, (2) hurricane, (3) wildfire, (4) earthquake, and (5) flood. The subjects of this study are mainly teen-agers from public and private high schools, college level students from public and private universities, and young professionals. The study assessed the benefits of using computer simulation games in disaster risk reduction and the Filipino youth's perception on the disaster simulation game, “STOP DISASTERS.”

After each game, the respondents were asked the following questions: (1) Do you think that computer simulation games can be beneficial in disaster preparedness, risk reduction and management? (2) What do like best in the game “STOP DISASTERS”? (3) What don't you like in the game “STOP DISASTERS”? (4) Would you recommend the game “STOP DISASTERS” to your friends or relatives? Why or Why not? (5) Did the game “STOP DISASTERS” increase your understanding of disaster preparedness, risk reduction and management? (6) Give suggestions/recommendations on how to improve the game “STOP DISASTERS”. Results of the study show that young people find the use of computer simulation games such as “STOP DISASTERS” beneficial in improving their understanding of disaster preparedness, risk reduction and management. Recommendations on how to improve the simulation game “STOP DISASTERS” to suit local situations/conditions in the Philippines are given in the full paper.

Figure 1. Snapshots of Grade 8 Filipino students playing “STOP DISASTERS” during the study.

Application of Tsunami Inundation Potential Maps on Evacuation Planning for Local Governments

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[3] Professor, Department of Civil Engineering, Kao Yuan University, Kaohsiung City, Taiwan

The tremendous tsunami induced by the Tohoku earthquake in Japan caused over 18,000 deaths and missing in 2011 and it drew considerable attention of Taiwanese people. As the threat of a tsunami event, if we can know the potentially affected areas and evacuate residents thoroughly before the tsunami came, the casualties could be reduced tremendously. Some local governments have amended specific characters or sections for tsunami disaster prevention in the Local Disaster Prevention and Rescue Plan. However, many local governments lack of tsunami inundation potential data to draw their tsunami evacuation plans. Therefore, we use tsunami simulation results from Wu (2011) to produce tsunami potential maps for 15 counties/cities in Taiwan. In order to help local governments make tsunami evacuation planning using tsunami potential maps, we completed a guideline including major frameworks, operation steps, and related measures which should be considered. Some examples were given in the guideline to demonstrate how to allocate the tsunami warning area, analyze the population influenced by tsunami, and plan the evacuation route, shelters, evacuation building and highland. This guideline and associated tsunami potential maps for 15 counties/cities have been submitted to the Department of Interior and local governments in Taiwan. One county was taken as an example to illustrate their applications. They may be helpful for local governments to understand where tsunami potential areas are and establish tsunami evacuation plans to protect people's lives.

