Introduction to the session on the surface ruptures during earthquakes

*Koji Okumura[1]

1. Graduate School of Letters, Hiroshima University

Recent surface ruptures associated with intermediate-sized earthquakes pose big questions about the occurrence and behavior of the ruptures at earth's surface. With the examples of recent subtle-and-puzzling and magnificent-and-complex ruptures, the scope of the session will be introduced.

Keywords: active fault, surface rupture, fault displacement

Towards a unified and worldwide database of surface ruptures (SURE) for Fault Displacement Hazard Analyses

*Stéphane Baize[1], Johann Champenois[1,2], Francesca Cinti[4], Timothy Dawson[3], Yann Klinger[2], James McCalpin[6], Koji Okumura[7], David Schwartz[5], Oona Scotti[1], Pilar Villamor[8]

1. IRSN, France, 2. IPGP, France, 3. CGS, USA, 4. INGV, Italy, 5. USGS, USA, 6. Geo-Haz Consulting, USA, 7. Hiroshima University, Japan, 8. GNS Science, New Zealand

Assessing Fault Displacement Hazard is based on empirical relationships predicting on-fault and off-fault surface rupture, these equations being derived from earthquake data. The regressions that are used so far are based on sparsely populated datasets, including a limited number of mainly pre-2000 events. A common effort has started in 2015 to constitute a worldwide and unified database to improve further estimations (SURE). This database would update existing databases that relate earthquake magnitude to surface faulting. Since 2015, two workshops have been organized to start discussions on how to build such a database: it was decided that, together with existing datasets, the future database will include 1) recent cases which deformation have been captured and measured with modern techniques, 2) new parameters which are relevant to properly describe the rupture.

Correlation of pre- and post-seismic optical images is one of the interesting techniques to complete the deformation fields. This technique has been successfully applied to “historical” cases in California (1992 Landers and 1999 Hector Mine events), demonstrating that a considerable part of coseismic deformation was distributed off the major fault. Applied with high resolution images, we could map in detail the surface deformation associated with the 2016 M7.8 Kaikoura earthquake (NZ), using the sub-pixel correlator MicMac which provides reliable results especially in near-fault area. We use pairs of ortho-images to measure the horizontal coseismic displacement field. Optical satellite images from different satellites are processed (Sentinel-2A, Landsat8, etc.) to present a dense map of the surface ruptures and to analyze high density slip distribution along all major ruptures. Displacement field from optical correlation will be combined to other co-seismic measurements to figure out the 3D displacement. Dealing with the new parameters in the database, two of them will be included first: fault geometry and segmentation, and geological nature of surficial layers. Recently, the 2010 M7.2 El Mayor-Cucapah (Mexico) studies have shown that the number of slip planes, their dip and the rupture zone thickness have been strongly influenced by them. For the Kaikoura earthquake, those aspects could be treated later, once this huge rupture will have been investigated in the field.

To date, the database, which includes the “earthquake table”, “fault portion table” and obviously “observation point table”, merges the existing databases. However, the objective is to incorporate well-known earthquake cases described in literature and to explore the post-2000 M6+ inland earthquakes that could potentially provide relevant data. A first search in the USGS earthquake database provided a catalog of 130 shallow M6+ onshore epicenters since 2000, most having occurred in Asia (China, Iran, Japan, Russia, Pakistan, Turkey, Kyrgyzstan, Nepal, Myanmar) and very few having reported surface rupture information. There is consequently a need for regional geologists’ participation: this will be one major task of the SURE working group in the next years and, in this perspective, the JpGU-AGU joint meeting in Japan is a unique opportunity to go ahead in gathering Asian geologists.

Keywords: earthquake-related hazard, surface faulting, worldwide & unified database

Surface rupture characteristics of the 2016 Kumamoto earthquake from correlation of lidar topography

*Lia Joyce Lajoie[1], Edwin Nissen[2], Chelsea Phillips Scott[3], J Ramon Arrowsmith[3], Tadashi Maruyama[4], Tatsuro Chiba[5], James Hollingsworth[6]

1. Colorado School of Mines, 2. University of Victoria, BC, 3. Arizona State University, 4. Japan Geological Survey, 5. Asia Air Survey, Co., 6. Université Grenoble Alpes

The Kumamoto earthquake sequence of April, 2016 included a Mw 6.2 foreshock on April 14th, followed two days later by the Mw 7.0 mainshock. Here we present an investigation of the mainshock surface rupture, its shallow slip characteristics, and geometrical rupture propagation effects. We use a combination of fault offsets surveyed on the ground by the Geological Survey of Japan, together with near-field surface displacements calculated from differential airborne lidar data. We use two 0.5 meter-resolution digital surface models provided by Asia Air Survey, Co. that are derived from lidar surveys flown following the foreshock on April 15th, and eight days after the mainshock on April 24th. Although the surface models have not been processed to remove vegetation, the close temporal spacing of acquisitions minimizes non-tectonic surface changes. The datasets are correlated using two methods: pixel tracking with the COSI-Corr software package to compute horizontal displacements, and an iterative closest point tracking algorithm in LIBICP that provides the full 3D displacement field. Results for both methods are compared for internal consistency and surface offsets are computed along fault-perpendicular transects. Where lidar- and field-measured offsets are co-located they are generally in good agreement, but the lidar offsets can also be used to fill in significant gaps in the field data (up to ~3 km). Both datasets reveal a strikingly smooth along-strike slip distribution as well strain partitioning into strike-slip and dip-slip components along distinct rupture planes, rare observations in large earthquakes.

Keywords: Kumamoto earthquake, slip distribution, iterative closest point, pixel tracking, differential lidar, rupture characteristics

Estimation of ground displacements around Aso-Caldera caused by the 2016 Kumamoto Earthquake, with the differential LiDAR DEM analysis

*Sakae Mukoyama[1], takumi sato[1], tomoyuki takami[1]

1. KOKUSAI KOGYO CO., LTD.

After the main shock of 2016 Kumamoto Earthquake (M7.3), seismic wide-area crustal deformation was observed around Aso-Caldera region in Kumamoto Prefecture, Japan. In order to estimate ground displacements and deformation in wide-area, we conducted differential LiDAR DEM analysis to measure displacements of less than 1m order. The data sets we used for the analysis are 1 m mesh DTM (Digital Terrain Model) data measured in 2009 (pre-event) and 2016 (4-30 days after the event). We applied the particle image velocimetry method to calculate 3-D vectors of co-seismic deformation (Mukoyama, 2011). As a result, upheaval and northward displacements were observed in N-NW area in the caldera, and upheaval and southwestward displacements were observed in W-SW area. And westward displacements and subsidence were observed in the central-cone volcanoes area. The locations of these ground displacements show a broad boundary zone of directional change extend across the caldera. Additionally, some clear strike-slip ruptures and discontinuous change of ground displacements appeared around the western rim of caldera. On the other hand, large lateral mass movements were observed in the local basin of flat sediment area.
From these results, we confirmed the distribution of the ground displacements suggests the existence of the NE edge of the earthquake fault at the west margin of intra-caldera area. These results are corresponding with the results of other field survey, the GNSS observations, D-InSAR survey and seismic-source-fault-model analysis. Additionally, some results would contribute to make up for the data gap of D-InSAR analysis, and let us know missed surface ruptures by field survey.

Acknowledgements
This study was carried out as a part of "Surveys of the 2016 Kumamoto-Oita Earthquake disaster investigation team in the Japan Society of Engineering Geology"

Keywords: the 2016 Kumamoto Earthquake, Differential DEM Analysis, LiDAR, Image matching analysis

