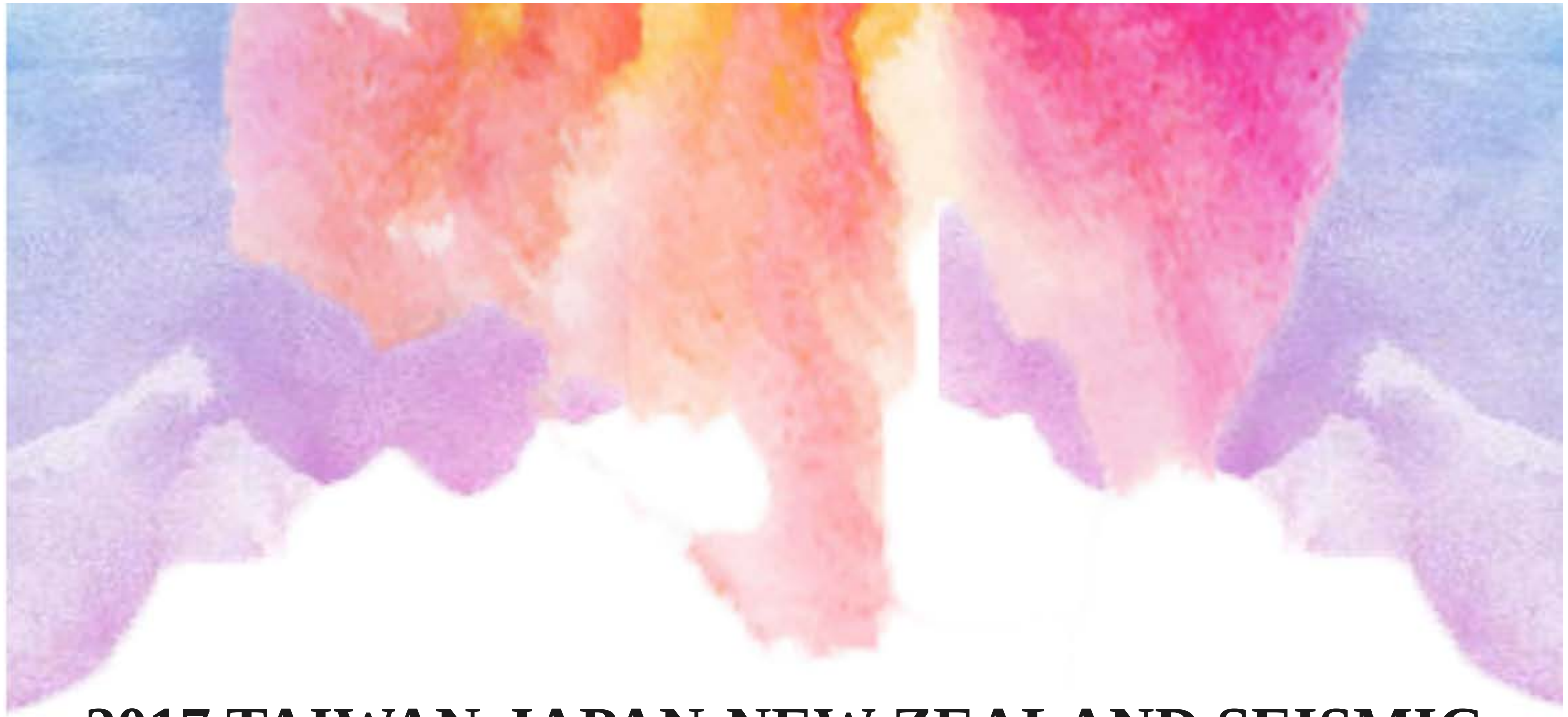


2017 TAIWAN-JAPAN-NEW ZEALAND SEISMIC HAZARD ASSESSMENT MEETING

National Cheng Kung University, Tainan, Taiwan

30 Oct. 2017 – 03 Nov. 2017

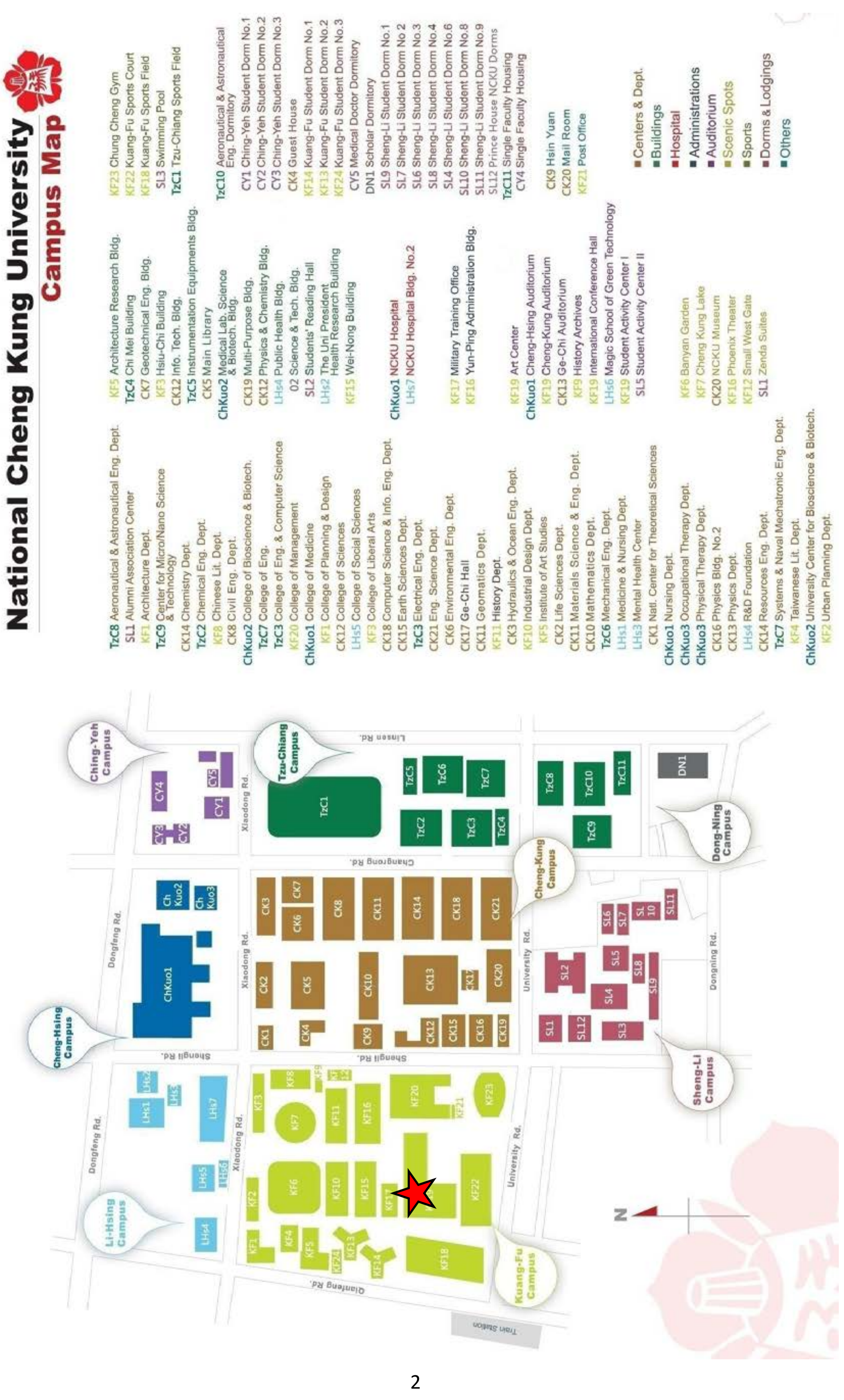
Program and Abstracts

Conference: 2017.10.30 – 2017.10.31

Field Trip: 2017.11.01 – 2017.11.03

Contents

Campus Map



★ 3rd Lecture Room, International Conference Hall, Kung-Fu Campus, NCKU

Venue Map

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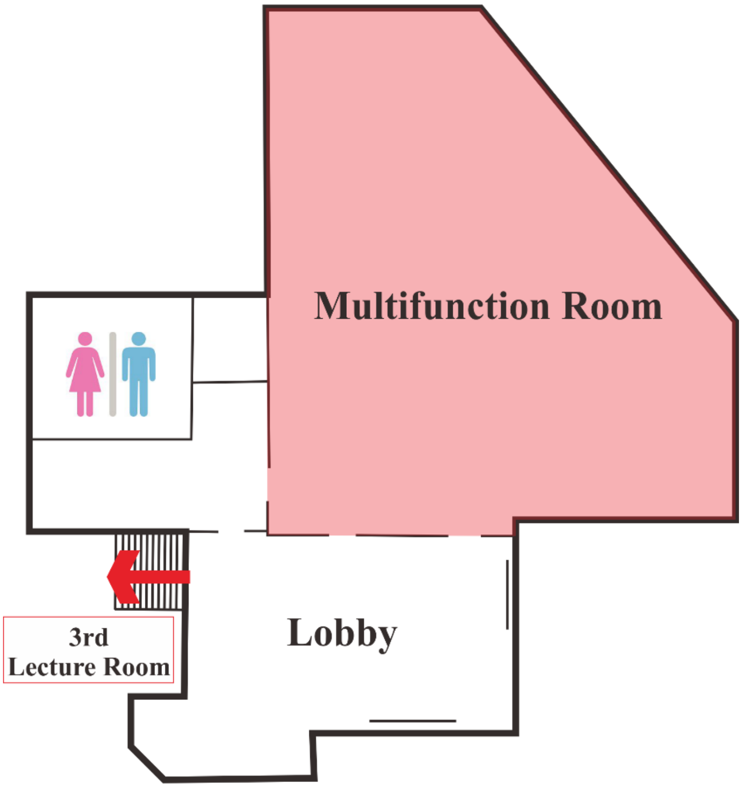