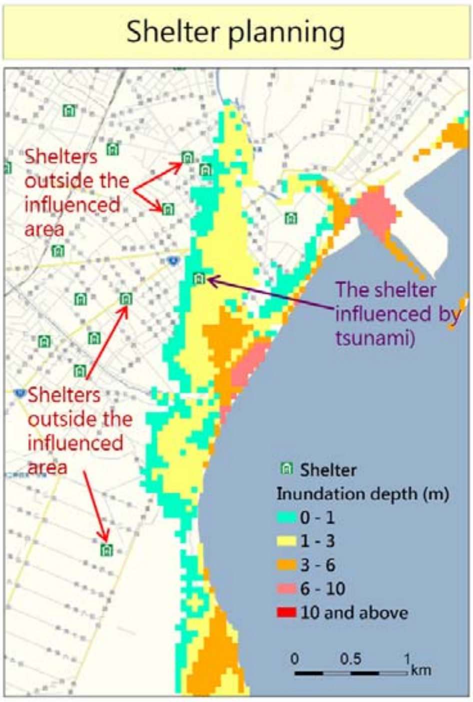

Figure 1. An example of shelter planning

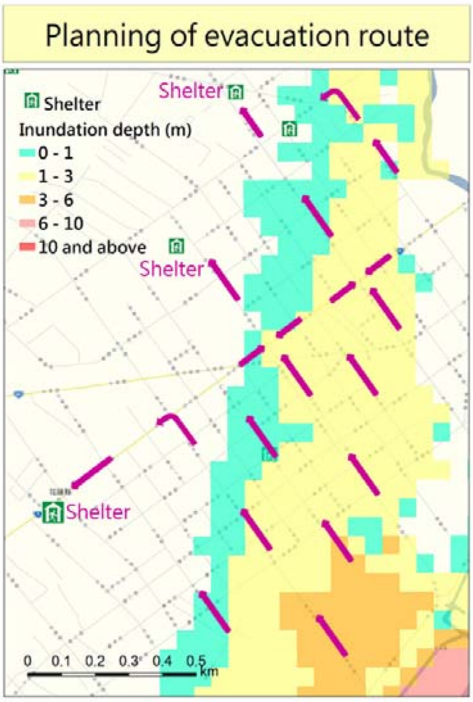

Figure 2. Planning of evacuation route

Novel Wave Glider Based Tsunami Warning System

Matthew DePetro[1], Todd Kleperis[1], and Long-Lih Huang[2]
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Detecting earthquakes from distant, sub-sea tectonic plate movement is a well-developed topic. However, detecting the presence, trajectory, and speed of a resultant tsunami is still a nascent activity. By detecting tsunamis created in the deep sea earlier and more reliably, untold amounts of lives can be saved through coastal warning systems. Various systems have been designed and deployed to meet the challenge of deep sea tsunami detection. Until now, the most prominent system has been the Deep-ocean Assessment and Reporting of Tsunamis (DART) buoy system. In the late 1990's, this system, and the ensuing DART II system, was developed by Pacific Marine Environmental Laboratory (PMEL). In 2004, the DART system was deployed by the National Data Buoy Center (NDBC). Since that time, multiple shortcomings to the system have been identified. The system presented in this paper seeks to address some of those shortcomings.

We demonstrate a comprehensive and persistent tsunami warning system utilizing the Liquid Robotics, Inc. Wave Glider® Ocean Drone and a sea-floor based tsunameter or bottom pressure recorder (BPR) developed by Sonardyne, Inc. The LRI Wave Glider is a revolutionary, wave powered unmanned ocean robot. The Wave Glider can tap into the inexhaustible supply of the planet's wave and solar energy, travel tens of thousands of miles, collect data in the most demanding sea states/conditions (doldrums, high currents, hurricanes/cyclones) and deliver this data in real-time to users around the globe.

The Wave Glider is an extensible platform that can be used to address multiple different applications. Tsunami detection is one of those applications. For tsunami detection, the Wave Glider based system can interface to multiple different BPRs. This includes BPRs deployed with DART buoys and the Sonardyne Tsunami Detection System. The Wave Glider acts as a gateway communications unit between BPRs and satellite constellations. This allows for re-use of an existing and proven infrastructure.

We compare the Wave Glider based solution to buoy offerings and note the unique advantages of the new system. The Wave Glider based system presents multiple advantages over the existing DART systems. The Wave Glider provides a functional time on station greater than a buoy system. The result is a more robust warning system as the communications link between the BPR and Wave Glider is functional more often despite inclement weather or seasonal impediments. Furthermore, the Wave Glider is immediately taskable and navigable from shore so it is able to avoid accidental ship based collisions and intentional vandalism. The result is a new tsunami detection system that is functional more often and easier to deploy and maintain.

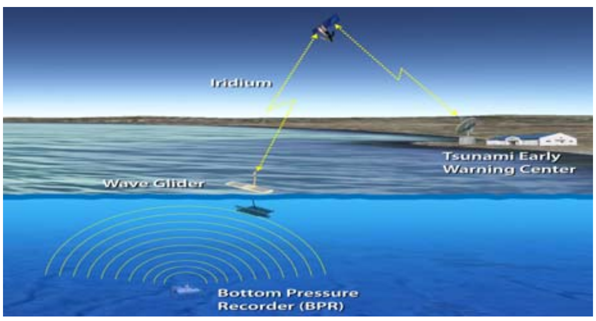

Figure 1. Wave Glider Usage in a Tsunami Warning System

An experimental study on wave attenuation over submerged array of vertical rigid cylinders