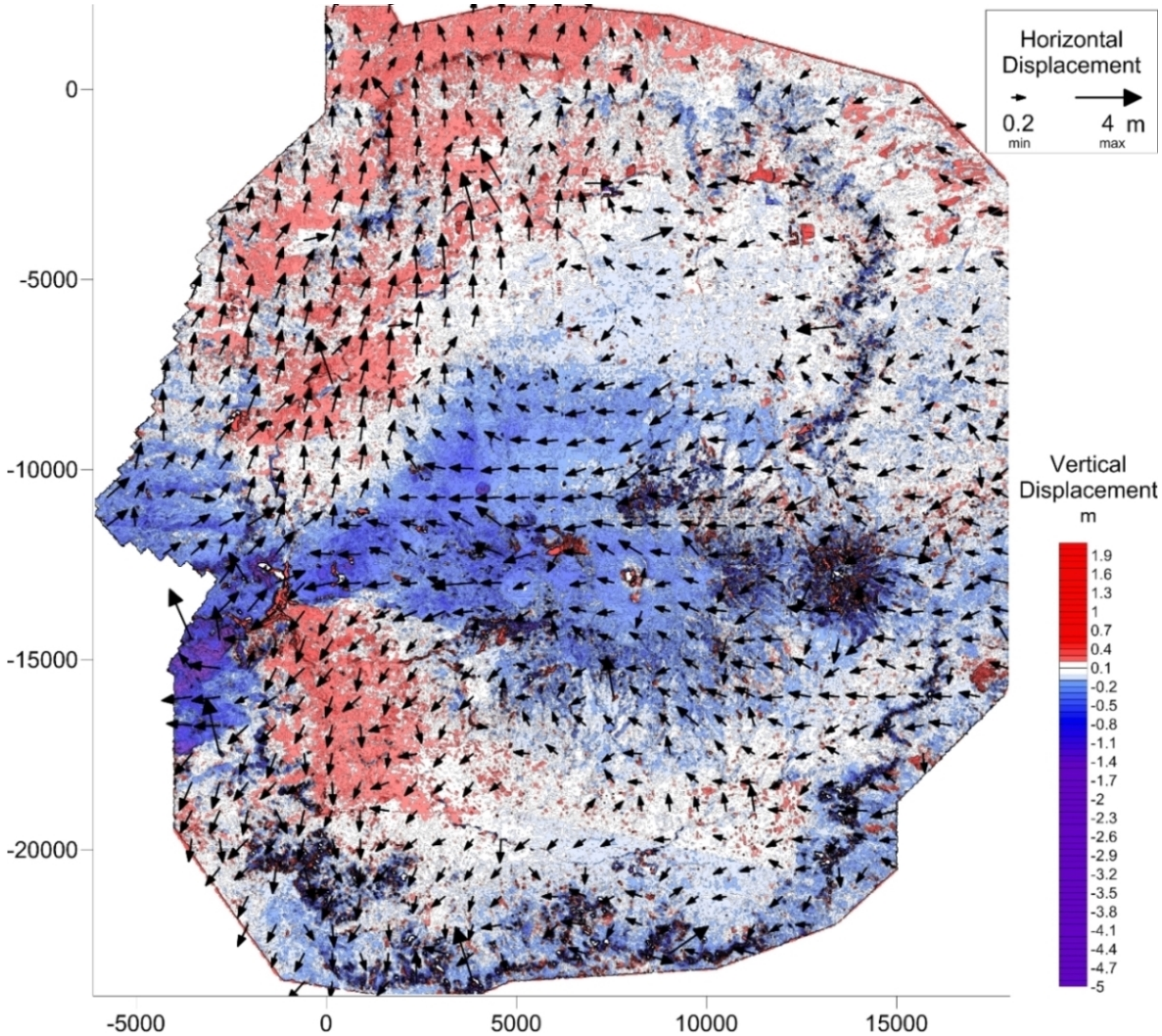


Fig.1 Ground displacements around Aso-Caldera by 2016 Kumamoto Earthquake,Japan
Coordinate System JDG2000/Japan Plane Rectangular CS II

Clues to evaluate short active fault learnt from the 2016 Kumamoto and Ibarakiken-hokubu, Japan, earthquakes

*Shinji Toda[1], Daisuke Ishimura[2]

1. International Research Institute of Disaster Science, Tohoku University, 2. Tokyo Metropolitan University

Inland large earthquakes occur not only on major active faults but also in areas no active fault and/or minor short fault mapped. The number of potential destructive earthquakes of M˜7 estimated from the major active faults would be significantly underestimated. It leads a conservative evaluation that seismogenic fault as long as ˜20 km is hidden or slightly truncated by the surface, and an M˜7 earthquake is assigned on each short fault. Based on field investigation and InSAR analysis at the 2016 Kumamoto earthquake, we here counter-argue that some of such minor and low-slip-rate faults might have been developed by insignificant but frequent slips triggered by nearby large earthquakes. Another implication is provided by recent M˜6 class earthquakes at Ibaraki-ken-hokubu, northern Kanto region. March 19, 2011 (Mj=6.1) and November 22, 2016 (Mj=6.3) Ibaraki-ken-hokubu earthquakes that might have shared a same short fault based on InSAR images and field survey. It enables us to interpret many short active faults might have been also developed by more frequent slip at only upper seismogenic layer due to M˜6 earthquakes.

Keywords: Kumamoto earthquake, short active fault, earthquake hazard assessment

Ground Motion Characteristics in the Vicinity of Surface Fault Ruptures due to the 2016 Kumamoto Earthquake

*Takao Kagawa[1], Shohei Yoshida[1], Hiroshi Ueno[1]

1. Tottori University Graduate School of Engineering

April 16, 2016, an earthquake of Mw7.0 occurred in the Kumamoto prefecture. The earthquake arose surface fault ruptures in disaster areas. Building damages due to fault displacement were dominant in the vicinity of surface fault rupture, however damages caused by strong ground motion were not to be dominant. This kind of disasters was also reported concerning other earthquakes with surface fault ruptures (e.g. 2011 Fukushima earthquake by Hisada, 2011). In order to evaluate effect of surface geology in the vicinity of surface fault ruptures, aftershock observations in suburb area of Mashiki town and dense microtremor observations in Mashiki town and Minami-Aso village were conducted. The observation points were set to cross the surface fault ruptures, and difference of subsurface structures around near fault area was evaluated. In this study, relation between subsurface structure and strong ground motions in the vicinity of surface fault ruptures is discussed.

Hisada et al., 2011, Journal of Japan Association for Earthquake Engineering, Vol, 12, No.4, pp.104-126.

Keywords: The 2016 Kumamoto earthquake, Surface fault rupture, Microtremor Observation, Subsurface structure

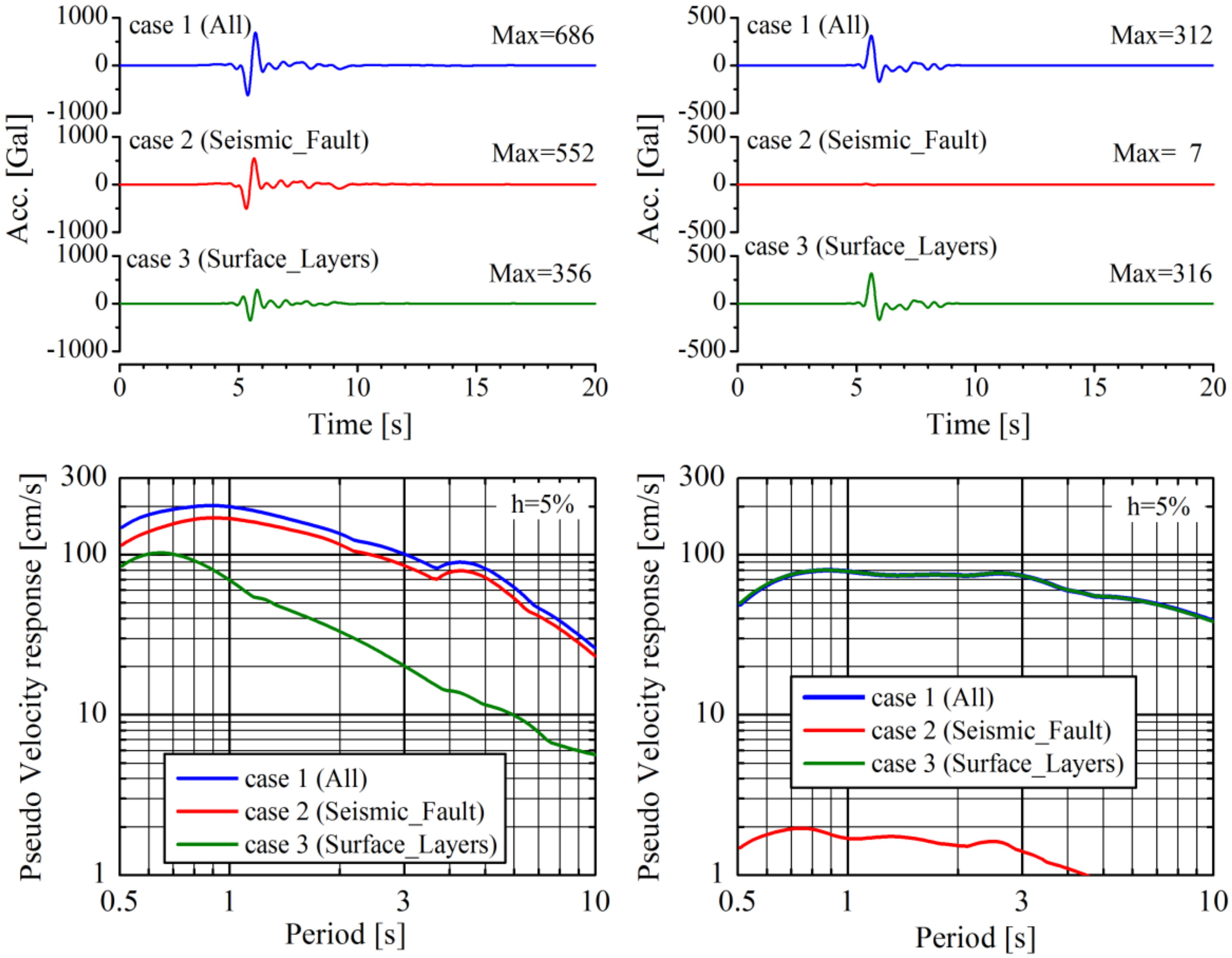
Proposal of Evaluation Method of Strong Ground Motions in Area Close to the Fault Trace