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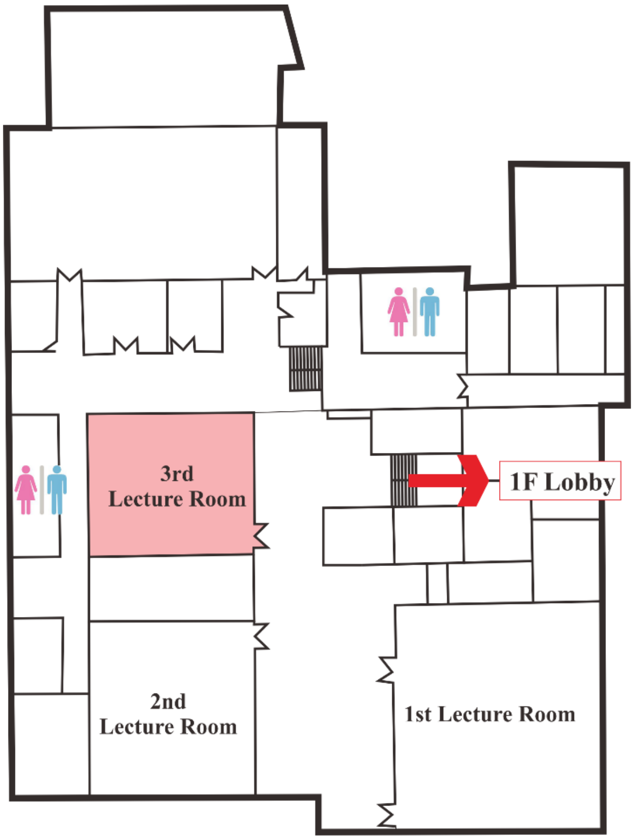

Conference Agenda

Oral Session

October, 30, 2017 (Monday)

Location: 3rd Lecture Room, International Conference Hall

08:30-09:00	Registration	
09:00-09:10	Opening (Ruey-Juin Rau)	
Session I: PHA Progress		
Chairs	Ruey-Juin Rau and Bill Fry	
Time	**Presenter**	**Title**
09:10-09:25	Matt Gerstenberger (GNS)	Recent seismic hazard modelling in New Zealand
09:25-09:40	Hiroyuki Fujiwara (NIED)	National seismic hazard maps for Japan and an integrated system for sharing information, J-SHIS
09:40-09:55	Ruey-Juin Rau and Ya-Ting Lee (NCKU & NCU)	The 2017 update of TEM PSHA
09:55-10:20	Mark Petersen (USGS)	Overview of U.S. National Seismic Hazard Model
10:20-10:50 Coffee Break		
Session II: NSHM Model Validation		
Chairs	Matt Gerstenberger and Kuo-Fong Ma	
Time	**Presenter**	**Title**
10:50-11:05	Nobuyuki Morikawa (NIED)	Validation of new probabilistic seismic hazard maps for Japan
11:05-11:20	Mark Stirling (U of Otago)	Points in hazard space: testing PSHA with multiple metrics
Session III: Deformation Model and Earthquake Hazard		
Chairs	Ian Hamling and Kuo-En Ching	
Time	**Presenter**	**Title**
11:20-11:35	Ian Hamling (GNS)	Geodetic observations of the pre-, co- and post-seismic deformation associated with the 2016 M_W 7.8 earthquake and its implications for seismic hazard in the region
11:35-11:50	Kuo-En Ching (NCKU)	Seismic hazard of the Hengchun Fault based on the geodetic data from 2002 to 2013
11:50-13:30 Lunch		

Session IV: Site Amplification		
Chairs	Katsumi Kimura and E. Abbott	
Time	**Presenter**	**Title**
13:30-13:45	Anna Kaiser (GNS)	The role of complex site and basin response in Wellington city, New Zealand, during the 2016 M_W 7.8 Kaikōura earthquake and other recent sequences
13:45-14:00	Shigeki Senna (NIED)	Modeling of the subsurface structure from the seismic bedrock to the ground surface for a broadband strong motion evaluation in Kumamoto plain
14:00-14:15	Chun-Hsiang Kuo (NCREE)	Site amplification and the effect on local magnitude determination
14:15-14:45 Poster Session and Coffee Break		
Session V: Ground Motion Prediction and Scenarios		
Chairs	Takahiro Maeda and M. Stirling	
Time	**Presenter**	**Title**
14:45-15:00	Takahiro Maeda (NIED)	Long-period ground motion simulation, and application of the simulation data to damage estimation of high-rise buildings
15:00-15:15	Po-Shen Lin and Yin-Tung Yen (Sinotech)	The integration of ground-motion prediction equations and ground motion simulations
15:15-15:30	**Group Photo**	
15:30-17:30	**Poster Session and Group Discussion**	
18:30 ~	**Banquet (2F, Hotel Tainan)**	

Group Discussion

- ✓ Group 1: PSHA and model validation (Ken Hao and Matt Gerstenberger)
- ✓ Group 2: Ground motion prediction and site amplification (Po-Shen Lin and A. Kaiser)
- ✓ Group 3: Scenarios and subduction zone modeling (Bill Fry and Takahiro Maeda)
- ✓ Group 4: Hazard and risk products (Matt Gerstenberger and Kuo-Fong Ma)
- ✓ Group 5: Fault structure and deformation model (Bruce Shyu and A. Nicol)

October, 31, 2017 (Tuesday)

Location: 3rd Lecture Room, International Conference Hall

Session VI: Fault Structure and Subduction Zone Modeling		
Chairs	Takashi Azuma and Bruce Shyu	
09:00-09:15	Andy Nicol (U of Canterbury)	Large magnitude earthquakes and seismic hazard in New Zealand
09:15-09:30	Ken Xiansheng Hao (NIED)	Surface rupture and crustal deformation around the Hundalee Fault during the 2016 Kaikoura M_W 7.8 earthquake
09:30-09:45	Marco Pagani (GEM)	Modeling subduction earthquake sources for seismic hazard analysis
09:45-10:45 Poster Session and Coffee Break		
10:45-12:00	Discussion	
12:00-13:30 Lunch		
Session VII: Hazard and Risk Products		
Chairs	Ken Hao and Chung-Han Chan	
13:30-13:45	Toshihiro Yamada (OYO RMS Corporation)	Prototyping Korean PSHA Model
13:45-14:00	Lizzie Abbott (GNS)	Seismic hazard and risk products in New Zealand
14:00-14:15	Kuo-Fong Ma (NCU)	Taiwan Earthquake Model (TEM): from understanding of Seismic Hazard to Risk assessment
14:15-15:00 Poster Session and Coffee Break		
15:00-17:00	Discussion & Conclusions	

Poster Session

October, 30 - 31, 2017 (Monday - Tuesday)

Location: Multifunction Room

	Name	Title
1	Shinichi Kawai (NIED)	Japan seismic hazard information station, J-SHIS
2	Hiromitsu Nakamura (NIED)	Improvement of the real-time system for damage estimation (J-RISQ) based on the 2016 Kumamoto Earthquakes
3	Shohei Naito (NIED)	Development of image recognition and machine learning methods for estimate damage of buildings by use of the aerial photographs acquired at the 2016 Kumamoto Earthquake
4	Hiroki Azuma (NIED)	Building observation via smartphone as a seismometer
5	Katsumi Kimura (NIED)	Construction of 3D geologic model with concealed active faults using thousands of borehole data in the Tokyo Lowland, Japan
6	Hongjun Si (Seismological Research Institute Inc.)	High attenuation rate for shallow, small earthquakes in Japan
7	Tadashi Kito (OYO Corporation)	Tsunami hazard assessment along the coast in Japan and potential tsunami risk in Taiwan.
8	Shu-Hsien Chao (NCREE)	Development of path-dependent ground motion model for Taiwan and its impact on probabilistic seismic hazard analysis
9	Jyun-Yan Huang (NCREE)	Inversion seismic parameter model of shallow earthquakes for stochastic ground motion simulation in Taiwan
10	Che-Min Lin (NCREE)	Microearthquake monitoring of the Shanchiao fault in Northern Taiwan
11	Arvind Kumar (NCREE)	Integrated radon monitoring around Shanchiao Fault and Tatun Volcanic Areas of Northern Taiwan using solid state nuclear track detectors
12	Chiao-Chu Hsu (NCREE)	Regional characteristics of ground motion within Taiwan
13	Wen-Tzong Liang (IES, AS)	Crustal stress field in Taiwan inferred from regional-scale damped inversion of AutoBATS CMT solutions
14	Chun-Te Chen (IES, AS)	Estimate shallow S-wave velocity structure in Western Plain of Taiwan using GA-Haskell method
15	Chih-Hsuan Sung (NCU)	Analysis of single-path sigma from single-station GMPEs
16	Chih-Hsuan Sung (NCU)	Single-path ground-motion prediction equations
17	Ming-Kai Hsu (NCU)	Using earthquake building damage data in establishing building fragility curves and its application

18	Wen-Fei Peng (NCKU)	The variation analysis of ground motion prediction models with M_W and M_L
19	En-Jui Lee (NCKU)	Rapid earthquake detection through GPU-based template matching
20	Pei-Ching Tsai (NCKU)	Coseismic and postseismic deformation of the 2016 M_W 6.5 Meinong, Taiwan, Earthquake
21	Chih-Yu Chang (NCKU)	Relocation and focal mechanisms of the 2016 M_L 6.6 Meinong, Taiwan, earthquake sequence
22	Po-Chin Tseng (NCKU)	Coseismic and postseismic velocity changes caused by the 2016 M_W 6.5 Meinong, Taiwan Earthquake using ambient seismic noise

Abstracts

Recent seismic hazard modelling in New Zealand

M.C. Gerstenberger[1], B.N. Fry [2], D.A. Rhoades[3], N. Litchfield[4]

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ABSTRACT

Recent seismic hazard work in New Zealand has focussed on developing seismic hazard models that include the impact of the November, 2017, Kaikoura M_W 7.8 earthquake. This large and complex earthquake occurred in a mostly rural part of the South Island, but caused significant damage in the capitol city of Wellington. Based on numerous modelling techniques, the seismicity rates in central New Zealand are expected to remain elevated for some decades to come. Here we will discuss the time-dependent Kaikoura Seismic Hazard Model and the main departures from the National Seismic Hazard Model (NSHM) which increase the modelled hazard; these changes include: 1) the use of a time-dependent hybrid clustering model; 2) the application of conditional probability models to significant South Island faults; 3) changes to modelling of the Hikurangi Subduction zone to allow for significantly more southward rupture of the Megathrust; and, 4) The use of multiple NGA2 West GMPEs. The use of multiple GMPEs has significantly increased the hazard across the entire region, whereas increases due to changes to the fault model and the introduction of the clustering model are limited to specific regions. Overall, the Hope Fault, which last rupture in 1888 in a moderate-sized M7 event dominates the hazard. Finally, the NSHM Programme has undergone international review in the last year and provided recommendations that are consistent with our Rethinking PSHA programme of the last few years. The review identifies limitations due to the lack of a funded NSHM programme, and in addition to recommending funding to establish an NSHM programme, the report includes recommendations for: 1) modelling of aleatory and epistemic uncertainty; 2) a regular update schedule to be aligned with building standards revisions; and 3) increased transparency in modelling procedures with web-based open access to model calculations and results.