Qian Wang[1], Xiao-Yu Guo[1], Ben-Long Wang[1], and Hua Liu[1]
[1]MOE Key Laboratory of Hydrodynamics, Shanghai Jiao Tong University

Aquatic vegetation plays an important role in coastal defense and ecological environment. However, the mechanism of the effects of aquatic vegetation on wave propagation is not understood fully. Understanding the effect of wave height, wave period and water depth on wave attenuation can be helpful to a deep insight into this complicated physical process. In addition, the numerical simulation for the whole problem is hard to do for current computational capability. Hence laboratory investigations are expected to be a reference for numerical validation of some simplified numerical model.

In present study, wave propagation through the submerged vegetation over a horizontal bottom is investigated experimentally. Submerged vegetation is presented by an array of vertical rigid cylinders. Wave attenuation is investigated by laboratory measurement with a mass of test cases. The main factors influencing wave attenuation such as wave height, wave period and water depth are investigated. It is found that long waves dissipate faster than shorter wave with the same wave height and wave attenuation ratios has a trend to be constant for the long waves; In addition, the depth of submergence (the ratio of water depth and cylinder height) plays an important role on wave attenuation. Wave decay along cylinder array follows exponential rule by regression analysis. The dependence of decay ratio on hydrodynamics parameters is discussed. Based on the measured wave height along cylinder array and linear wave theory, the drag coefficient is calculated and the variation of drag coefficient with KC number is obtained. Drag coefficient decreases sharply with KC number and then almost keeps constant for larger KC number. The relative cylinder height has much effect on drag coefficient as shown in Fig.1. Finally, local flow field are measured in a wave flume using an array of wave gauges and PIV system respectively. A four- deck flow structure is proposed to describe the vertical variation of flows around the rigid cylinders.

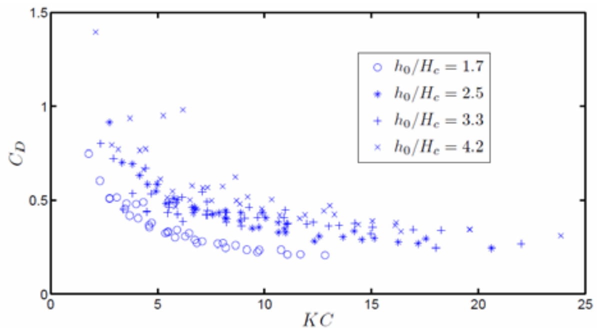

Fig.1 The relation between drag coefficient and KC number

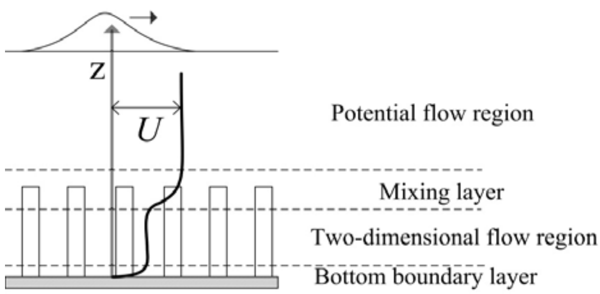

Fig.2 The schematic for four-deck flow structure

Modelling Landslide Avalanches and Resulting Tsunami in a Coupled System

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[2]National Institute of Water & Atmospheric Research, Wellington, New Zealand

Landslides may trigger catastrophic tsunami waves and pose significant threats to boats, coastal infrastructure and communities when entering into water or occurring under water in the form of rock slides, slumps or avalanches. In New Zealand subaerial and submarine landslides have been widely observed. For example, at least three major landslides have been documented from the Waihi Fault scarp at the southern end of Lake Taupo over the past 230 years, i.e. those in 1780, 1846 and 1910. Historical accounts indicate that the latter two spreaded out over a few kilometers and entered into Waihi Bay, causing wide-spread water disturbances in Lake Taupo. Evidence for hundreds of submarine landslides is known around the New Zealand continental margin from multi-beam bathymetry and other geophysical data. Recently, a very well defined landslide scar and matching landslide deposit of approximately 2.5 cubic km was revealed in approximately 2500 m water depth on the side of the deep sea Hikurangi channel.