*Dan Kazuo[1], Kiyoshi Irie[1], Saruul Dorjpalam[1], Torita Haruhiko[1]

1. Ohsaki Research Institute, Inc.

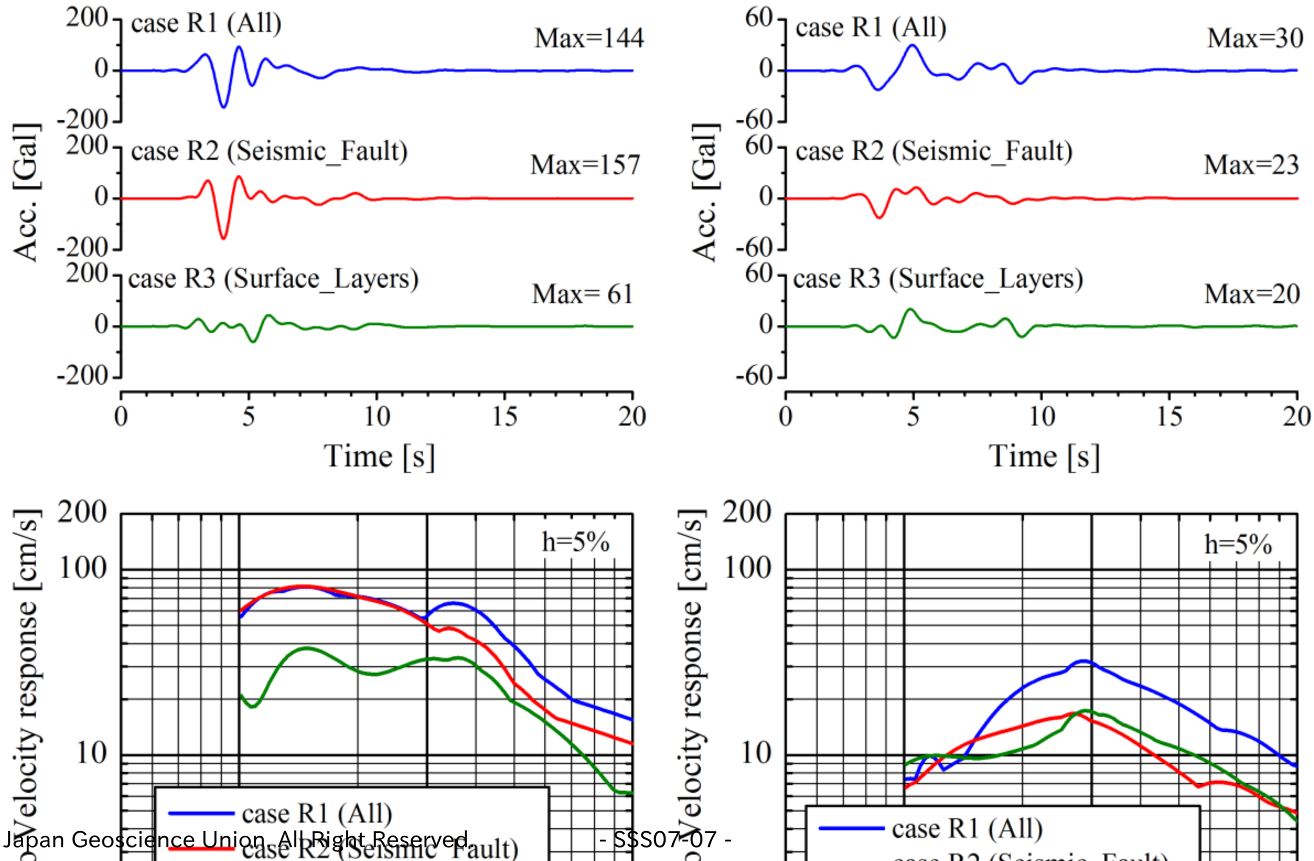
In Japan, only the seismic waves radiated from the fault in the seismogenic layer under the surface layers are considered in the usual strong motion prediction (e.g., Headquarters for Earthquake Research Promotion, 2016). However, in the inland crustal earthquakes, the seismic waves radiated from the fault in the surface layers above the seismogenic layer could influence the strong ground motions in the areas close to the fault traces. Hence, we proposed an evaluation method of the seismic waves radiated from the faults in the surface layers in vertical strike-slip and dipping reverse faults to investigate their influence on the strong motions.
In this method, we synthesized the seismic waves by the wave number integration technique, using the slip-velocity time functions obtained from the dynamic fault rupturing simulation by the three-dimensional finite difference method. And we calculated seismic waves at two points 50 m and 2 km close to the fault traces as a demonstration (in this abstract only the results at the 50 m point will be shown). The used dynamic fault rupturing model was 25 km in length, with the surface layers of 3-km thickness, the seismogenic layer of 15-km thickness, and the slip-weakening law. We decided the model parameters under the constraints by three empirical relationships among fault parameters of the surface and subsurface faults.
As the results of the vertical strike-slip fault show, 80 to 90 % of the fault normal component of the seismic waves radiated from the entire fault was attributed to the seismic waves radiated from the fault in the seismogenic layer. Almost 100 % of the fault parallel component at the point 50 m close to the fault trace was attributed to the seismic waves radiated from the fault in the surface layers. At the point 50 m close to the fault trace of the vertical strike-slip fault, the seismic waves of the fault normal component were larger than those of the fault parallel component in the period range of 0.5 to 6 seconds.
Also, we evaluated the seismic waves radiated from the dipping reverse fault by the same procedure as that for the vertical strike-slip fault. As the results of the dipping reverse fault show, 100% of the seismic waves of the fault normal component of the seismic waves radiated from the entire fault at the point 50 m close to the fault trace were attributed to those from the fault in the seismogenic layer in the period range shorter than 3 seconds. The seismic waves of the fault normal component from the fault in the seismogenic layer decreased to about 70% of those from the entire fault in the period range longer than 3 seconds. On the other hand, about the seismic waves of the fault parallel component, the seismic waves radiated from the fault in the surface layers have similar amplitudes to those from the fault in the seismogenic layer. At the point 50 m close to the fault trace of the dipping reverse fault, the seismic waves of the fault normal component were larger than those of the fault parallel component in the entire period range of 1 to 10 seconds.

Keywords: strong motions, close fault, dynamic simulation



(a) fault normal component (b) fault parallel component

Comparison of the seismic waves of case 1 (All), case 2 (Seismic_Fault), and case 3 (Surface_Layers) at point A (fault distance is 50 m) from the vertical strike-slip fault



Development Risk Evaluation Methods and Measures for Fault Movement by Engineering Approach

*Tadashi Narabayashi[1]

1. Hokkaido University

The Atomic Energy Society of Japan (AESJ) would like to promote “Development Risk Evaluation Methods and Measures for Fault Movement by Engineering Approach” by establishing a study committee.

In Japan, as a frequent earthquake country, impact of earthquake and tsunami have been considered when selecting the site and designing the industrial facilities. Of course, nuclear power plant is one of such facilities. When the Great East Japan Earthquake occurred on March 11, 2011, the components and pipes in the primary containment vessel (PCV) of the Fukushima Daiich Nuclear Power Plants of Tokyo Electric Power Company were not damaged by the earthquake, as mentioned in the AESJ’s Report by the Investigation Committee on Fukushima Daiichi NPS Accident investigation. However, the station blackout and multi-units severe accidents were induced by huge tsunami of height beyond the design basis.

From these lessons learned, the new regulation criteria have been established based on the strategy of defense-in-depth, requiring a various countermeasures not limited to earthquake and tsunami but also against other natural disasters. This new criteria will be applied when reviewing the restart applications of operating plants that are currently under shutdown. In order to enhance safety, AESJ think it important the development risk evaluation methods and measures for fault movement by engineering approach.

This committee evaluated development Risk Evaluation Methods and Measures for Fault Movement by Engineering Approach.

(1)An open fruitful discussion by experts in the area of earthquake, geology, geotechnical, civil, and aseismic design as well as other stakeholders such as academia professors, nuclear reactor engineers, regulators, and licensees,

(2)Investigation to select the most advanced scientific and rational judgement based on the domestic and global knowledge obtained so far, and,

(3)Continuous discussions and efforts in the global field in order to collect and organize this knowledge and reflect the global standers and nuclear regulations, such as definition and evaluation method for the active and prevention of severe accidents based on the accumulated database in the world.

There are several faults definitions for active and non-active faults. Damage evaluation for Faults Movements, damaged components and piping for PWR. Almost all the damage in primary piping in PWRs are the event of LOCA Scenario. Piping damages were simulated by FEM Analysis under faults displacement in reactor building. We would like to point out the importance of auxiliary cooling system, recovery of containment cooling by mobile system and recover of heat sink will be attained.