KEYWORDS: New Zealand, Kaikoura, time-dependent hazard, hybrid models, GMPE

National seismic hazard maps for Japan and an integrated system for sharing information, J-SHIS

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ABSTRACT

We have been conducting seismic hazard assessment for Japan under the guidance of the Headquarters for Earthquake Research Promotion of Japan (HERP) since the 1995 Hyogo-ken Nanbu Earthquake, and have made national seismic hazard maps for Japan. The national seismic hazard maps for Japan are prepared to estimate strong motions caused by earthquakes that could occur in Japan in the future and show the estimated results on the maps. The hazard maps consist of two kinds of maps. One is a probabilistic seismic hazard map that shows the relation between seismic intensity value and its probability of exceedance within a certain time period. The other one is a scenario earthquake shaking map.

In order to promote the use of the national seismic hazard maps, we have developed an open web system to provide information interactively, and have named this system the Japan Seismic Hazard Information Station, J-SHIS. This J-SHIS system provides a web mapping system based on open source software that allows public users to easily view various data by Internet browsers. The system manages various data in an integrated manner, including provide detail information on seismic hazard and site amplification models with a 250 m mesh resolution, and the deep subsurface velocity structure models.

The 2011 Great East Japan Earthquake (M_W 9.0) was the largest event in the history of Japan. This mega-thrust earthquake was not considered in the national seismic hazard maps for Japan. The 2016 Kumamoto earthquake sequence occurred on active faults where strong-motion evaluation was executed based on the long-term evaluation and strong-motion prediction method 'Recipe' by HERP. Based on lessons learned from these earthquake disasters, efforts to revise the seismic hazard assessment for Japan are progressing.

We, as project staffs of the NIED, consider problems and issues to be resolved for seismic hazard assessment and make new proposals to improve seismic hazard assessment for Japan, based on experiences that we have engaged in the seismic hazard mapping project of Japan.

KEYWORDS: National seismic hazard maps for Japan, J-SHIS, probabilistic seismic hazard map, scenario earthquake shaking map

The 2017 update of TEM PSHA

Ya-Ting Lee[1], Yu-Ju Wang[2], Chung-Han Chan[3], J Bruce H Shyu[4], Ruey-Juin Rau[5] and Kuo-Fong Ma[1]

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[2]Institute of Nuclear Energy Research, Taiwan Power Company, Taipei City, Taiwan.

[3]Earth Observatory of Singapore, Nanyang Technological University, Singapore

[4]Department of Geosciences, National Taiwan University, Taipei City, Taiwan.

[5]Department of Earth Sciences, National Cheng Kung University, Tainan City, Taiwan.

ABSTRACT

Taiwan Earthquake Model (TEM), established in 2012, published the first version of the public probabilistic seismic hazard assessment map for Taiwan, named ‘TEM PSHA2015’. The model adopts the source parameters of seismogenic structures, background seismic activities, and subduction intraplate and interplate earthquakes for the hazard analysis. The TEM PSHA2015 had been widely discussed through applying to the 2016 Meinong earthquake (M_L=6.6) to clarify the seismic source contributing to the hazard and the seismic hazard potential remain in southern Taiwan. For the next generation of TEM PSHA, we improve the calculations to a higher resolution (500 m × 500 m) PSHA map that could provide to the government as a reference for mitigating seismic hazard and its risk for key infrastructure facilities. In addition, site effect (Vs30) and 3D fault geometry of 44 onland seismogenic structures is considered. For the future TEM PSHA, time dependent, 3D fault geometry of offshore structures and multiple-segment ruptures will be further considered. These innovations, however, gave us new challenges, e.g., long-term slip rates of the offshore structures, characteristics of multi-segments rupture, maximum magnitudes of subduction zone events, etc. These issues and challenges will be addressed for future seismic hazard assessment studies. We look forward to improve the TEM PSHA map through international cooperation and apply the up-to-date PSHA model for the seismic risk evaluation to bring the close link from hazard to risk.

KEYWORDS: Taiwan Earthquake Model, PSHA, site effect, 3D fault geometry, seismic risk.

Overview of U.S. national seismic hazard model

Mark D. Petersen[1]

[1]U.S. Geological Survey, National Seismic Hazard Model Project

ABSTRACT

The USGS-National Seismic Hazard Model Project (NSHMP) has produced hazard maps over the past 40 years and new maps are planned for 2018 and 2020 that will be considered in building codes, insurance rates, and other public policy documents. We produce many types of products such as long-term and short-term ground motion hazard forecasts, hazard curves, potential damage maps, urban hazard maps, Q-fault database, etc. We plan to update the 2014 hazard maps during 2018 by considering an updated earthquake catalog, new NGA-East and other ground motions models, and inclusion of basin-depth terms in the NGA-W2 and subduction models. The 2020 maps will consider new information provided by the deadline of June 2018 (e.g., magnitude-scaling equations, ground motion simulations, directivity, NGA-Subduction, etc.). These closely timed maps will allow engineers more time to evaluate the impacts of two versions of the map on the updated seismic design criteria. The updated hazard models will allow the building codes to account for more site classes and spectral accelerations and will better account for factors that contribute to the large uncertainties, moving aleatory variability to epistemic uncertainty. For example, the NGA-East models account for a broader range of epistemic uncertainty, incorporate new soil amplification factors, and allow for ground motions at many additional site classes and ground motion spectral periods. Another example is in the western U.S. where engineers developing the building code provisions recognized that the modeled ground motions were often significantly lower if basin depth terms were not explicitly accounted for in the ground motion models. Basin-depth terms were available in the NGA-W2 models but published information on the depth to the 1 km/s and 2.5 km/s horizons, needed to implement the terms, was not available for most areas and for subduction and stable continental margin earthquake ground motion models. To help engineers in developing better building codes we will update the hazard model in 2018 by including basin-depth terms for Los Angeles, San Francisco, Seattle, and Salt Lake City where this information is available and we are also developing a National Crustal Model that defines these horizons across the U.S. for future improvements. For future versions of the maps we plan to consider earthquake 3-d simulations, new multi-segment rupture models, and additional short-term forecasts. The UCERF3 model accounts for continuous ruptures along adjacent faults that are located within 5 km and results in 250,000 rupture sources. Future models will rely on physics based simulators and other new geological and geodetic information on earthquake sources. Short-term forecasts such as the Operational Earthquake Forecasts and Induced Seismicity Damage 1-year forecasts in Oklahoma have also been useful for communicating hazard information, probabilities, and potential impacts to residents. We will continue to provide information to the engineering community and better define uncertainties so that the models can be applied properly for a given purpose.

Validation of new probabilistic seismic hazard maps for Japan

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Session II

ABSTRACT

The seismic activity model of Japan was revised after the 2011 great Tohoku earthquake. The probabilistic seismic hazard maps for Japan (PSHMJ) based on the new seismic activity model was released in 2014 by the Headquarters for Earthquake Research Promotion of Japan. In order to discuss the validation of the PSHMJ, we applied the analysis by Ishikawa et al. (2011). Probabilistic and experienced seismic hazard maps for a time period of 30 years starting from 1890, 1920, 1950, 1980 and 2010 are developed and compared each other. The experienced seismic hazard maps are developed from the earthquake catalogue during the corresponding time period. The probabilistic maps somewhat overestimate against to the experienced maps in the time periods from 1920, 1950 and 1980. However, the probabilistic map from 2010 underestimate against to the experience map which consists of only the great Tohoku earthquake.

Next the JMA (Japan Meteorological Agency) seismic intensities from K-NET's strong-motion records during the past 20 years compare with the corresponding values on the PSHMJ. A large JMA seismic intensities such as 5-lower or 6-lower was mainly observed in the regions where the hazard level is high in PSHMJ.

Finally a site factor for JMA seismic intensity is obtained for each K-NET station from observed strong-motion records and compared with a model factor used in PSHMJ. The model factor is based on the engineering geomorphologic classification by Wakamatsu and Matsuoka (2013). The model factors are distributed in the range of plus or minus 0.6, whereas the site factors are distributed in the range of plus or minus 1.2. Most number of large JMA seismic intensities were observed at K-NET stations with large site factor.

KEYWORDS: National probabilistic seismic hazard maps for Japan, Experienced seismic hazard maps, Seismic activity model, K-NET, Site factor.

Points in hazard space: testing PSHA with multiple metrics

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Session II

ABSTRACT

While there has been considerable debate in recent scientific literature as to the validity and usefulness of Probabilistic Seismic Hazard Assessment (PSHA) results, their application is almost ubiquitous as a fundamental input to international building codes and major civil and infrastructure developments. Recent destructive earthquakes around the world have stimulated discussions about testability of seismic hazard assessments. A new wealth of data provides an opportunity for researchers and practitioners to ensure that we use state-of-the-art methods and appropriate input models informed by testing and based on thorough and objective decision-making. Owing to the long time periods involved in hazard forecasts, PSHAs will not yield a fully testable model in our lifetime. Furthermore, as modelling techniques become more sophisticated, how can we determine whether "improvements" are truly "improvements" in skill and not just additional complexities? New developments in hazard assessment are striving to build partial testability into the models. In the realm of PSHA, as with any science, testing is not only about model validation, but is a tool to learn about strengths and weaknesses of a model. Furthermore, modern evaluation techniques can support future model improvements. Research into the use of Fragile Geological Features and initiatives such as the Collaboratory for the Study of Earthquake Predictability (CSEP) aim to develop standardized methods to test hazard models. Here we present research based on the ideas of points in hazard space that brings together multiple modes of testing to best inform of the skill of hazard models across a range of metrics.

KEYWORDS: hazard testing, New Zealand, Fragile Geologic Features, CSEP, PSHA

Geodetic observations of the pre-, co- and post-seismic deformation associated with the 2016 M_W 7.8 earthquake and its implications for seismic hazard in the region

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Session III

ABSTRACT

The 2016 Mw7.8 Kaikoura earthquake ruptured at least a dozen faults in the northern South Island of New Zealand, within the transition from the Hikurangi subduction zone (in the North Island) to the transpressive Alpine Fault (in the central South Island). The earthquake was the most powerful experienced in the region in more than 150 years and raises many questions on the degree to which earthquake ruptures are controlled by fault segmentation. Prior to the Kaikoura earthquake, the southern terminus of Hikurangi subduction zone beneath the northern South Island was not considered as a potential rupture source. However, a growing number of observations suggest that this portion of the subduction zone did undergo coseismic slip and that it continued to move post-seismically. Here we will present InSAR and GPS observations acquired before, during and after the Kaikoura earthquake which indicate that this part of the interface can slip co-seismically. InSAR and GPS data also show that a large amount of afterslip (up to 0.5 m) occurred on the subduction interface beneath the crustal faults that ruptured in the M7.8 earthquake, during the months following the earthquake. Modeling of GPS velocities for the 20 year period prior to the earthquake indicate that interseismic coupling was occurring on the Hikurangi subduction interface beneath the northern So uth Island, in a similar location to the suggested coseismic and postseismic slip on the subduction interface. We will also discuss the broader implications of the observed coseismic and postseismic deformation for understanding the kinematics of the southern termination of the Hikurangi subduction zone, and its role in the transition from subduction to strike-slip in the central New Zealand region which have significant implications for the seismic hazard of the region.