In numerical studies, the avalanche type of mass failure presents added challenges in the simulation of its failure and tsunami generation processes due to its deformable characteristics in comparison with solid rock slides with little deformation. In this study, we present a two-layer coupled system which simultaneously calculates the evolution of the landslide avalanche and its resulting tsunami. In this system, sub-aerial or submarine landslides are simulated as a viscous fluid or debris avalanche with thickness-integrated mass and momentum conservation equations in a local topography-linked coordinate system. The computed landslide evolution then serves as a transient boundary condition for the simulation of tsunami generation and evolution.

Using this coupled model, we investigated the failure process of the aforementioned submarine landslide as well as the tsunami it might have generated. High-resolution multi-beam imaging was used to define the geometry and volume distribution of this submarine slope failure and reconstruct the pre- and post-landslide bathymetry. The modeled deposition agrees fairly well with the observation (Figure 1). The 1910 Waihi landslide was also studied numerically and the resulting tsunami in Lake Taupo shows consistent patterns with historical descriptions. The coupled model demonstrated a high efficiency in simulating coupled evolutions of landslides and tsunami. This is crucial for large scale computations, e.g. in probabilistic hazard analysis which usually requires a few hundreds to thousands of simulations.

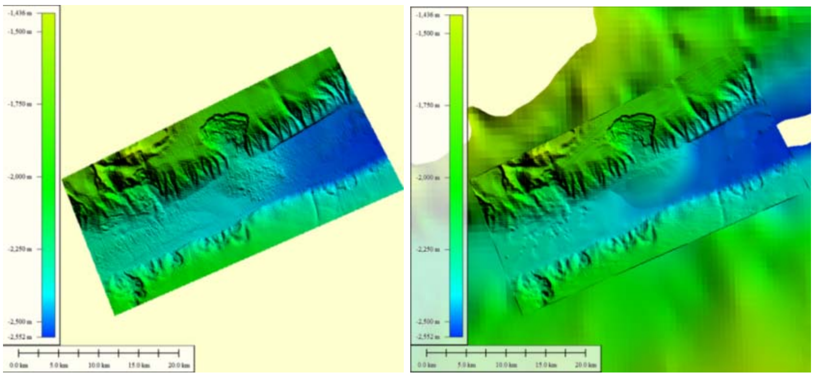

Figure 1. The observed (left panel) and the computed (right panel) depositions of submarine landslide

Modeling Dispersive Tsunami Waves in South China Sea

Zhi-yuan Ren[1], Per A. Madsen[2], Hua Liu[1]
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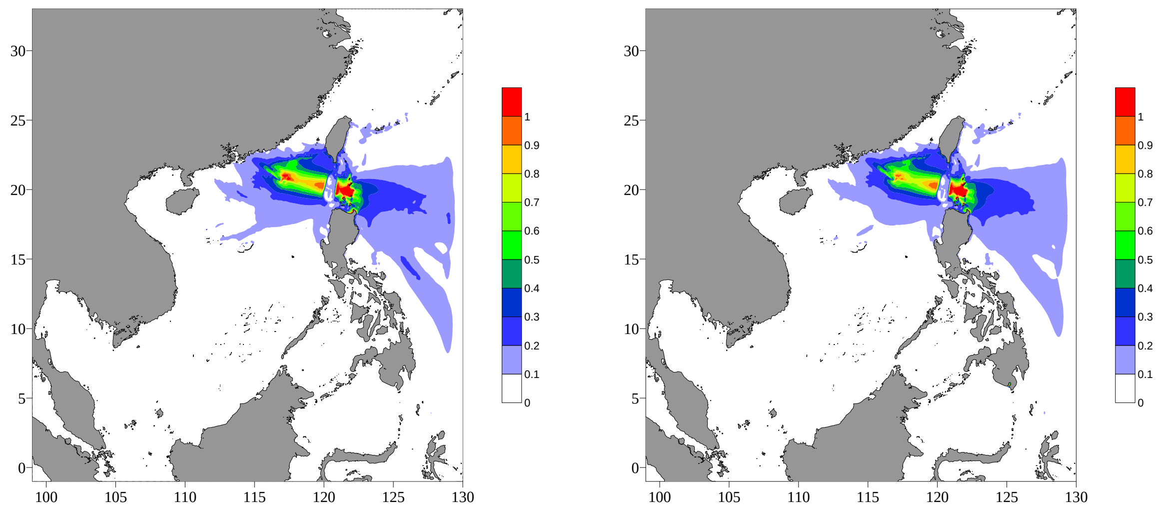
As the Manila Trench is becoming the most tsunami-hazardous in South China Sea, it is interesting to ascertain the dispersion effects of tsunami wave in the field of tsunami simulation, generated from potential earthquake source along the Manila subduction zone. To describe the dispersion effect, two tsunami numerical models have been coupled. The Okada model is employed to generate tsunami, and the wave field at the first 5 min from the tsunami beginning is simulated with GeoClaw. The surface elevation and depth-averaged horizontal velocity at t=5 min are then interpolated in the weakly dispersive model (FUNWAVE) to calculate tsunami propagation and far-field impact.