Fault displacement hazard analysis for risk evaluation

*Yoshikazu Suzuki[1], Makoto Takao[2], Koji Okumura[3], Kazuo Tani[4]

1. Japan Nuclear Safety Institute, 2. Tokyo Electric Power Company Holdings, Inc. , 3. Hiroshima University, 4. Tokyo University of Marine Science and Technology

In October 2014, the Atomic Energy Society of Japan (AESJ) established an investigative expert committee to develop risk evaluation methods and measures for fault displacement on the basis of engineering approach. Following the launch of the committee, meetings were held seventeen times to discuss and examine the issue, and the committee ultimately published an investigative report in March 2017 to disseminate the research results. In this presentation, we will give an outline of the evaluation method in terms of fault displacement hazards.
Fault displacement hazards for risk evaluation should be analyzed both deterministically and probabilistically.
On a deterministic basis, a fault displacement, which is necessary for deterministic margin evaluation (hereinafter, 'the fault displacement for evaluation'), is to be determined on the basis of three kinds of approach, namely: 1) geological investigation approach, 2) numerical simulation approach, and 3) database of earthquake surface faults approach. 'The fault displacement for evaluation' should be set not only upon comprehensive consideration of 1), 2) and 3) but also taking into account uncertainties related to 1), 2) and 3).
On a probabilistic basis, hazard curves, which are necessary for Probabilistic Risk Assessment (PRA), should be determined in accordance with Probabilistic Fault Displacement Hazard Analysis (PFDHA), proposed by Youngs et al. (2003), Petersen et al. (2011), Takao et al. (2013) and so on. Furthermore, the hazard curves will be utilized as references when 'the fault displacement for evaluation' is examined.
As stated above, the AESJ has established a methodology to determine the fault displacement hazards. In order to improve the reliability of the method, it is essential to accumulate technical knowledge and for the related academic fields to cooperate with one another.

Keywords: fault displacement, deterministic basis, probabilistic basis, Probabilistic Fault Displacement Hazard Analysis (PFDHA)

Study on occurrence probability of distributed faults in PFDHA

*Makoto Takao[1], Satoshi Kaneko[1], Tetsushi Kurita[2]

1. Tokyo Electric Power Company Holdings, Inc., 2. Tokyo Electric Power Services Company, Ltd.

A probabilistic fault displacement hazard analysis (PFDHA) is a methodology that assesses the annual rate at which an amount of displacement of a surface earthquake fault exceeds a certain quantity. According to Safety Standard No. SSG-9 that was published by the International Atomic Energy Agency (IAEA) in 2009, it is recommended to perform a PFDHA for existing nuclear power plants in case there is a capable fault at the site.
Although Youngs et al. (2003) proposed PFDHA evaluation formulae in the USA, no study on PFDHA had been done in Japan. Therefore, Takao et al. (2013) proposed evaluation formulae in terms of both principal and distributed faults based on data from surface earthquake faults generated by reverse and strike-slip faults in Japan.
In addition, Takao et al. (2014) proposed alternative evaluation formulae by conducting model experiments and numerical analyses based on the discrete element method (DEM) in order to compensate for the lack of data regarding distributed faults.
As for the occurrence probability of a distributed fault, grid-size dependency was studied by Takao et al. (2014) and evaluation formulae were proposed. However, the range (distance from the principal fault) to be considered when analyzing the occurrence probability of a distributed fault has not been studied at all so far.
Therefore, we demonstrated parametric analyses which can clarify how the range, which is considered in the analysis of the occurrence probability of the distributed fault, impacts on the evaluation formulae. As a result of the study, a rough indication of the range could be proposed.
Finally, in our oral presentation, we will show future tasks to be addressed, such as improvement of the evaluation formulae reflecting the latest earthquakes such as the 2014 Nagano-ken Hokubu earthquake and 2016 Kumamoto earthquake.

Keywords: Probabilistic Fault Displacement Hazard Analysis, distributed fault, occurrence probability

Occurrence ratio of estimated fault displacement along active faults

*Takashi Azuma[1]

1. National Institute of Advanced Industrial Science and Technology

Evaluation of fault displacement along the active fault before the occurrence of large earthquake is very important to save the facilities from ground deformation. Although amount of fault displacement can be calculated from magnitude of earthquake or fault length, it is difficult to evaluate the amount of fault displacement at a specific site caused by earthquake in the future. There are two major reasons for this problem. One is variation of fault displacement from earthquakes with same size, another is variation of it along the fault trace.

Many of formulas showing a relationship between amount of fault displacement and magnitude of earthquake were proposed by many researchers, such as Wells and Coppersmith (1994) and Matsuda (1975). These formulas were based on data of many earthquakes, distributing with some range. Even though if this range is narrow, about half of fault displacement will be larger than estimated one by using the formula.

On the other hand, there were many records of slip distributions of the historical earthquakes accompanied by surface faults. They usually shows several peaks and section with similar amount of fault displacement. Locations where the amount of fault displacement exceed against the value estimated from the formula were limited. And another problem is recurrence model of slip distribution, such as uniform or not.

Keywords: active fault, fault displacement, surface fault, active fault evaluation

High density distributions of victims of inland earthquakes in the vicinity of the faults

*Yoshinobu Tsuji[1]

1. Fukada Geological Institute

The main shock of the Kumamoto earthquake M7.3 at 1 AM, 25 minutes of 16th, June, 2016 was generated by right strike slip of the Futagawa fault which runs from the western edge of Aso Caldera to Uto city. On two days before the main shock, in the evening of 14th July, an fore shock (M6.3) occurred on the same fault as the main shock, and nine people were killed. Caused by the main shock, 41 people were killed, and 37 people were killed in their own house. The square-street name of the houses of those victims were reported on the local newspaper “Kumakoto-Nichinichi Shinbun” up to 25th June. The present author obtained those papers up to three weeks after the main shock, and collected the articles of the victims, and the distribution of the houses of victims was clarified (Fig. 1). It is presumable that the occurrence time of the main shock was midnight, 1 o’clock 25 minutes, so, almost all victims kept sleeping in their own houses. Fig shows that almost all victims were killed in the zone within 3 kilometers north side of the fault. On the other hand the distribution of entirely destroyed houses, about 8000 houses in total, is extends more widely. It should be noticed that the distribution of victims was sharply concentrated at the fault more than that of house damage. Images of traffic monitoring cameras show that, in the area close to the fault, the necessary time to a house to be entirely collapsed was only two to three second. It is considerable that only such a short time it is impossible to make effective protection to keep life in the destroyed houses.

Fig 2 shows the distribution of the mortality ratio (= number of killed per population) of the 1927 Kita-Tango earthquake M7.3 with its generation faults Gomura and Yamada faults. In this case we can recognize that the victims were densely distributed in the zone close to those faults.

Fig. 3 shows the distribution of the mortality of villages around Iga-Ueno castle town, Mie Prefecture caused by the 1854 Ansei Iga-Ueno earthquake. Matsuda et al. (1982) proposed that this earthquake wae generated by the activity of the Kizugawa fault. For this case also we can recognize that the victims were densely distributed in an area close to the fault. The rule discovered in the present study is valid for estimation wich fault was moved in the occurrences for historical earthquakes.

Acknowledgement: This study was achieved as a part of the investigation of Grant-in Aid for Sientific Research (C) named “Study on the distribution of casualties caused by earthquqkes and tsunamis (2014-2016, No. 26350479, Head investigator: Yoshinobu Tsuji)” which is supported by the Ministry of Education, Calture, and Sciences (Monbusho).

Keywords: The 2016 Kumamoto Earthquake, The 1927 North Tango Earthquake, The 1854 Iga Ueno Earthquake, motallity distribution, mortallity distribution and fault lines

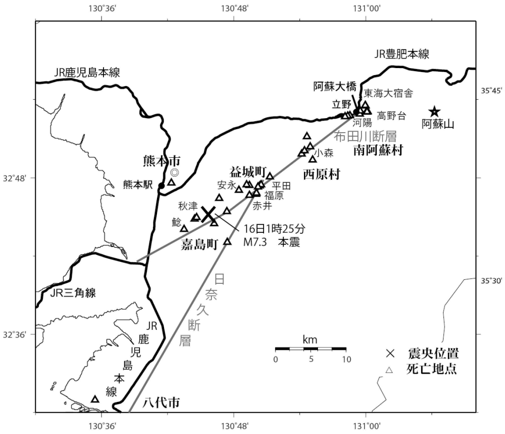


図１　2016年4月16日熊本地震の死者発生地点

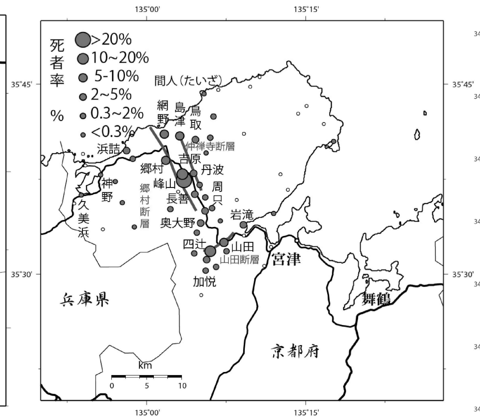


図２　1927年（昭和2年）北丹後地震の町村別死者率

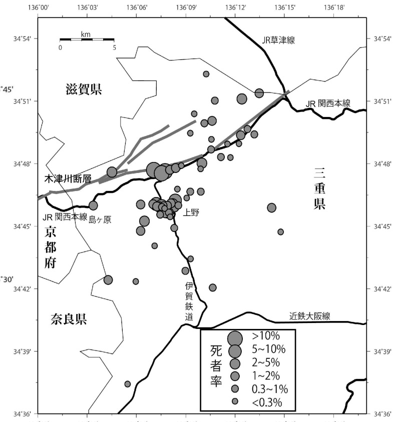


図３　安政元年(1854)6月15日伊賀上野地震の集落別死者率

Surface Rupture and Structural Damage

*Shinichi Matsushima[1]