Seismic hazard of the Hengchun Fault based on the geodetic data from 2002 to 2013

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Session III

ABSTRACT

The long-term uplift in the Hengchun peninsula, the southernmost tip of Taiwan mountain belt, has been inferred from the dating data at oceanic terraces since the late Holocene. However, the geodetic data from 2002 to 2006 indicate that the land subsidence penetrates whole peninsula and the activity of the Hengchun fault is not significant. The comparison of short-term and long-term deformation rates indicates that the Hengchun fault has a possibility to generate earthquake. In this study, we used the GPS observations and precise leveling measurements during 2002-2013 to comprehend the kinematics of Hengchun fault and its earthquake potential. Based on the coordinate time series, the 2006 M_L 7.0 Pingtung offshore earthquake and April 2010 are two epochs to separate the crustal deformation in peninsula into three stages. Before the 2006 earthquake, the Hengchun peninsula is subsidence in about 5 mm/yr. After the 2006 event, the creeping rates of up to 5-8 mm/yr on the Hengchun fault was detected by the leveling data and the creeping rate in southern segment is larger than northern segment. After April 2010, the creeping rate in southern segment of the fault is lower than the northern segment. The slip deficit rate of 8-16 mm/yr and two coupled areas from north to south were estimated on the Hengchun fault based on the geodetic data before the 2006 event using baseline inversion model. The source models show the slip patches propagate from south at stage 2 to north at stage 3. We therefore suggest that the Hengchun fault was triggered by the 2006 Pingtung offshore earthquake. The accumulated strain before the 2006 event is released by aseismic slow slip on the fault after 2006 earthquake. In other words, the seismic hazard on the Hengchun fault should be re-estimated in the future.

KEYWORDS: Creeping fault, Aseismic triggered event, Hengchun fault

The role of complex site and basin response in Wellington city, New Zealand, during the 2016 M_W 7.8 Kaikōura earthquake and other recent sequences

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Session IV

ABSTRACT

We present analysis of ground motion and complex amplification characteristics in Wellington during recent earthquake sequences and an overview of the 3D basin characterization and ongoing site effect research to update site parameters for seismic design. Significant damage was observed in central Wellington, New Zealand's capital city, following the 2016 M_W 7.8 Kaikōura earthquake. Damage was concentrated in mid-rise structures (5 – 15 storeys) and was clearly exacerbated by the presence of site and basin effects. Due to the distance of the source (50 – 60 km), peak ground accelerations were moderate (up to ~0.28g) and well within ultimate limit state (ULS) design levels. However, spectral accelerations within the 1 -2 s period range, exceeded 1 in 500 year design level spectra (ULS) in deeper parts of the basin. Amplification with respect to rock at these locations reached factors of up to 7, and was also observed with factors up to at least three across all central city soil recording sites. While similar amplification was observed during the 2013 M_W 6.6 Cook Strait and Grassmere earthquakes, which struck close to the termination of the Kaikōura earthquake rupture, these sources were not sufficiently large to excite significant long-period motions. However, other M7.2+ sources in the region that dominate the seismic hazard, e.g. Wellington Fault, Hikurangi subduction interface and other large proximal crustal faults, are also potentially capable of exciting significant long-period basin response in Wellington. These observations and the expectation of ongoing heightened seismicity have prompted re-evaluation of the current seismic demand levels. Additional field campaigns have also been undertaken to update geotechnical properties and the 3D basin model, in order to inform ongoing research and seismic design practice.

KEYWORDS: site response, basin effects, 3D model, spectral inversion, spectral ratios

Modeling of the subsurface structure from the seismic bedrock to the ground surface for a broadband strong motion evaluation in Kumamoto plain

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Session IV

ABSTRACT

The 2016 Kumamoto earthquake happened in Masiki town. And that, both of the foreshock [Mjma6.5] on April 14 and mainshock [Mjma7.3] on April 16 measured level on the Japanese intensity scale of 7. The earthquake caused heavy damage to buildings etc. near the faults. On distribution of building damage such as houses, it was found that damage was heavier roughly near the surface earthquake faults which caused the mainshock. On the other hand, although some areas suffered slighter damage despite just above the faults, other ones suffered severer damage despite away from the faults. It is said that these phenomena are likely to be caused by subsurface structure. Therefore, first, in mainly Kumamoto plain near the faults where damage was severe, we collected boring survey data and developed initial geological models. Secondly, we obtained records of microtremor observation and earthquake observation, and then improved layer thickness and S-wave velocity structure of initial geological models. We conducted microtremor array surveys at 26 points in Kumamoto Plain and made the 3D subsurface structural model. We obtained dispersion curves and H/V spectrums from the microtremor array surveys. Then, we calculated 1D structural model at each array by inverting the dispersion curves and H/V spectrums simultaneously. We made 3D subsurface structural model from the seismic basement to the engineering basement with 0.25 km horizontal interval based on the J-SHIS model made by using the 1D structural model. In the area with where is no 1D structural model, subsurface structural model created using relation between 1D structural models and gravity data in GALILEO (AIST). The 3D structural model indicates that the velocity layers of deep parts are deepening from Aso caldera toward Ariake Sea, and that graben-like structures run northeast along Kiyama River and north along Tsuboi River. Finally, we modeled subsurface structure from seismic bedrock to ground surface, and then compared our models with building damage distribution and investigated the relation.

KEYWORDS: S-wave model, Microtremor, Strong motion evaluation, Active fault, Kumamoto plain.

Site amplification and the effect on local magnitude determination

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Session IV

ABSTRACT

This study analyzed site effects including PGA and empirical transfer functions using records of surface–downhole network in Taiwan. The site amplification factors of the PGA were calculated using the ratio between the surface and downhole recordings. In addition, the power law relationships between the PGAs at the surface and downhole were evaluated to understand how amplification varies as PGA increases. Strong ground motions with and without site effects throughout Taiwan could be observed by comparing intensity distribution maps generated using the surface and downhole accelerations from four large earthquakes with magnitudes >6. Empirical transfer functions derived using the HHSR and HVSR showed comparable dominant frequencies and amplification factors at most stations; however, the empirical transfer function derived using the HHSR showed clearer resonance peaks, not only at fundamental frequencies but also at higher mode resonance frequencies. The HHSR and the HVSR were highly similar, particularly at medium frequencies. This finding indicates that the HVSR can be used instead of the HHSR when only the surface recording is available. Moreover, the local magnitudes calculated using surface recordings were higher than those calculated using downhole recordings. The differences are attributed to the amplification caused by the sedimentary layers and resultant in significant difference for events with M_L of larger and smaller than 6. Furthermore, high and medium frequency of HHSRs were strongly correlated with PGA amplifications and M_L differences, respectively.

KEYWORDS: Site amplification, surface-downhole network, local magnitude, spectral ratio

Long-period ground motion simulation, and application of the simulation data to damage estimation of high-rise buildings

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ABSTRACT

We simulated the long period ground motion generated by megathrust earthquakes and then estimated the damage of high-rise buildings based on the simulated long-period ground motion data. As for the ground motion simulation, we constructed 274 characterized source models for the Sagami-Trough earthquake by assuming different source area, rupture starting point and asperity configuration. We introduced a multi-scale heterogeneity (Sekiguchi and Yoshimi, 2006) to rupture propagation of the characterized source model. The long-period ground motion for many source models were simulated by the three-dimensional finite difference method using three-dimensional velocity structure model. The effect of the rupture heterogeneity was significant for shorter period range and was vary with rupture starting point and asperity configuration. As for the high-rise building damage estimation, a relationship between the maximum inter-story drift angle and velocity response value at the natural period of buildings was obtained by a response analysis of multiple high rise building models with different structure and floor number using a large number of simulated long-period ground motion with various ground motion level as input. Then, using this relationship, it was possible to easily estimate the maximum inter-story drift angle for each type of structure directly from the simulated velocity-response values without the response analysis. By combining these results with the height (natural period) and the number of building, damage evaluation of high-rise buildings could be done.

KEYWORDS: Long-period ground motion, Finite Difference Method, High-rise building, Sagami Trough.

The integration of Ground-Motion Prediction Equations and Ground Motion Simulations

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ABSTRACT

A comprehensively probabilistic seismic hazard analysis (PSHA) analysis was utilized to develop the design specification of ground motion level (i.e. design spectrum, peak ground acceleration etc.) and understanding the seismic hazard for a specific site. Due to robustness and reliability of Ground motion prediction equation (GMPE) models as well as easy to implement. GMPEs are still a general tool for hazard analyses. Due to the significant improvements in computing power and techniques, knowledge of undersurface structure and site condition, experiences of case studies, ground motion simulation (GMS) can provide comprehensive time-histories, ground motion value (peak ground acceleration, velocity, displacement) and response spectra in a wide frequency range which are necessary for PSHA analyses. An alternative way to balance the advantage and disadvantage of both of empirical and theoretical methods can contribute to achieving efficient implementation in practical projects. By introducing ground motion simulation techniques, complex site and path effects can be physically modeled. Furthermore, overall characteristics of ground motion at a specific site of interest can also be delineated throughout multiple earthquake-scenario cases. How to apply the results of GMS in adjusting GMPE input parameters and adding additional adjustment is a key issue. Current research cases and anticipated future achievements are discussed.