The 2011 Tohoku tsunami has been simulated to validate this model coupled scheme. In addition, the simulation results with and without dispersion have been compared and analyzed. As could be expected from the short distance from the epicenter, little dispersion effects are shown in the near-field, while the dispersion effects are a little significant in the far-field.

To investigate the dispersion effects in South China Sea, the wave filed is investigated and analyzed due to the hypothetical earthquakes with magnitude of M_w=8.0, and an excessive tsunami with M_w=9.35, respectively. At the given measured points, including Sanya, Hong Kong, Kenting, Quy Nhon, Manila, and Brunei, the leading waves with and without dispersion effects have have no differences, while only a little difference after several hours exist. A non-dimensional parameter defined by Glimsdal et al. (2013) as “dispersion time”, is used to analyze the significance of dispersion effects in South China Sea. The dispersion effects are not significant, partly because the distance from the epicenter to coast is short, e.g. the distance to South China Coast (Hong Kong) is 800km, to Hainan Island is 1000km, and to Quy Nhon is more than 1200 km. However, it is a little significant for tsunami in Pacific Ocean for long distance propagation.



a. Shallow water equations　　b. Boussinesq equations

Figure 1. Maximum surface elevation without and with dispersion effects refer to M_w=8.0.

A numerical investigation on run-up of non-breaking double solitary waves with equal wave heights on a plane beach

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It is a classic research topic of long wave run-up on a plane beach in tsunami studies. Tsunami waves usually appear as a wave train when they attacked coastlines. Studies of the run-up of multiple waves could give insight into the dynamic behaviors of tsunami waves and inundation on coasts. We calculated the evolution of run-up of double solitary waves on a plane beach using the nonlinear shallow water equations (NSWEs) and the Godunov scheme.

The numerical model was validated through comparing the present numerical results with analytical solutions and laboratory measurements available for propagation and run-up of single solitary wave. Good agreements are observed between numerical model and analytical formula and laboratory data. It turns out that the present model is valid for run-up of long waves.

The run-ups of double solitary waves were simulated using the numerical model. Two successive solitary waves with equal wave heights and variable separation distance of two crests were used as the incoming wave on the open boundary at toe of a slope beach. The run-ups of the first wave and the second wave with different separation distances were investigated. It was found that the run-up of the first wave does not change with the separation distance and the run-up of the second wave is affected slightly by the separation distance when the separation distance is gradually shortening. A unified separation factor σ^* related to wave heights and slopes was proposed. With the unified factor, it is found that $0<\sigma^*<0.27$ is the attenuation zone, $0.27<\sigma^*<0.6$ is the amplification zone and $\sigma^*>0.6$ is the undisturbed zone as shown in Figure 1. Moreover, the run-ups of double solitary waves were compared with the linearly superposed results of two individual solitary-wave run-ups. Comparison revealed that linear superposition gives reasonable prediction when the separation distance is large, but it may overestimate the actual run-up when two waves are close.

The detail of the numerical model, the validation, the simulation of single solitary wave and double solitary waves will be presented in the full paper.