1. Disaster Prevention Research Institute, Kyoto University

During the 2016 Kumamoto Earthquake, surface rupture was observed along the Futagwa-Hinagu Fault zone for the distance of more than 20km. This is a very rare case and this shows that it is very difficult to specify where the surface rupture will appear before the earthquake. For this matter, it is more important to investigate the relationship between the active fault and source fault and the deep basin structure that is a result of the fault activity for many years, rather than the very precise location of the active fault. This was proved after the thorough investigation of the cause of the damage belt during the 1995 Kobe Earthquake. However, if the displacement of the surface rupture is surveyed thoroughly, the information can be used to investigate the relation to the slip on the source fault, which can be used to predict the amount of slip on the source fault of future earthquake occurring on the active faults.
On the other hand, there are concerns that the surface rupture will damage the structures on top of it. If the rupture speed is very slow, the rupture will not be able to split the structure, but the structure will restrict the deformation by the rupture. If the rupture speed is fast enough, it may have the energy to split the structure, so it will be worthwhile to observe the speed of the surface rupture and investigate the relation to the slip on the source fault.

Keywords: Surface rupture, Structural damage, Source fault

Earthquake-induced surface deformations in a small mud volcano: multi-temporal high-definition measurements using TLS and UAS-SfM

*Yuichi S. Hayakawa[1], Shigekazu Kusumoto[2], Nobuhisa Matsuta[3]

1. Center for Spatial Information Science, The University of Tokyo, 2. University of Toyama, 3. Okayama University

Tectonic signals are often found in mud volcanoes which are formed both in the land and undersea areas. Earthquakes often enhance the activities of mud volcanoes, including the surface deformations, mud eruptions, and gas emissions. Extensional stresses by upcoming underground pressures of liquid mud and gas may result in the formation of surface ruptures on mud volcanoes. Subtle changes of such surface deformations can be detected by the use of high-definition topographic measurements, including terrestrial laser scanning (TLS) and unmanned aerial system-based structure-from-motion multi-view stereo photogrammetry (UAS-SfM). The Murono mud volcano, located in Niigata Prefecture in north-central Japan, is an ideal test site for the measurements because of its small size and frequent deformations by strong earthquakes in this region. The spatiotemporal variations in the surface morphology have been explored in the mud volcano using TLS. While the TLS approach is suitable for accurate three-dimensional measurements of the surface morphology, the UAS-SfM approach is capable of acquiring visual images of the ground surface from which cracks can be readily extracted and mapped with a certain accuracy. The fusion of TLS and UAS-SfM point cloud data enables to enhance the accuracy of the UAS-derived data. We demonstrate a case study of the crack mapping using these data, as well as a result of numerical simulation of crack formations based on the pressure distribution by earthquakes.

Keywords: TLS, SfM-MVS photogrammetry, UAS, Point cloud, Digital Elevation Model, Cracks

ACTIVE FAULT AND SURFACE RUPTURES OF PIDIE EARHQUAKE ON 7 th DECEMBER 2016, ACEH, INDONESIA

*Asdani Soehaimi

Seismicity of Sumatera Island Indonesia, consist of three seismic source zones are West Sumatera Subduction seismic source zone, Sumatera Active Fault seismic source zone and North Sumatera Back Arc Thrusting seismic source zone.
Pidie earthquake on 7th December, 2016 has the magnitude 6.5 Richter scale and the depth 15 Km. This earthquake caused the damaged of geology and infrastructures, panic and perished. Total losses caused this event estimated is about 1.854 Trillion rupiah. The geological damaged during this event are surface ruptures, liquefactions and landslides. The surface ruptures mainly found in West –East and North - South directions. The West –East surface ruptures found parallel to coastal line and the North –South surface ruptures found crossing the West –East surface ruptures. Liquefactions generally appear in North –South surface ruptures as the extensional zones. Horizontal offset found is 12 centimeters and the vertical offset is 10 centimeters. Landslides commonly found in the areas of mountainous slopes at southern part of Pidie Jaya district.
Base on focal mechanism solutions, distribution and propagation of aftershocks, pattern of intensity map and the direction of surface ruptures, expected this earthquake caused by sub marine oblique thrust fault and call as the North Sumatera Back Arc Thrusting. This fault located in offshore area is about 23.5 Km from coastal line of Pidie Jaya region.

Keywords: Surface Ruptures, North Sumatera Back Arc Thrusting

Imaging the seismic history of the MFT: a 100km-long Airborne Lidar Survey in Eastern Nepal

*CAGIL KARAKAS[1], Paul Tapponnier[1], Soma Nath Sapkota[2], Paramesh Banerjee[1], Sorvigenaleon Ildefonso[1], Laurent Bollinger[3], Yann Klinger[4], Magali Rizza[5], Aurelie Coudurier Curveur[1]

1. Earth Observatory of Singapore, NTU, 639798 Singapore, 2. National Seismic Center, Department of Mines and Geology, Lainchaur, Kathmandu, Nepal., 3. Département Analyse et Surveillance Environnement, CEA, DAM, DIF, F-91297 Arpajon, France, 4. Institut de Physique du Globe de Paris, UMR 7154, 75238 Paris, France, 5. Laboratoire Géosciences Montpellier, UMR 5573, Université Montpellier 2, 34095 Montpellier Cedex 05, France

In May-June 2015, an airborne Lidar survey of the Main Frontal Thrust (MFT) was conducted for the first time along the south side of the Siwaliks in eastern Nepal. The ~ 100 km long swath covered a 10 km wide area from east of Lahan (86°27’ E) to west of Bardibas (85°53’ E), encompassing large fractions of the surface ruptures of the great 1934 and 1255 earthquakes. The survey, acquired at the driest season of the year, provided a high-resolution (4 data points /m^2) digital elevation model over a surface area of about 1000km^2, covering cultivated/forested terrains. We use this new, high quality topographic dataset to build a regionally integrated interpretation of the tectonic geomorphology of the thrust front. The data help refine our mapping of the thrust trace and identify tectonically abandoned fluvial channels and terraces. In parallel, it helps assess the depth of hanging-wall river incision, and quantify the dynamic interaction between cumulative thrust throw and drainage evolution. It affords a critical, wide-ranging comparison of the multiple uplifts of hanging-wall terraces, previously measured at only a handful of field sites. The continuous Lidar swath coverage reveals new areas with striking tectonic geomorphology that lay hidden beneath Sal forests. We discuss the main results and new insights provided by the Lahan/Bardibas Lidar survey. Such results justify the systematic acquisition of comparable Lidar data along the entire length of the MFT in Nepal and adjacent countries.

Keywords: Nepal, MFT, Imagery, Mapping, Rupture

Surface ruptures of great (M>8) earthquakes in Eastern Himalayas: characteristic slip over the last 9ky

*Aurelie Coudurier Curveur[1], Elise Kali[2], Paul Tapponnier[1], Jerome van der Woerd[2], Swapnamita Choudhury[3], Saurabh Baruah[4], Cagil Karakas[1], Paramesh Banerjee[1], Sorvigenaleon Ildefonso[1], Emile Okal[5]

1. Earth Observatory of Singapore, NTU, Singapore, 2. IPGS, CNRS, Univ. de Strasbourg, France, 3. Wadia Institute of Himalayan Geology, Dehradun, India , 4. NEIST, Jorhat, India, 5. Dept. of Earth and Planet. Sciences Northwestern Univ., Evanston, IL, United States

The great 1950 Assam earthquake of magnitude M_w8.7, which triggered devastating landslides and numerous aftershocks in the Abor and Mishmi mountain ranges, emphasizes the potential high earthquake hazard in Eastern Himalayas. However, active faults of the Eastern Himalayan Syntaxis are poorly mapped and seismic history is unknown. By combining morpho-tectonic field observations, satellite imagery analyses, and high-resolution topographic datasets, we document the recent 1950 surface break as well as past surface ruptures associated with 5 historical earthquakes along the mountain front. We analyse the height and shape of tectonic escarpments to separate recent co-seismic from cumulative surface deformation. We stack topographic profiles across sets of uplifted alluvial surfaces to quantify individual co-seismic vertical throw for each earthquake. We show that they are similar to the recent 1950 vertical throw at each investigated site. These throws differ between the Main Himalayan Frontal Thrust (MFT) and the Mishmi Thrust (MST) from 4 ±1 m, to 7.3 ±0.3 m and 11.5 ±0.5, respectively. This suggests characteristic slip for the last 6 successive earthquakes, likely of similar size, producing a surface rupture over at least 200 km along the MFT and the MST. By combining these results with cosmogenic dating of uplifted surfaces, we estimate a return time between these great (M>8) earthquakes of about 1800 yrs on both thrusts over the last 9ky.