KEYWORDS: Ground Motion Simulation（GMS）, Ground-Motion Prediction Equation(GMPE), PSHA

Session V

Large magnitude earthquakes and seismic hazard in New Zealand

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ABSTRACT

Analysis of moderate to great historical earthquakes since 1840 and paleoseismic records for active faults provide constraints for seismic hazard in New Zealand. Historical earthquakes can suffer stationarity issues while paleoseismic records are incomplete. This incompleteness arises because not all events rupture the ground surface and/or surface-ruptures for low slip rate faults (<1 mm/yr) with long recurrence intervals (> 10 ka) may be eroded or buried. Despite these sampling limitations, collectively the available datasets support the following conclusions. 1) About half of $M_W \geq 7.0$ historical earthquakes would not have been identified as active prior to the event based on today's state of knowledge of active fault locations. 2) Approximately three quarters of historical surface-rupturing earthquakes occurred on low to moderate slip rate (i.e., ≤ 4 mm/yr) faults primarily because they constitute a greater proportion of the total active-fault population and collectively have higher recurrence rates than events on high slip-rate faults. 3) Historically multi-fault ruptures have been important and may make an important contribution to seismic hazard. These conclusions are consistent with fault rupture in the November 14 2016 M_W 7.8 Kaikoura Earthquake. Preliminary analysis suggests that sample incompleteness may be accounted for by background seismicity in the Nation Seismic Hazard Model, while some multi-fault ruptures are also included in the model. However, further detailed analysis is required to determine if multi-fault ruptures and incomplete sampling could require future adjustments to the seismic hazard model.

KEYWORDS: surface-rupturing earthquakes, earthquake incompleteness, multi-fault rupture.

Surface rupture and crustal deformation around the Hundalee Fault during the 2016 Kaikoura M_w 7.8 earthquake

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ABSTRACT

Complex co-seismic faults and crustal deformations occurred over a strike length of at least 150 km during the 14 November 2016 Kaikoura M_W 7.8 earthquake in the northeastern South Island of New Zealand. We conducted a field survey around the NW-SW striking Hundalee Fault on 19-21 December and compared field data with analysis of the ALOS-2 Synthetic Aperture Radar(SAR) data. Field investigation started by 5 hours air reconnaissance from a helicopter. In rugged mountain terrain north of the Hundalee Fault, the N-S striking Stone Jug fault showed variable uplift. We landed at two locations. We observed easterly upthrow of ~1 m at P1 and westerly upthrow of ~0.6 m at P2. Two other aerial observations (no landing) showed no vertical component at P3, while at P4 a ~0.7 m sinistral offset can be identified from 4K aerial video footage.

Differing relative uplifts, mostly NW side up but some SE side up, were found along the SW-NE striking Hundalee Fault. The maximum vertical displacement on the Hundalee Fault was at the Oaro coast, where ~1.5 m upthrow to the NW was accompanied by as much as ~3.7 m dextral offset, as measured across offset road and railway. This location marks the southern limit of extensive co-seismic coastal uplift of ~1-2 m. These varying senses of surface rupture movements cannot be conclusively explained.

The ALOS-2 SAR Pixel Offset (130 m/pixel) reveals the whole earth crust deformation and can be complemented by the field observations. The locations of observed surface faults fit well with the 3D displacement field retrieved from the multiple SAR Pixel Offset results. The difference of the up-down displacements both of the relative small surface ruptures and the absolute large movements of the SAR data could be explained by the complementary of the crust deformation in the wide range.

The updated work and more observed points based on the on-going summary will be introduced on the workshop.

KEYWORDS: Surface rupture, Hundalee Fault, Crustal deformation, SAR, Pixel Offset

Modeling subduction earthquake sources for seismic hazard analysis

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GEM Foundation

ABSTRACT

Subduction earthquake sources are the most productive and energetic sources on earth. Common categories used to classify subduction related earthquakes are interface, intraslab, shallow crustal events or outer-rise (Kishida et al., 2017), the former three of which produce the most relevant events from a seismic hazard perspective.

The comprehensive characterization of subduction sources is of crucial importance for a reliable calculation of seismic hazard, however, the approaches currently adopted for the construction of subduction earthquake sources are poorly discussed in the literature and comparisons between the different methods are scarce. Differences between the various approaches include the geometry used for modeling the different sources, the magnitude frequency distribution, the floating of ruptures on fault surfaces and the interrelation between the ruptures generated by the same earthquake source.

In this contribution we review the approaches adopted for the modeling of subduction earthquake sources used in several national and regional probabilistic seismic hazard analyses and we illustrate some of the methodologies currently developed within the GEM hazard team.

Prototyping Korean PSHA Model

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ABSTRACT

The 2016 Gyeongju Earthquake reminded people the presence of seismic risk in the Korean Peninsula. The Korean PSHA model we introduce in the presentation is the model we developed inspired by the earthquake to understand the seismic risk in the Korean Peninsula spatially and more quantitatively.

Our Korean PSHA model consists of following three components:

1) The seismic source model consists of a crustal background earthquake model and an active fault model. The crustal background earthquakes were modelled for each tectonic zone by the Gutenberg-Richter law analysis of the observed seismic source data by Korea Meteorological Administration (KMA) and the historical earthquake catalogues.

2) The seismic propagation model was derived from a number of GMPEs which are considered to be in the near ground condition to the Korean Peninsula.

3) The subsurface amplification model consists of a subsurface ground model based on USGS “Global Vs30 Model” and an amplification equation by Atkinson and Boore (2006).

At the end, we show the PSHA maps by this model comparing with other maps and discuss future challenges improving the model.

KEYWORDS: Korean Peninsula, PSHA model

Seismic Hazard and Risk Products in New Zealand

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ABSTRACT

PSHA using New Zealand seismic hazard models forms the basis for a wide range of down-stream applications in earthquake engineering. There are many aspects of PSHA in New Zealand, including, but not limited to, defining seismic loading standards for the New Zealand building code and supplying information that enables engineers to comply with it.

Recently the main components of New Zealand seismic hazard models have been converted from legacy software formats to the Natural Risk MarkUp Language (NRML) format and incorporated into the Global Earthquake Model's open-source seismic hazard and risk engine, OpenQuake, for use. While OpenQuake's flexibility and open-source philosophy bring new functionality and development opportunities to hazard and risk work in New Zealand, there are a number of challenges that come with implementing and testing the existing New Zealand seismic hazard models in OpenQuake and enhancing OpenQuake's own capabilities to address New Zealand's requirements. Examples include aspects of New Zealand hazard assessments for which the specific calculation is not (yet) included in the OpenQuake engine, such as development of deterministic spectra, production of 'mean' disaggregations, or the ability to output contribution to shaking by source when a source model comprises only simple or characteristic earthquake sources.

New Zealand's seismic hazard models also underpin a large variety of significant work in seismic risk and loss modelling.

KEYWORDS: New Zealand, seismic hazard, seismic risk, seismic loss, OpenQuake

Taiwan Earthquake Model (TEM): from understanding of Seismic Hazard to Risk assessment

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ABSTRACT

Taiwan Earthquake Model (TEM) aims to understand the probability of seismic hazard and the further risk analysis by integration of the earthquake science, earthquake engineering and social science communities of Taiwan. Under the scope of TEM, we would like to provide new insight into seismic hazard and risk assessments for Taiwan. The disaggregation of the seismic hazard and hazard curves for metropolitan cities provided key elements to public awareness on PSHA, which emerging the opportunity to the education for earthquake hazard mitigation. An occurrence of a moderate earthquake with significant damage in 2016 following the publication of Taiwan PSHA map was an important alert to the government and the industrial community. We further compiled the fragility curves using the damaging data of the 1999 Chi-Chi (7.6) earthquake, and the 2016 Meinong (6.3) earthquake to justify the exiting fragility curves. The development of these fragility curves is a key to link the hazard analysis from science to risk assessment for engineering. Through the PSHA information, earthquake scenario from three dimensional wave propagation simulations (carried out by TEM partner Inc., SinoTec) is now also made for a selected fault/seismogenic structure to exercise the integration of science, engineering and end users for policy making. We hope through this exercise, we can establish the database for seismic hazard and risk assessment, and, evaluate our knowledge and hazard management. We can, thus, improve our knowledge for the better understanding of the seismic hazard and risk of Taiwan.

Japan seismic hazard information station, J-SHIS

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ABSTRACT

J-SHIS was established to help prevent and prepare for earthquake disaster by providing a public portal for seismic hazard information across Japan since 2005 (http://www.j-shis.bosai.go.jp/en/).

It mainly consists of 4 parts, J-SHIS map, J-SHIS Portal, J-SHIS Web API, and J-SHIS Labs.

J-SHIS map shows National Seismic Hazard Maps for Japan and related data. We can also download the data from this site. It contains 8 tabs as follows.

- PSHM, which shows probabilistic seismic hazard maps and hazard curve for each mesh.
- Averaged Hazard Map, which shows maps of the expected intensities of earthquake ground motions with long-term return period such as 500-100,000 years.
- PSHM by EQ Cat., which shows PSHM of 3 earthquake categories and contribution factor map.
- CPE, which shows maps of conditional probability of exceedance of scenario earthquakes.
- SESM, which shows scenario earthquake shaking maps and wave form for each mesh.
- Site Amp., Which shows maps of Engineering geomorphologic classification, Average shear-wave velocity in the upper 30m depth, and Site amplification factor.
- Subsurface Structure, which shows maps of the 3D deep subsurface structure model down to the engineering bedrock, and to the seismic bedrock, to carry out the strong motion simulation.
- Exposed Pop., which shows maps of distribution of population exposed to a certain level of seismic intensity during a scenario earthquake.

J-SHIS Portal is the portal site of J-SHIS. We can get some information about how to use J-SHIS and get some basic knowledge about seismic hazard.

J-SHIS Web API provides for developers to support making web page or mobile application utilizing seismic hazard information of J-SHIS.

J-SHIS Labs provide experimental contents such as seismic hazard chart, which shows seismic hazard information about each mesh of PSHM, and liquefaction record map, which shows the liquefaction area by past earthquakes. (This site is only written in Japanese at the moment.)

KEYWORDS: J-SHIS, probabilistic seismic hazard map, Scenario earthquake shaking map, subsurface structure, API

Improvement of the real-time system for damage estimation (J-RISQ) based on the 2016 Kumamoto Earthquakes

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ABSTRACT

The National Research Institute for Earth Science and Disaster Resilience (NIED) is developing a real-time earthquake information system for damage estimation and situation assessment (J-RISQ) as a Cross-ministerial Strategic Innovation Promotion Program (SIP). J-RISQ is able to immediately estimate earthquake damage by combining methods for predicting ground motion using amplification characteristic data for subsurface ground, basic information on population and buildings, damage assessment methods for buildings using fragility functions, and strong motion data obtained by K-NET, KiK-net, local governments, and JMA. J-RISQ issued the first report 29 seconds after the Kumamoto earthquake (M7.3) occurred and a total of eight reports for about 11 minutes. The estimated spatial distribution of the belt-shaped region at Mashiki town qualitatively agrees with the actual damage status; however, the estimated results tend to overestimate the actual damage.

Therefore, we develop a method of updating the damage estimation by reflecting the actual number of damaged buildings, which was obtained in advance for some areas. The method uses the numbers of damaged buildings in limited areas as observation in Bayesian updating protocol, to update estimation error in safety margin, which is difference between load effect and capacity, of buildings all over the disaster area.