Tsunami Generation and Propagation by the Dislocation of the Whole Manila Trench

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After Chi-Chi earthquake, the concept of asperity has been adopted in evaluating trench rupture slip rates. Here the analysis of entire Manila Trench dislocation is conducted based on behaviors obtained from 2011 Japan Trench activities in which asperity had been taken into account. Moreover, a scenario that a northward shifting of rupture is also considered in order to further evaluate the probable impact on the vicinity of Manila Trench.

SEC-HY21 is an integrated software package developed by Sinotech Engineering Group for two-dimensional depth-averaged hydraulic simulations. Finite-volume well-balanced Roe/TVD schemes on unstructured grids to solve nonlinear two-dimensional shallow water equations are adopted for simulating tsunami propagation and runup. The developed numerical tsunami model is tested by the exhaustive series of benchmarks suggested by NOAA (Synolakis, et al., 2007). In this study, the application of SEC-HY21 on tsunami simulation is introduced to simulate the potential tsunami triggered by fault movements along the Manila Trench.

In SEC-HY21, the Okada (1985) formulation based on the elastic earth crust theory is applied to specify the initial waveform. From Fig. 1(a), it can be observed that the initial wave height with 20% asperity taken into consideration can reach an elevation of 23.62 m. Then, tsunami propagates rapidly in deep-water regions but becomes slower in the shallower regions. Fig. 1(b) ~ Fig. 1(d) demonstrate the simulation results of tsunami propagation. It is shown that once the tsunami generated by the dislocation of Manila Trench occurs, the west coast of Luson island group of the Philippines will soon be attacked with a wave height of 10 ~ 20 meters. The highest sea water level at the east coast of Vietnam is about 3 ~ 5 meters, occurred 2 hours after the initiation of the tsunami. The southeast coast of China will also be affected by waves 5 meter high, the first wave front and the highest tsunami wave arrive 2.5 and 3 hours after the quake, respectively. The first wave front hit the coast of Taiwan from Tainan to Pingtung in 12 minutes, and the highest tsunami wave arrives in 1 hour.

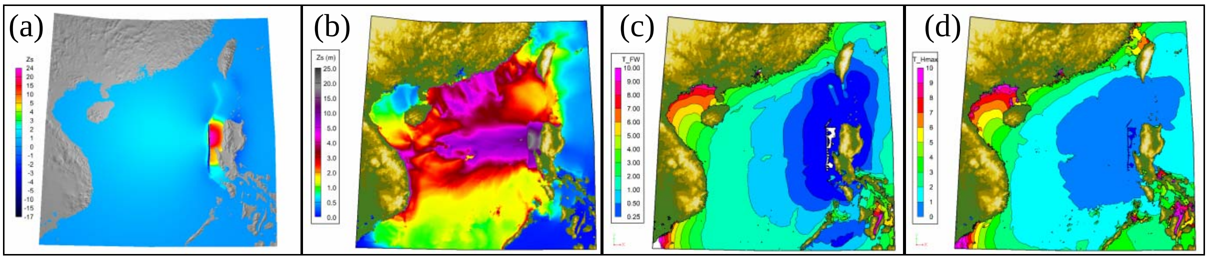

Figure 1. (a) Initial wave form (b) Highest sea water level (c) Propagation time of first wave front (d) Occurrence time of highest sea water level

On the magnetic anomaly at Easter Island during the 2010 Chile tsunami

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A magnetic anomaly was recorded at Easter Island on 27 Feb 2010 during the Chile tsunami event. By joint analysis of the magnetic observations, tide gauge data and numerical results of the global tsunami propagation, we show the close resemblance between the predicted spatial and temporal magnetic distributions and the field data, indicating the magnetic anomaly at Easter Island was actually induced by the motion of seawater under tsunami waves.