Keywords: Surface rupture, Himalaya, Characteristic slip, Return time, Earthquake

Non-characteristic surface rupturing earthquakes on the ISTL active fault system, Japan

*Hisao Kondo[1]

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

Intraplate earthquakes generally have recurrence intervals of a few thousands to tens of thousands of years, in contrast to interplate earthquakes, which repeat at intervals shorter than a few hundred years. We here report the first evidence for an extremely short recurrence time on an intraplate fault in Japan. The Kamishiro fault consisting of the northern end of the Itoigawa-Shizuoka Tectonic Line active fault system generated a Mw 6.2 earthquake on 22 November 2014. The surface rupture extends for about 9 km long mostly along the previously mapped active faults, but the source fault is inferred to be about 20 km long by aftershock distribution. It indicates that the 2014 event was partially ruptured and non-characteristic event comparing with the total length of the Kamishiro fault for about 24 km long. A paleoseismological trench excavation across the 2014 surface rupture showed a down-dip increase in displacement along the fault strands of the 2014 earthquake and two prior paleoearthquakes. The slip of the penultimate earthquake was similar to the slip of 0.5 m with the 2014 earthquake at the trench site, and the timing was constrained to be after AD 1645. The antepenultimate event might be correlated with the historical AD 762/841 earthquake. Judging from the timing, the damaged area, and the amount of slip, we infer that the penultimate earthquake corresponds to the AD 1714 historical earthquake. Therefore, the Kamishiro fault has generated moderate sized earthquakes both in AD 1714 and 2014, with a recurrence interval of about 300 years. This recurrence interval of surface rupturing earthquakes is extremely short compared with intervals on other intraplate active faults known globally. In addition, the spatial extent of the 2014 surface rupture accords with the distribution of a serpentinite block. The relatively low coefficient of friction of serpentinite may account for the unusually frequent earthquakes. These findings would affect long-term forecast of earthquake probability and time-dependent seismic hazard assessment under the various geological settings in Japan.

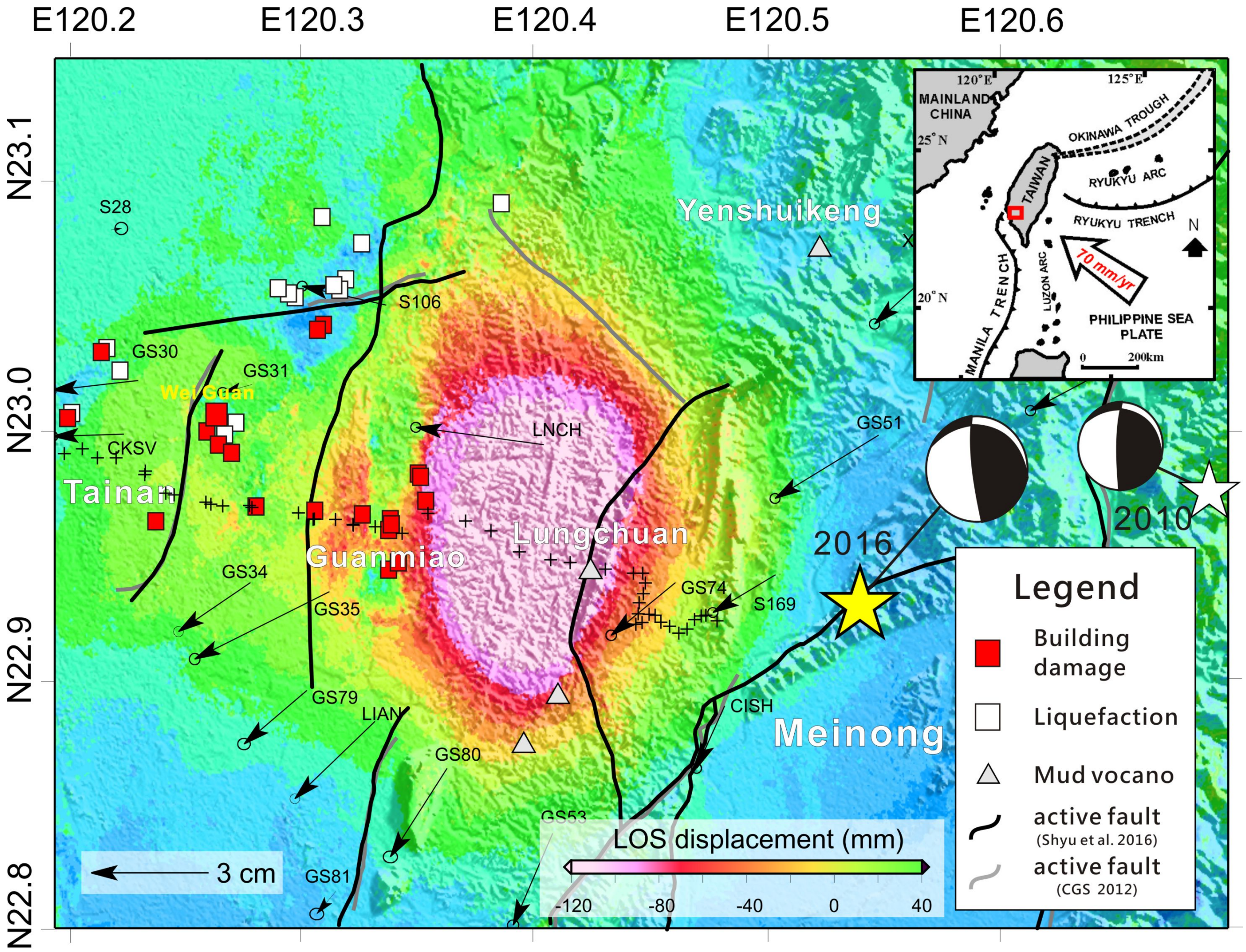
Shallow crustal structures triggered by the M_L 6.6 Meinong earthquake, southwestern Taiwan, from field investigation of surface deformation and damages

*Ling-Ho Chung[1], Ray Y Chuang[2], J Bruce H Shyu[3], Mong-Han Huang[4], Kenn-Ming Yang[5], Kuo-En Ching[6], Yuan-Hsi Lee[1]

1. Department of Earth and Environmental Sciences, National Chung Cheng University, 2. Department of Geography, National Taiwan University, 3. Department of Geosciences, National Taiwan University, Taipei, Taiwan, 4. Jet Propulsion Laboratory, California Institute of Technology, Pasadena, USA, 5. Department of Earth Sciences, National Cheng Kung University, 6. Department of Geomatics, National Cheng Kung University

The M_L 6.6 Meinong earthquake on 6 February 2016 caused serious damages in southwestern Taiwan. Coseismic displacement derived from GPS and InSAR shows ~10 cm dome-shaped surface uplift 15 km west of the epicenter with two clear N-S trending discontinuities in the InSAR fringes around the town of Guanmiao, which are highly related to building damages and surface cracks observed in the field. In this study, we integrate seismic reflection data, geologic data, and results from field investigation to construct shallow crustal structural geometry. The two lineaments near Guanmiao seen in the InSAR result may be induced by local shallow folding in the Liushuang - Erhchuangchi (LS-EC) Formation. Instead of being a traditional fault-bend fold, the significant uplift west of Guanmiao may be associated with pure shear deformation of clayey Gutingkeng (GTK) Formation. Our result suggests that lower crustal earthquakes can trigger active structures at shallower depths, which is capable of generating localized surface deformation and damages.

Keywords: Meinong earthquake, InSAR


E120.2
E120.3
E120.4
E120.5
E120.6
N23.1
N23.0
N22.9
N22.8
MAINLAND CHINA
120°E
125°E
25°N
20°N
OKINAWA TROUGH
TAIWAN
RYUKYU ARC
RYUKYU TRENCH
MANILA TRENCH
LUZON ARC
70 mm/yr
N
PHILIPPINE SEA PLATE
0
200km
S28
S106
GS30
GS31
Wei Guan
CKSV
Tainan
LNCH
Yenshuikeng
GS51
Lungchuan
Guanmiao
GS34
GS35
GS74
S169
2016
2010
GS79
LIAN
CISH
Meinong
GS80
GS53
GS81
3 cm
LOS displacement (mm)
-120
-80
-40
0
40
Legend
Building damage
Liquefaction
Mud vocano
active fault
(Shyu et al. 2016)
active fault
(CGS 2012)

Field survey and interpretation of the surface linear ruptures in northwest of the outer rim of the Aso caldera emerged on SAR interferogram

*Hiroshi Une[1], Takayuki Nakano[1], Satoshi Fujiwara[1], Tomokazu Kobayashi[1], Yu Morishita[1], Kazumi Iwata[1], Hiroshi, P. Sato[2], Hiroshi YAGI[3]