In this study, we report an example in which the estimation precision of the overall damage distribution over the entire affected area was improved by applying damage data for a part of the area, such as Mashiki town, interpreted based on aerial photographs taken after the Kumamoto earthquakes to this updated method.

Acknowledgements

This work was supported by the Council for Science, Technology and Innovation (CSTI) through the Cross-ministerial Strategic Innovation Promotion Program (SIP), titled "Enhancement of societal resiliency against natural disasters" (Funding agency: JST). The seismic intensity data from local governments and JMA that were used in the real-time system were provided by JMA.

KEYWORDS: real-time system, J-RISQ, Kumamoto earthquake, Bayesian updating protocol, SIP

P 2

Development of image recognition and machine learning methods for estimate damage of buildings by use of the aerial photographs acquired at the 2016 Kumamoto earthquake

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ABSTRACT

It is effective to know the distribution and the amount of damages immediately after the earthquake utilizing photographs taken from an airplane in terms of the decision-making for authorities.

In case of the 2016 Kumamoto earthquake, we have acquired more than 1,800 orthographic projection photographs clos to damaged areas. These photos have taken by airplanes soon after the mainshock, then we have distinguished damages of all buildings with 4 levels, and organized as approximately 320,000 GIS data corresponding to the fundamental Geospatial data published by Geospatial Information Authority of Japan.

These data have made by effort of hundreds of engineers. However, it is not considered practical for more extensive disasters by only human powers. So, we have been developing the automatic damage identification method utilizing image recognition and machine learning techniques.

First, we have prepared training data of more than 10,000 buildings which have equally damage levels divided in 4 grades. With these training data, we have been raster scanning in each scanning ranges of entire images, then clipping patch images which represents damage levels each. By utilizing these patch images, we have been developing discriminant models by two ways. One is a model using the Support Vector Machine (SVM), and another is a model using the Convolutional Neural Network (CNN). We have been comparing the accuracy of both ways.

The damage identification method utilizing aerial photos would be helpful for more prompt and widespread damage detection than visual judgement.

Acknowledgments:

This work was supported by CSTI through the Cross-ministerial Strategic Innovation Promotion Program (SIP), titled “Enhancement of societal resiliency against natural disasters”. Pasco Corp have helped us developing training data. MHIR Corp have helped us developping discriminatnt models.

KEYWORDS: Image recognition, Machine learning, Damage identification, Building damage investigation

Building observation via smartphone as a seismometer

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ABSTRACT

NIED and Hakusan corporation have been developing the application "i-Jishin" and the cloud server "Geonavi / icomi" that enabled smartphones to be used as a seismograph since 2010. We are currently observing with more than 200 buildings, and we plan to install even 700 more in the next 5 years. This platform aims for observing strong motion installed in the buildings that frequently become an end point of human and property damage. Organizing the achievement points and the future direction of this initiative, we present following eight facts related to i-Jishin.

1) i-Jishin is compatible with Japanese, English and Chinese.
2) Since the release in August 2010, about 150,000 downloaded for the entire series in the world.
3) Strong earthquake with seismic intensity 3 or higher can acquire data comparable to K-NET.
4) 4 E-Defense experiments were conducted, demonstrating the damage degree assessment.
5) Natural period change of SRC 15-story apartment is detected by the 2011 Tohoku Earthquake.
6) Proved ability to grasp the furniture falls remotely, use to secure safety.
7) Currently installed in hundreds of buildings and actually in operation.
8) Approximately 50% will stop measuring one or two years for some reason.

Through these efforts, two problems have been revealed in this platform. One is the instability in observation. Because of software or hardware origin troubles and/or due to network environment, the visible utilization rate from the network remains at only about 50%. Another is the immature of data utilization. For general users, utilizing the obtained data seems difficult because of the threshold as a web service with an account, the unfriendliness of the interface, the expertise of the waveform analysis obtained in the building, and so on. For this reason, there are also a certain number of users hesitating to set up due to unclear what kind of effect can be obtained. Coping with these issues, we would like to try improvements through future efforts.

KEYWORDS: Smartphone Application, Cloud system, Sensor Network, Building Response, Proof Experiment.

Construction of 3D geologic model with concealed Active faults using thousands of borehole data in the Tokyo Lowland, Japan

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ABSTRACT

Underground structural surveys are very difficult in the densely populated urban area such as the Tokyo metropolitan area, Japan. However, such area offers voluminous borehole data useful for detecting concealed faults as well as constructing ground model. In the Kanto plain, both the Fukaya Fault zone and the Ayasegawa Fault have been known as main active faults. The center of Tokyo metropolitan area is located for the southeastern extension of these active faults. So far no active faults have been known there except for some concealed Quaternary faults.

Based on geologic and 3D analysis of more than seven thousands of borehole data, 3D geologic model has been constructed in the center of Tokyo metropolitan area. This area is located in the Tokyo Lowland in the east and the Musashino upland in the west. The geologic starata consist of the latest Pleistocene to Holocene incised-valley deposits (so-called Chuseki-so), the Kanto Loam beds, the Musashino conglomerate bed (80 to 100 ka), Tokyo Formation (120 to 200 ka) and the underlying lower to middle Pleistocene strata. The 3D model consists of surface models of these strata and 3D voxel models of N-values and lithology calculated based on borehole data.

The result of this research is as follows: 1) the Tokyo Formation and Musashino conglomerate bed make a half-dome structure plunging to the northeast direction, 2) A series of a right-stepping NNE-trending and a NW-trending faults are inferred in the southeastern margin of the upland and the western margin of the Tokyo Lowland. These faults extend more than 20 km and displace vertically about 5 to 10m the Tokyo Formation and Musashino conglomerate bed. A major branch of them, named the Shinonome fault displaces the lower Chuseki-so. 3) The geomorphic development of the upland and buried geographic surface covered by the Chuseki-so should be strongly controlled by these faults.

We inferred the detailed location of concealed active faults based on geologic evidences. Further detailed researches on these concealed faults are required to prepare for earthquake disasters in the center of Tokyo metropolitan area.

KEYWORDS: borehole data, 3D geologic model, Active faults, Tokyo Lowland, Upland

High attenuation rate for shallow, small earthquakes in Japan based on observation data

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ABSTRACT

We compared the attenuation characteristics of peak ground accelerations (PGAs) and velocities (PGVs) of strong motion from shallow, small earthquakes that occurred in Japan with those predicted by the equations of Si and Midorikawa (J Struct Constr Eng 523:63–70, 1999). The observed PGAs and PGVs at stations far from the seismic source decayed more rapidly than the predicted ones. The same tendencies have been reported for deep, moderate, and large earthquakes, but not for shallow, moderate, and large earthquakes. This indicates that the peak values of ground motion from shallow, small earthquakes attenuate more steeply than those from shallow, moderate or large earthquakes. To investigate the reason for this difference, we numerically simulated strong ground motion for point sources of M_w 4 and 6 earthquakes using a 2D finite difference method. The analyses of the synthetic waveforms suggested that the above differences are caused by surface waves, which are predominant at stations far from the seismic source for shallow, moderate earthquakes but not for shallow, small earthquakes. Thus, although loss due to reflection at the boundaries of the discontinuous Earth structure occurs in all shallow earthquakes, the apparent attenuation rate for a moderate or large earthquake is essentially the same as that of body waves propagating in a homogeneous medium due to the dominance of surface waves.

KEYWORDS: Ground motion, Ground motion prediction equation, Small earthquake, Moderate and large earthquake, Attenuation rate.

Tsunami hazard assessment along the coast in Japan and potential tsunami risk in Taiwan.

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ABSTRACT

NIED (National Research Institute for Earth Science and Disaster Prevention) is conducting the project on the probabilistic tsunami hazard along the coast in Japan (Fujiwara et al., 2013, JpGU). We constructed about ten thousand characterized fault models based on the Tsunami Recipe by the Headquarters for Earthquake Research Promotion (2017) for subduction-zone earthquakes in the Japan Trench, Nankai Trough, Sagami Trough and Kuril Trench. Slip heterogeneities in a characterized fault model are expressed by the combination of 3 kinds of slip area, called background slip area, large slip area and super large slip area. The large slip area has 2 times of average slip amount and 30% of total fault area, and the super large slip are has 4 times of average slip amount and 10% of total fault area. Subsequently, tsunami simulation was carried out based on the nonlinear long wave equation for each characterized fault model and tsunami height was calculated along the coast in Japan. Tsunami hazard curves at specific coastal points were then produced based on the calculated tsunami height and probability of earthquake occurrence, which tells us the exceedance probability that the maximum tsunami height exceeds a specific level within a specific time. In this study, we selected 3 typical characterized fault models from the largest-class earthquakes along the Ryukyu (M_w 9.4) and the Nankai Trough (M_w 9.1), and we calculated tsunami height along the coast in Taiwan. The maximum tsunami height was estimated to be approximately 13 m at the coastal points of the eastern part of Taiwan, though one should note that the tsunami height may be underestimated because of the relatively low resolution topographic data (1350m grid size). This study is conducted as a part of the research project “Research on the hazard risk assessment for natural disaster” in NIED.

KEYWORDS: Characterized fault model, Probabilistic tsunami hazard assessment, Tsunami simulation

Development of path-dependent ground motion model for Taiwan and its impact on probabilistic seismic hazard analysis

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ABSTRACT

In the past, most of available ground motion models were developed for Taiwan based on the assumption that the average attenuation rate derived from whole Taiwan ground motion database can be approximately applied for all different paths in Taiwan. In this study, the methodology proposed Rodriguez-Marek in 2013 is used to develop the path-dependent ground motion model for crustal and subduction earthquakes in Taiwan. The region-dependent attenuation rate is quantified for crustal and subduction earthquakes separately by analysing the spatial distribution of record-specific residual of Taiwan ground motion model proposed by Chao et al. in 2017. The path-to-path variability, path-specific residual and single-path standard deviation for crustal and subduction earthquakes in Taiwan are also derived. It is found that the path-to-path variability of Taiwan ground motion is significant especially for subduction earthquakes in Taiwan. The proposed path-dependent ground motion model is applied for probabilistic seismic hazard analysis of several test site by using zoneless seismic source model. It is found that the seismic hazard curves as well as seismic hazard disaggregation results of path-dependent or path-independent ground motion models may be significantly different to each other for some target sites. This is due to high spatial variation of seismicity as well as different path-effects of ground motion for different target sites. This evidence shows the importance of considering path-dependent attenuation rate and developing the path-dependent ground motion model for Taiwan.