We start with modeling the sea surface elevation during the selected tsunami events, employing the phase resolved global tsunami propagation equations. Giving that the free surface elevations are known from the global tsunami propagation model at Easter Island during the tsunami event, we are able to address the associated kinematic dynamo problem. The space-time behavior of magnetic anomalies induced by tsunamis in open oceans has been investigated. It was found that the magnitude of the magnetic anomaly induced by a 0.2 m tsunami is on the order of 1.0 nT at the sea surface. Based on the spatial and temporal behavior of magnetic signals over the ocean surface, the motion of seawater at certain scales could be detectable by in situ measurements or by unmanned airships near space or satellites in space, which may provide a novel methodology for scientific research.

Two consequences then follow: first, large scale tsunami do induces observable magnetic anomaly over the total earth magnetic field, which inspires new methodology for disaster detecting and warning systems. Second, the mechanism governing the motion of the seawater to induce such a magnetic field can be properly explained using linear kinematic dynamo theory.

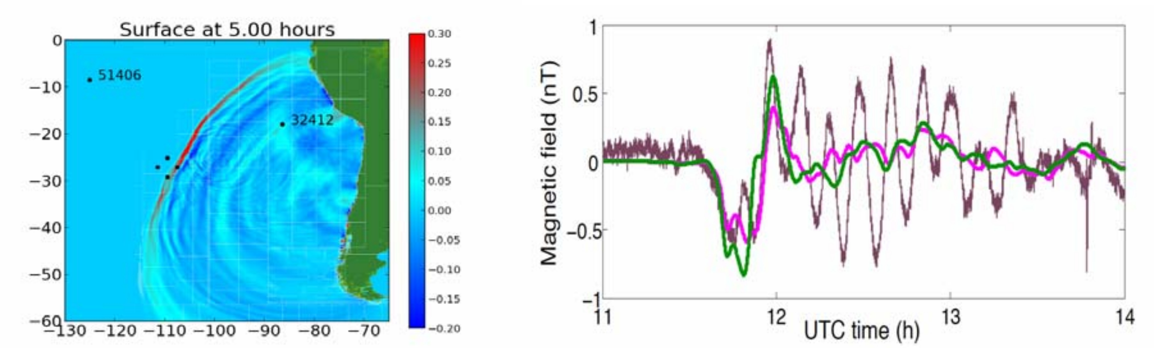

Figure 1. Left: Sea-surface elevations during propagation of the tsunami waves across the South Pacific Ocean. The dual-crest wave front can be observed around East Island. Right: Comparison of the predicted and field observed magnetic field at IPM. Thin line is field data at IPM, thick lines are predicted curves with present theory.

An Inversion Method for Determining Tsunami Source Spatial Distribution by Remote Water-Level Measurements

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One of the major issues of the tsunami modeling is gaining some insight into a tsunami source. It is known that only after a certain time after an event has occurred, having analyzed various seismic, tidal and other data, it appears possible to estimate the basic characteristics of the tsunami source. Thus, numerical simulation of a tsunami source is one of available tools for the research into tsunami problems.

This paper proposes an approach to reconstructing the initial tsunami waveform in tsunami source areas based on the inversion of remote measurements of water-level data. The forward problem of tsunami wave propagation is considered within the scope of the linear shallow-water theory. The ill-posed inverse problem is regularized by means of the least-square inversion using the truncated SVD approach. As a result of the numerical process, an r-solution is obtained. This solution is a projection of the exact solution onto a linear span of the r first right singular vectors corresponding to the largest singular values of the direct problem operator. It is reasonable that the larger r, the more informative the solution. However, the number r depends on the rate of decreasing a singular spectrum of the resulting matrix, which is tightly bounded with the parameters of the observational system. A sharp decrease in the singular values, when their number increases, is typical of all calculations in all our cases of the study due to the ill posedness of the problem.

Analyzing the singular spectrum of the matrix enables us to control the numerical solution instability and to obtain an acceptable result in spite of the ill-posedness of the problem and, which is also important, to make an assumption about the forthcoming goodness of the inversion by a given monitoring system. Finally, we have clarified the dependence of the inversion goodness on certain characteristics of the observational system such as the number and location of receivers, frequency or temporal range of data and signal-to-noise ratio. One of the main advantages of the method proposed is that it is completely independent of any particular source model.