1. Geospatial Information Authority of Japan, 2. Nihon Univ., 3. Yamagata Univ.

Among many linear discontinuities identified using satellite radar interferometry images of the ALOS-2 showing small surface displacement associated with the 2016 Kumamoto Earthquake, vertical displacement pattern of east-west linear discontinuities with the lengths of a few kilometers in northwest area of the outer rim of the Aso caldera shows south-side-down in northern part and north-side-down in southern part by three dimensional deformation analysis (Morishita et. al., 2016), suggesting half-graben-like normal faulting triggered by north-south tensional stress field derived secondary from the stress changes associated with the main source faulting (Fujiwara et. al. 2016).
We carried out field surveys of the sites on these discontinuities and identified characteristic surface ruptures at many places. Strikes are approximately east-west and both width and throw are 30 cm at maximum. Such ruptures continue straightly at least a few tens meters. All of positions, strikes and direction of surface ruptures are consistent with the assumption by SAR interferometry. Some of those have characteristics in shape that can be misread as surface earthquake faults.
From the geomorphologic point of view, raptures are found on “Kuratake Faults” identified by preceding literatures (Kyushu Active Fault Research Group 1989, Nakata and Imaizumi 2002) with the displacement direction in accordance with geomorphological assumption. Besides, many ruptures were found where geomorphologically active faults are not recognized. This area is thickly covered by the pyroclastic flow deposits and volcanic products from Aso Volcano, consequently it is inferred that activities of buried tectonic structure were triggered.
Recently passive, or “accompanied” deformation of existing structure triggered by the change of stress field or seismic motion associated with earthquakes have been often reported since SAR interferometry has enabled the seamless and detailed understanding of surface deformation. These passive deformation might have occurred universally in nature and not special for the reported events. Such passive deformation may be possibly included in the list of past surface earthquake faults and events recognized by trench surveys. We should start the discussion on the issue of reexamination of identification of characteristic earthquake events of active faults.

Keywords: SAR interferometry, surface ruptures, triggered displacement, accompanied displacement

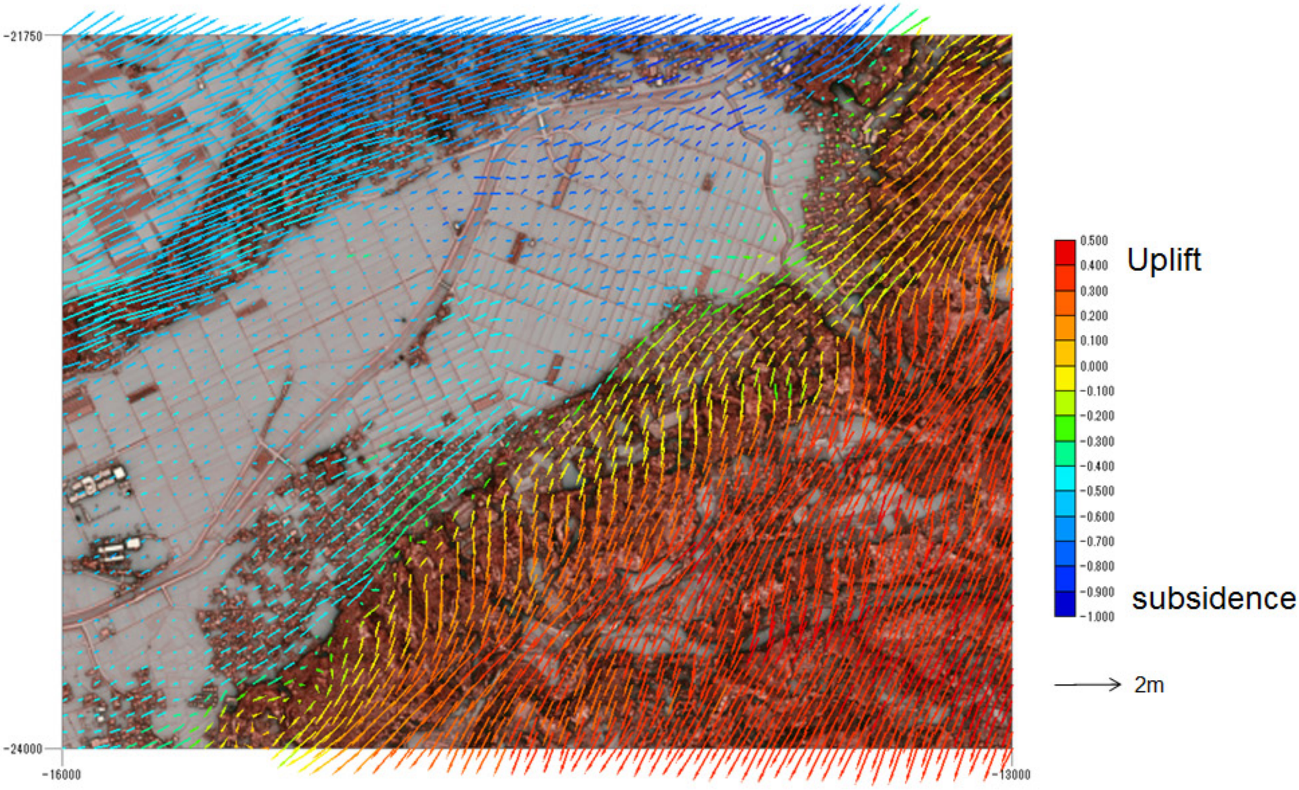
Surface rupture characteristics of the 2016 Kumamoto earthquake from compare of LiDAR DEM

*Tatsuro Chiba[1], kazuo oda[1], kazuya funakoshi[1], toko takayama[1]

1. Asia Air Survey Co., Ltd.

In the earthquake of M 7.3 occurred in Kumamoto Prefecture at 1:25 on April 16, 2016 (hereinafter referred to as the Kumamoto earthquake), surface earthquake faults had appeared in the area including Aso-city to Mifune-cho. In order to grasp these ground deformation quantitatively and quantitatively, the authors used airborne LIDAR data captured at two time periods immediately before this earthquake (April 15,14: 59 - 19: 20) and immediately after (April 23,10: 14 - 11: 53).
Elevation difference using mesh data is common as a method of comparing terrain data at multiple times. However, when large horizontal displacement is involved such as fault displacement, accurate fluctuation situation cannot be grasped by this method.
Therefore, we investigated a method to calculate three dimensional displacement vector by using point cloud data acquired by aviation laser measurement. An ICP (Iterative Closest Point) method is a general technique for registration between two point clouds. By repeating the process of obtaining the nearest neighbor point between two point clouds as the corresponding point and estimating the geometric transformation of reducing the distance of the corresponding point, it is possible to perform automatic positioning without a marker. In this study, we also adopted a method (CCICP: Classification and Combined ICP) that also takes into consideration minimizing the distance between the plane and the plane that the point group comprises.
Model area was set up near Mt. Miyake in Mashiki Town and CCICP method was applied as shown in Fig.1. From this result, it was confirmed that two right lateral strike-slip faults in the east-west direction along the north and south edges of the Kiyamagawa Lowland and the northwest-southeastward fault going on to it.
In addition, the uplift was observed in the mountainous area on the south side and the subsidence in the plateau portion on the north side. It was revealed that in some places where there are almost no horizontal movement locally in the vicinity where the fault crosses.

Keywords: LiDAR, Active Fault, 2016 Kumamoto Earthquake, Iterative Closest Point algorithm


-21750
-24000
-16000
-13000
0.500
0.400
0.300
0.200
0.100
0.000
-0.100
-0.200
-0.300
-0.400
-0.500
-0.600
-0.700
-0.800
-0.900
-1.000
Uplift
subsidence
2m

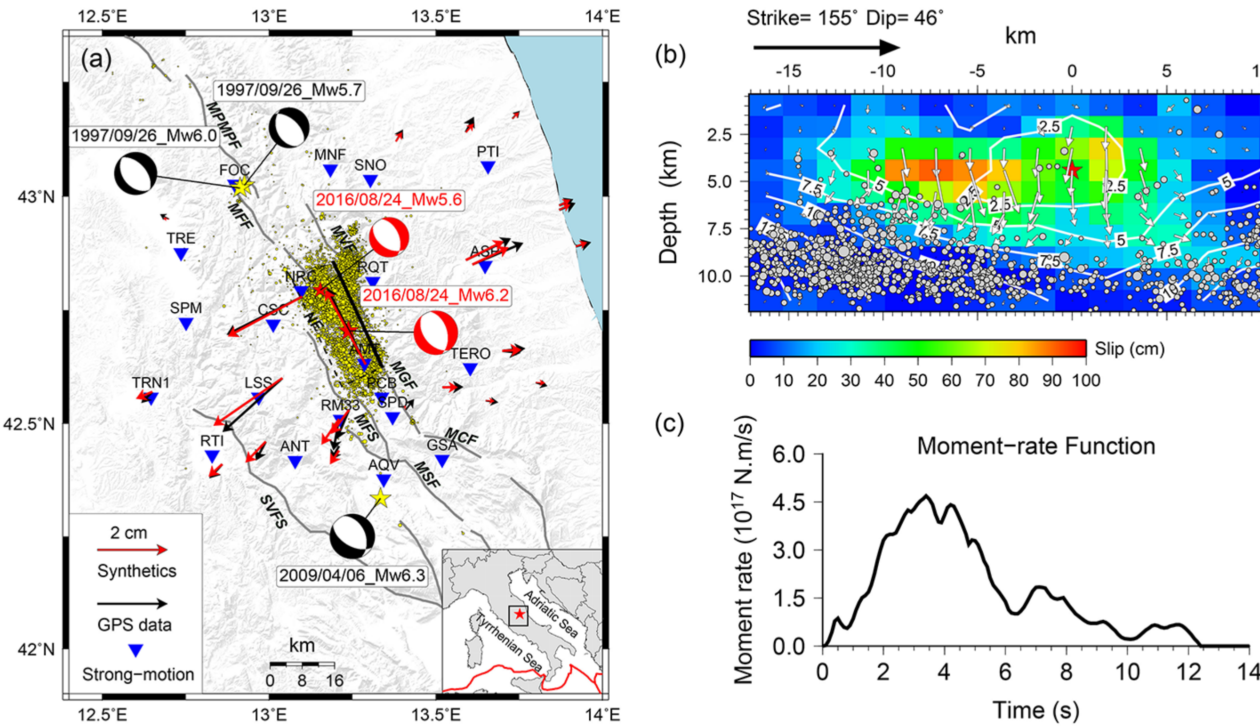
Rupture features of the 2016 Mw6.2 Norcia earthquake and its possible relationship with strong seismic hazards