KEYWORDS: Ground Motion Model, Path Effect, Probability Seismic Hazard Analysis

Inversion seismic parameter model of shallow earthquakes for stochastic ground motion simulation in Taiwan

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ABSTRACT

Stochastic ground motion simulation technique (Boore, 1983; Boore, 2003) is useful tool to get synthetic ground motions for future possible earthquakes when applying suitable seismic parameters. The parameter models are varied within different regions due to difference in seismogenic structure. Regional parameters used in stochastic simulation that need to be checked are including stress drop, Q, geometric spreading, kappa, site transfer function etc. Parameter models for stochastic point source or finite fault simulation in previous Taiwan researches are usually collected each piece of seismogenic parameters from different studies and composed them together to deal with prediction problems (Sokolov et al., 2000; Sokolov et al., 2001; Sokolov et al., 2009; Huang et al., 2017) or inverted parameters together but some of the path attenuation relation might are far from traditional imagination about wave propagation tectonics in Taiwan (D'Amico et al., 2012).

In this study, seismological records from TSMIP rock sites (Vs30 within 600-900 m/s) will be used for shallow crust earthquakes for parameter inversion for shallow events. Initial path attenuation models will be fixed first to solve other parts of the parameter setting. The inverted results could have more confident that all of them are goes together and fix the Brune's spectrum (Brune, 1970) assumed in stochastic simulation technique with physical meanings of each of the parameters but not composed ones. The inverted model could be applied to study regional difference of different area such as Taiwan against Japan or California region when comparing seismograms in different regions.

KEYWORDS: seismic parameters, stochastic ground motion simulation, shallow Taiwan

Microearthquake monitoring of the Shanchiao fault in northern Taiwan

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ABSTRACT

The Shanchiao fault, located to the west of the Taipei Basin, is the primary active fault in northern Taiwan. It's normal faulting resulted in the deep Tertiary basement of the Taipei Basin. It shall be noted that there are two nuclear power plants locate within distances of several kilometers with the north end of the Shanchiao fault. This fault, which may trigger a M_W 7.0-plus earthquake, is undoubtedly the most significant potential seismic threat to the Taipei metropolitan area. However, there is a dormant volcano, the Tatun volcano, located at the southwestern hanging wall of the Shanchiao fault. The complex tectonic environment makes the seismicity of this fault unclear. To assessing the seismic hazard of the Shanchiao fault, a dense microearthquake monitoring can provide valuable information about its recent seismicity and the source parameters.

In this study, a real-time microearthquake monitoring network was set up with thirteen broadband seismometers to observe the seismicity of the Shanchiao fault continuously since April 2015. Additional thirty-five stations operated by the other three organizations are integrated with our monitoring to cover the fault zone fully. Almost 2000 microearthquakes were observed in the monitoring region until now. Most of the epicenters concentrate on the Tatun volcano area. The focal depths are mostly within 5 km. The double-difference earthquake location algorithm (HypoDD) was used to relocate the earthquakes observed by the network, and the focal mechanisms for some events were computed from P-wave first motion polarities. According to these results, several earthquake clusters happened in this region were identified. Although the involving of the Tatun volcano make it hard to clarify the seismicity of the Shanchiao fault, we hope that the probable seismogenic structures and source ruptures can be evaluated by long-term monitoring in the future.

KEYWORDS: earthquake monitoring, Shanchiao fault, earthquake location, focal mechanism.

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Integrated radon monitoring around Shanchiao Fault and Tatun Volcanic areas of Northern Taiwan using solid state nuclear track detectors

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ABSTRACT

In the present study solid state nuclear track detectors (SSNTDs) technique has been used for the measurement of radon-thoron concentrations in soil gas for volcanic and seismic study in Taiwan. The pre-calibrated radon-thoron discriminators with LR films has been installed in Hsiaoyoukeng (SYK), Dayoukeng (DYK), Bayen (BY) and Gungtzeping (GTP) of Tatun Volcanic area in a hole (about 50 cm depths) having different temperatures for a defined period (bi-weekly to monthly). The observations have shown potential precursory signals for some earthquakes that occurred during the observation period having an epicenter in and around the TVG. In addition to that soil gas geochemical surveys had been undertaken in and around Shanchiao fault to select the sites for integrated radon monitoring using SSNTDs to see the tectonic activity of the fault systems. The occurrence of gas emanation has been investigated by the soil-gas surveys and three sites has been selected for integrated monitoring with respect to tectonic activity to check the sensitivity of the sites using SSNTDs. After this a site will be selected for long term monitoring on the basis of its sensitivity towards the tectonic activity in the region

KEYWORDS: Solid state nuclear track detectors, soil gases, Sanchiao fault, Tatun Volcanic areas

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Regional Characteristics of Ground Motion within Taiwan

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ABSTRACT

The regional characteristics of ground motion within Taiwan is studied by analyzing the spatial distribution of event-specific residual, site-specific residual and record-specific residual of Taiwan ground motion model proposed by Chao et al. in 2017 which capturing the average source effect (by parameters of magnitude, top depth of rupture plane, aftershock flag, SOF factors, Manila subduction flag), average path effect (by parameter of closet distance to rupture plane) and average site effect (by parameters of Vs30 and Z1.0) by using whole Taiwan ground motion database. The major finding is that the mean values of station-specific residual for stations located at the north of Chianan Plain and at the east of Coastal Mountain Range are higher representing stronger site amplification than the stations located at the south of Chianan Plain and at the west of Coastal Mountain Range. The standard deviation of record-specific residual for stations located at the east of Coastal Mountain Range are higher than the west of Coastal Mountain Range representing stronger variability of ground motion. The mean value and standard deviation of event-specific residuals are also discussed to identify the difference of the earthquake sources located within or outside Taiwan main island as well as oceanic crust or continental crust. The result of this study can benefit the development of regionalized ground motion model for Taiwan to achieve a better ground motion prediction of the future earthquake.

KEYWORDS: Ground Motion Model, Regional Difference

Crustal Stress Field in Taiwan Inferred from Regional-scale Damped Inversion of AutoBATS CMT Solutions

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ABSTRACT

A regional seismic stress field of the crust in Taiwan has been obtained by applying the damped stress inversion algorithm to a newly derived focal mechanism dataset. To construct this homogeneous dataset, which is composed of more than 3000 centroid moment tensor solutions, we have developed a new multiple solution method to invert the high quality broadband waveforms collected in the past two decades. Only solutions with high quality and shallower focal depth (<40 km) are selected in the stress inversion. To test the reliability of the stress field, we implement a series of checkerboard tests with various grid spacing. Our results show that the maximum principle seismic stress, σ_1, is dominated by the NW-SE collision direction between the Eurasia plate and the Philippine Sea plat. It presents a fan-shape distribution in the western part of Taiwan. A dramatic change of σ_1 direction at ~24.3°N along the eastern coast, which may mark the transition from collision to subduction in the NE Taiwan area. In addition, we also notice that there is an S-shape trajectory across the Central Range that is suspected to be associated with spatial rheology heterogeneity. Normal faultings are mainly observed in the Okinawa Trough, Central Range, and SW offshore Taiwan, which are referred to different tectonic processes in this region. Obvious interface focal mechanisms in the eastern offshore region are also delineated with their NS striking and shallow angle thrusting pattern. Our principle seismic stress axes are comparable with the principle strain axes derived from GPS observation, implying that the crust in Taiwan may deform largely in an elastic manner. However, remarkable rotational patterns of σ_1 presented in Ilan and Pingtung area may reflect the complicated tectonic forces and geological settings in the Taiwan region.

KEYWORDS: BATS network, AutoBATS CMT, seismic stress field, Taiwan

Estimate shallow S-wave velocity structure in Western plain of Taiwan using GA-Haskell method

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ABSTRACT

We had conducted 63 microtremor array measurement in the western plain of Taiwan to achieve one-dimension shear wave velocity structure of these sites. To improve the accuracy of the shear wave velocity profile in spatial, this study using Horizontal to Vertical Spectral Ratio of microtremor (MHVSR) inversion technology with the initial velocity model that obtained by our array inversion. We carry out GA-Haskell method based on that the 1622 MHVSRs confirmed with the theoretic SH wave transfer functions to improve the level to a resolution about two kilometers in spatial. Comparison between the velocity profiles of this study and borehole logging data has a good agreement and it shows our results are acceptable. Combine more than 1500 velocity profiles, we redraw an upgrade VS30 map with more detail variation. The depth contour of Vs = 600 m/s and Vs = 1000 m/s are also mapped. The engineering bedrock (assumed the S-wave velocity to be 600 m/s) is around 30 m in the piedmont area and become around 500 m in the coastline. The depth to Vs = 1.0 km/s (Z1.0), which is an important parameter accounting for basin effect in recent ground motion prediction equations. The contour increases from 100 m in the piedmont to reach almost 1000 m in the west coastal area. Moreover, we compare the relation between VS30 and Z1.0, the result can be used to upgrade the Relation between Vs30 and Z1.0 for Taiwan.

KEYWORDS: microtremor, HVSR, GA-Haskell, shallow velocity structure

Analysis of single-path sigma from single-station GMPEs

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ABSTRACT

Recent studies have found that the aleatory uncertainty and epistemic uncertainty is not easy to distinguish when analysing the single-station variability because the elements of aleatory variability that are treated as being random, but come from the epistemic uncertainties. In this study, we propose the single-station GMPE to solve this problem. This GMPE is established from observed records by a station, so its site uncertainty can be ignored directly. In here, we use 19,887 records for 150 crustal earthquakes with moment magnitudes greater than 4.0 obtained from the Taiwan Strong-Motion Instrumentation Program network to build 305 single-station GMPEs. The nonlinear regression analysis of ground-motion prediction model is the mixed-effect model with maximum likelihood method. Comparing the total sigma (σ_T=0.621), general single-station sigma which is estimated by the variability decomposition method (σ_{ss}=0.576) and the single-station sigma of single-station GMPEs (σ_{ss}, station=0.420-0.522). The result shows the σ_{ss}, station is the smallest variability and always depends on the regional site. Finally, we advance the new approach which is the spatial-correlation mobile window to analyse the single-path sigma for each station and using this sigma in PSHA, the resultant hazard level would be 20% lower than the traditional one in 2475 return period.