The following fundamental questions are investigated: (1) What a minimum number of marigrams should be used to reconstruct a tsunami source well enough? (2) Where should the receivers of the water-level oscillations be disposed in a defended region? (3) How accurately can a tsunami source be reconstructed based on recordings at a given monitoring system? (4) Is it possible to improve the quality of reconstructing a tsunami source by distinguishing the "most informative" part of the observational system? We discuss our results of modeling for synthetic data and different types of computational domains including a real bathymetry in terms of answering these questions.

It is shown that the accuracy of the tsunami source reconstruction strongly depends on the signal-to-noise ratio, the azimuthal and temporal coverage of recording stations with respect to the source area, and bathymetric features along the wave path. The “most” informative are the records distributed along the reflection ray corresponding to the direction of the most variable shape of the source. This result should be kept in mind when designing a tide-gauge network to study a tsunami source.

Shuttle Bus Schedule

Departure Time	Destination	Bus No.
18th November		
17:30	National Museum of Natural → 921 Earthquake Museum of Taiwan	line A
21:10	921 Earthquake Museum of Taiwan → National Museum of Natural	line A
19th November		
08:10	National Museum of Natural → 921 Earthquake Museum of Taiwan	line A
08:20	High Speed Rail Taichung Station(Exit No. 6) → 921 Earthquake Museum of Taiwan	line B
17:40	921 Earthquake Museum of Taiwan → National Museum of Natural	line A
20th November		
08:10	High Speed Rail Taichung Station(Exit No. 6) → National Museum of Natural	line A
21th November		
18:00	National Museum of Natural → High Speed Rail Taichung Station	line A
21:00	The Splendor Hotel → High Speed Rail Taichung Station	line B
22th November		
09:00	The Splendor Inn → Earthquake Museum of Taiwan	line A
09:10	The Splendor Inn → Nuclear Power Plant	line B

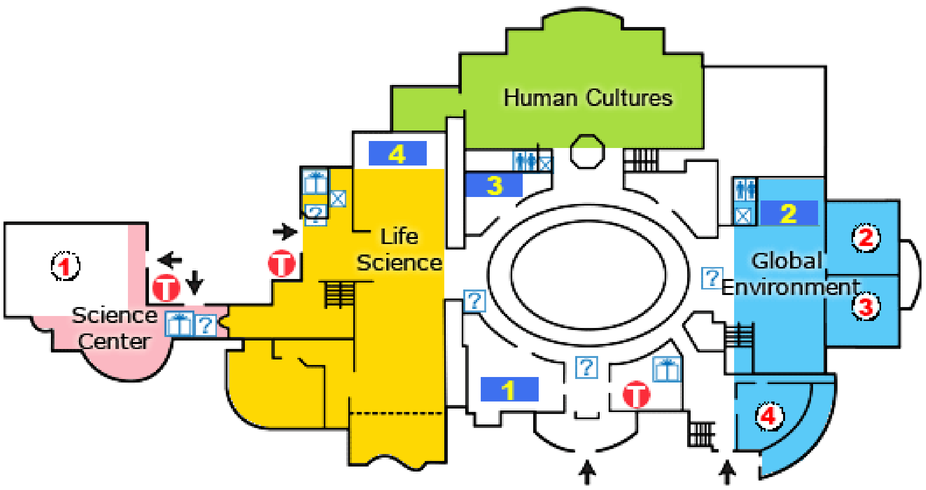
Floor Plan (B1) of Venue

Life Science Human Cultures Global Environment

Toilet Elevator stairs

① Science Classroom (1)
② Science Classroom (2)
③ Conference room: Blue Hall
④ Conference room: Red Hall

Map of National Museum of Natural Science



- Science Center
- Life Science
- Human Cultures
- Global Environment B1:SOS
- Information
- Shop
- Toilet
- Elevator
- (1) Space Theater
- (2) Environment Theater
- (3) Bird's Eye View Theater
- (4) 3-D Theater
- 1 The 1st Special Exhibition Gallery
- 2 The 2nd Special Exhibition Gallery
- 3 The 3rd Special Exhibition Gallery
- 4 The 4th Special Exhibition Gallery
- Ticket Office
- Entrance

Note

Note

Note