KEYWORDS: ground motion, single station, sigma, variability, PSHA

Single-path ground-motion prediction equations

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ABSTRACT

The results of the probabilistic seismic hazard analysis (PSHA) are sensitive to the standard deviation for empirical ground-motion prediction models (GMPEs), and, even small reductions in sigma may have a significant impact on the hazard level especially with long return periods. Recent studies have proved that the variability decomposition cannot reduce the hazard level, when we move the epistemic uncertainty into the logic tree. So, how to reduce the total uncertainty directly is a critical issue. In this study, we use 960 crustal earthquakes with moment magnitudes greater than 3.5 obtained from the Taiwan Strong Motion Instrumentation Program network to build the single-station and small-source regions GMPEs. Not only consider the single-station condition, but also set up the different source zones parameters into a GMPE to do the regression analyses. The results show the sigma of the single-station and small-source regions GMPEs is ranging from 0.402 to 0.526 which is far less than the total sigma (0.626 in ln unit), in other words, the total uncertainty can be reduced from 12% to 25% by this approach. Finally, we further use this sigma in PSHA, and we found the hazard level could be reduced about 27% in 475 return period, and 36% in 2475 return period.

KEYWORDS: ground motion, single station, sigma, variability, PSHA

Using earthquake building damage data in establishing building fragility curves and its application

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ABSTRACT

The assessment of the seismic risk for the city represent an important resources in order to measure the potential losses due to future earthquake. The evaluation of seismic risk involves the combination of three main components: seismic hazard model, exposure model defining the spatial distribution of elements exposed to the hazard and vulnerability functions capable of describing the distribution of percentage of loss for a set of intensity measure levels. Building fragility curve is an important component to influence the seismic risk. The fragility curves in this study will be made based on the building damage records collected from the 1999 Chi-Chi and 2016 Meinong earthquakes. The fragility curves in Taiwan were previously developed based on the value in peak ground acceleration (PGA). In the knowledge finding on the relation of hazard to damage as to be risk related, PGA is not a critical parameter for this estimation. In view of this, we intend to develop building fragility curves in other strong motion parameters (e.g., peak ground velocity or revised intensity). By using maximum likelihood estimation method we estimate the building damage and economic loss in comparison to the previously established PGA-based curves. In this case the reliability of the building damage and economic losses for our result are higher than the estimation from pre-existing fragility. We implemented both the pre-existing fragility curves and those we have obtained to the probabilistic seismic risk assessment for Taipei and Tainan City. Our intention is to give the new building fragility curves in different types of intensity and the first attempt on the modeling the seismic risk on an open platform for Taiwan.

The variation analysis of ground motion prediction models with M_W and M_L

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ABSTRACT

The purpose of this study is to analyze the appropriateness that using moment magnitude (M_W) and local magnitude (M_L) as the magnitude parameter in Ground-motion prediction equations (GMPEs) to predict response spectrum within diverse natural-period range.

In this study, two GMPEs, which defined as a function of M_W and M_L respectively, were developed based on the same seismic database recorded by the Taiwan Strong Motion Instrumentation Program during 1993–2014. The prediction accuracy of these two GMPEs was compared. The results show that the GMPEs scaled by M_L, which tend to describe the high frequency energy released by fault rupture, represents the better prediction accuracy for estimating the peak ground acceleration (PGA) and acceleration response spectrum in natural period of 0.01~0.50 sec, in which the intensity measures are controlled by short period seismic wave. On the contrary, the scale M_W, which related to average amount of slip on the fault and the size of the area that slipped, is the reasonable parameter to predict the displacement response spectrum in natural period of 2.0~8.0 sec where the energy is controlled by longer period seismic wave. The result of this study reveals that it is unreasonable for using just only single kind of magnitude scale in GMPE to predict the response spectrum in different natural periods.

In some regression process of GMPEs, the value of M_W was obtained by converting the observed M_L to M_W based on the M_W-M_L empirical relation of Taiwan, due to the small earthquakes are not scaled by M_W. According to the comparison of prediction accuracy, this study also reveal that, in assistance of M_W-M_L empirical relation, this alternative regression procedure would not brought the advantage of M_W into the GMPE.

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Rapid earthquake detection through GPU-Based template matching

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ABSTRACT

The template-matching algorithm (TMA) has been widely adopted for improving the reliability of earthquake detection. The TMA is based on calculating the normalized cross-correlation coefficient (NCC) between a collection of selected template waveforms and the continuous waveform recordings of seismic instruments. In realistic applications, the computational cost of the TMA is much higher than that of traditional techniques. In this study, we provide an analysis of the TMA and show how the GPU architecture provides an almost ideal environment for accelerating the TMA and NCC-based pattern recognition algorithms in general. So far, our best-performing GPU code has achieved a speedup factor of more than 800 with respect to a common sequential CPU code. We demonstrate the performance of our GPU code using seismic waveform recordings from the M_L 6.6 Meinong earthquake sequence in Taiwan.

KEYWORDS: Graphics Processing Unit (GPU); Template-matching algorithm; Earthquake detection

Coseismic and postseismic deformation of the 2016 M_W 6.5 Meinong, Taiwan earthquake

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ABSTRACT

The 6 February 2016 M_W 6.5 Meinong earthquake ruptured an unknown fault with the left-lateral and thrust motion at the depth of 14.6 km in southwestern Taiwan, and resulted extreme disaster in the Tainan city. Analyses of GPS daily solution time series in SW Taiwan indicated 5-33 mm coseismic horizontal displacements located mainly in the Tainan-Kaohsiung area, and the coseismic deformation represents a fan-shaped pattern between 210° and 312°. The coseismic vertical displacements show uplifting from 8 mm to 90 mm west of the hypocenter and the maximum uplift is distributed at the Guanmiao-Lunchuan area. East of the hypocenter indicates subsidence from -7 mm to -13 mm. The postseismic deformation of 329 days indicates 5-43 mm horizontal displacements moving toward the western and 5-39 mm uplift displacements in the vertical pattern located in the Tainan-Kaohsiung area. The optimum fault geometry for the coseismic dislocation model indicates the strike of 293°, dip of 21° and the depth of 25 km, the main slip showed left-lateral with minor thrust motion in a depth range of 15-20 km and the maximum slip of 527 mm. The calculated coseismic geodetic moment is 5.03×10^{25} N-m and equivalent to M_W 6.43. We use the same fault geometry with the coseismic model for the inversion of the postseismic slip in the 329 days. There are two main slip in the postseismic model, one is on the west of the coseismic main slip with the left-lateral and thrust motion, another one is on the shallow depth of 7-10 km with thrust motion. The calculated postseismic geodetic moment is 7.59×10^{25} N-m and equivalent to M_W 6.55. According to the time series analysis the postseismic deformation showed differences between the south and north of the Hsinhua fault, where no apparent postseismic displacements recorded by the GPS stations located at north of the Hsinhua fault. There is the extrusion in Southwestern Taiwan, this processes occurs towards the SW. The interseismic GPS velocity field shows the 20-50 mm/yr from west to the southwestern with the sinistral rotation. Both of our models showed the similar motions of the slip in fault plane with the extrusion processes in SW Taiwan. Thus, we assumed that the Meinong earthquake might be resulted by the extrusion processing in the SW Taiwan.

KEYWORDS: Meinong earthquake, Coseismic and postseismic deformation, Dislocation model, Extrusion processing

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Relocation and focal mechanisms of the 2016 M_L 6.6 Meinong, Taiwan, earthquake sequence

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ABSTRACT

Three moderate earthquakes occurred in southwestern Taiwan in the last 7 years all displayed mid- to lower- crustal focal depth, similar focal mechanisms with NWW striking, north dipping plane and ENE-WSW compression. The aftershocks of the 2016 Meinong earthquake were not only restricted to the main shock area, but also reached as far as 30 km away in the Tainan area. According to waveform-HypoDD result, earthquakes in the mainshock area displayed two clusters with different faulting style. One included the mainshock ruptured along a shallow dipping fault plane, which is consistent with the dip of mainshock focal mechanism, about 10˚ at initial rupture, and the other showed normal faulting on a north steep dipping plane. Events in Tainan all concentrated at 23-26 km depth and we inferred that these events as the subduction interface seismicity. Moreover, the T-axis of seismicity in Central Range is sub-parallel to the P-axis of mainshock, which indicating the extension on hanging wall of mainshock fault. The offshore events presented normal faulting that implying the activation of pre-existing normal faults and the area was still undeformed by convergence. We conclude that these mid-crust earthquake sequences occurred with similar focal mechanisms were resulted from the inversion of inherited normal fault, which is likely to be connected to the Chishan transfer fault zone (ChiTFZ) in the southwestern Taiwan fold-and-thrust belt, the offshore structures represent the activation of pre-existing normal fault which triggered by the Meinong earthquake. These moderate earthquakes sequences are evidently basement-involved thrust faulting events in southwestern Taiwan.

KEYWORDS: Meinong Earthquake, Double-Difference Relocation, Chishian Transfer Fault Zone, Matched Filter Technique

Coseismic and Postseismic Velocity Changes caused by the 2016 M_W 6.5 Meinong, Taiwan Earthquake using Ambient Seismic Noise

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ABSTRACT

The 6 February 2016 M_W 6.5 Meinong earthquake with a focal depth of 14.6 km produced widespread strong shaking in the 30-km-away Tainan city and caused about 10 buildings collapsed and 117 death. We collected seismic waveforms from 17 high broadband stations within 40 km epicentral distances and reconstruct the Green's functions from cross-correlation function of ambient seismic noise between two stations. We analyzed seismic data for six different frequency ranges from 0.01 to 2 Hz, which yielded time series for different station pairs from January 2014 to December 2016. We found coseismic velocity drops of about 0.463% mostly in 0.5 to 1 Hz at the north of the Hsinhua fault and 0.206% at the south part, however postseismic velocity variation differs between these two regions. The time series of velocity change presented a non-recovery trend at the north area, however the south region is indicated by a recovering trend three months after the Meinong earthquake. For the surface wave tomography results in southwestern Taiwan, the regional geological structures are recognizable in the estimated phase-velocity dispersion maps. The 3D velocity model displays low velocity in the alluvial plain, but indicates high velocity in the north of the Hsinhua fault. During the six months of the postseismic period, based on the GPS observations in the Hsinhua fault area, the block south of the fault continuously moved ~30 mm along the southwest direction while the north of the fault remained stationary. The Hsinhua fault is located near the boundary between the Tainan basin and the muddy continental shelf, and where the block south of the fault is on the continental slope. We suggest that the coseismic velocity drop was caused by the earthquake shaking in the soft deposited materials with increase of permeability, corresponding to soil liquefaction. The shorter recovery time and thus velocity increase in the block south of the Hsinhua fault was resulted from the afterslip of the Meinong earthquake, which resulted in the stress increases and the closure of the micro-fracture. Apparently, the Hsinhua fault acts as a barrier blocked the afterslip south of the fault.

KEYWORDS: Ambient seismic noise, Surface wave tomography, 2016 Meinong earthquake.

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