*Chengli LIU[1], Yong ZHENG[1,2], Zujun XIE[2], Xiong XIONG[2]

1. Hubei Subsurface Multi-Scale Imaging Key Laboratory, Institute of Geophysics and Geomatics, China University of Geosciences, 2. State Key Laboratory of Geodesy and Earth’ s Dynamics, Institute of Geodesy and Geophysics, Chinese Academy of Sciences

For analyzing possible reasons for the heavy damage and seismogenic features of the 24 August 2016 Norcia earthquake, we constructed and analyzed its rupture process by incorporating datasets of near-field strong motion, teleseismic and static GPS displacements. The optimized model revealed a relatively compact slip pattern with mainly normal fault components. The maximum slip was around 0.9 m, while the rupture areas extended ~11 km and ~20 km along dip and strike, respectively. The total seismic moment was 2.3×10^{18} Nm, equivalent to Mw 6.2. Most seismic moments were released within 10 s, radiating 3.5×10^{13} J of seismic energy. The rupture history showed asymmetric propagation and is characterized by a relatively high rupture velocity within the first 6 s with a maximum of ~3.2 km/s. The mainshock slip pattern correlated well with the aftershocks distribution, and most of the accumulated strain was released in the east of seismic gap between the nearby 1997 and 2009 earthquake sequences.

Keywords: Norcia earthquake, Rupture features, Joint inversion, Seismic hazards



An example of slip on a capable fault: Near-field co-seismic deformation of the 30th October Central Italy earthquake (6.6 Mw) measured using low-cost GNSS

Maxwell Wilkinson[1], Laura Gregory[2], Richard Walters[3], Luke Wedmore[4], Ken McCaffrey[3,1], Richard Jones[1], Gerald Roberts[4], *Robert Holdsworth[1,3]

1. Geospatial Research Limited, Department of Earth Sciences, Durham University, Durham, DH1 3LE, 2. School of Earth and Environment, University of Leeds, Leeds, LS2 9JT, 3. Department of Earth Sciences, Durham University, Durham, DH1 3LE, 4. Department of Earth and Planetary Sciences, Birkbeck, University of London, London, WC1E 7HX

Capable faults and the ground motions they produce in the near-field are of great importance to the construction of major infrastructure facilities such as nuclear plants, yet few datasets exist to constrain these effects. Here we present a record of co-seismic displacement of the 30th October Central Italy earthquake measured in the near-field using low-cost GNSS, an example of co-seismic slip on a capable fault. Four low-cost GNSS units were installed across the causative Mt. Vettore fault as two footwall-hangingwall pairs with baselines of 1,286 m and 1,870 m with an along-strike separation of 6.2 km. The displacement records reveal near-synchronous co-seismic displacement along each baseline, values of finite co-seismic displacement, rise-time and rupture velocity. A rigorous comparison of these values has been conducted using independent datasets of displacement and acceleration derived from regional GPS, InSAR, a local strong motion station and mapping of surface ruptures which intersect the two baselines. This comparison and analysis, whilst not without discrepancy, validates low-cost GNSS for the first time as an appropriate method for the temporal measurement of near-field co-seismic displacement. The derived empirical values will benefit the process of fault rupture modelling and accurate ground motion prediction in the near-field of capable faults worldwide.

Keywords: capable fault, surface ruptures, near-field co-seismic deformation , low-cost GNSS, 30th October Central italy earthquake


MANCHESTER
UNITED
THE
NORTH
FACE

Co-seismic offsets and damage associated with the Hundalee Fault during the 2016 Kaikoura, New Zealand, M7.8 earthquake

*Ken Xiansheng Hao[1,4], David Barrell[2], Mark Stirling[3], Katrina Sauer[3], Jack Williams[3], Grace Duke[3]

1. National Research Institute for Earth Science and Disaster(NIED), 2. GNS Science, 3. UNIVERSITY OF OTAGO, 4. GEM Foundation

The 14 November 2016 Kaikoura M 7.8 earthquake occurred in the northern part of South Island, New Zealand. Complex co-seismic faults and crustal deformations occurred over a strike length of at least 150 km, both on land and off shore, with extensive landsliding that caused great damage to the national highway and railway.

We conducted a field survey on the Hundalee Fault and associated features from 19-21 December 2016 as one of multi-institutional teams. Field investigation started by 5 hours air reconnaissance from a helicopter. At temporary landing sites (site A and B, Figure) on a NNW-SSE fault in mountain terrain, we found up-down relative movement with eastern side uplifted ~1m at A but western side uplifted ~0.6m at B suggested a complex dip-slip movement possibly with some sinistral strike-slip.

On ground survey, co-seismic fault displacements recorded mainly at C, D, E, F and G (Figure). Nearby the previously mapped line of the NE-SW Hundalee Fault on GNS Science geological map, surface rupture had the NW side uplifted at D, F, while a SE side uplift at E, suggests that the Hundalee Fault rupture was complex. The maximum vertical displacement on the Hundalee Fault was ~1.5 m, there accompanied by as much as ~3.7 m dextral offset, as measured across offset road and railway at F. The coast around beach G was uplifted coseismically ~1-2 m. Residence house damaged at H as well as some other houses along the Hundalee Fault.

According to the updated survey results of the multi-institutional research team (GNS, 2016), the Hundalee Fault was one of more than 12 individual faults that collectively ruptured during the earthquake.

We will present the updated work and more observed points based on the on-going summary.

Reference: GNS, 2016, http://info.geonet.org.nz/pages/viewpage.action?pageId=20971550

Keywords: Kaikoura earthquake, field investigation, co-seismic fault, New Zealand, Hundalee fault


Date on
161219
161220
161221
:Sinistral offset
:Uplifted side
Hundalee Coseismic faults by Ken Hao.
Background by GNS.
0 0.35 0.7 1.4 2.1 2.8
Kilometers
A
B
C
D
E
F
G
H
Oaro
Monument

Satellite SAR differential interferometry analysis on surface deformation associated with 2011 and 2016 earthquakes in northern part of Ibaraki prefecture

*TAKUMI ONUMA[1]

1. JGI, Inc.

Surface deformation pattern associated with earthquakes occurred in northern part of Ibaraki prefecture on March 19, 2011, and on December 28, 2016, was investigated by using co-seismic pairs of Satellite SAR data. Two co-seismic pairs of ALOS PALSAR data observed from the ascending and the descending orbits were used for the analysis of the earthquake in 2011. The earthquake occurred in 2016 can be covered by two co-seismic pairs of Sentinel-1 CSAR data acquired in ascending and descending orbits. The distribution patterns of vertical and horizontal (E-W) surface displacement associated with these two earthquakes were derived from the 2.5 dimensional analyses using these SAR data pairs. As the co-seismic pairs of ALOS PALSAR data contain non-uniform regional displacement pattern associated with M9.0 the 2011 off the Pacific coast of Tohoku Earthquake, occurred on March 11, 2011, the displacement amount along the line of sight of interferometric pairs were simulated from GNSS data and were removed from the differential interferograms, in order to extract local displacement associated with the earthquake on March 19, 2011. Fault traces inferred from the satellite SAR differential interferometry analyses of earthquakes in 2011 and 2016 perfectly coincide, indicating that these earthquakes, from macroscopic viewpoint, may be associated with the activity of the same fault. Geographic location of the peak of vertical displacement was found not to coincide with that of horizontal displacement by 2.5 dimensional analyses, for both earthquakes. The distribution patterns of vertical and horizontal displacement indicate the normal fault activity along the listric fault. Amount of the surface displacement associated with the earthquake in 2011 is as twice as of that in 2016, in both vertical and horizontal directions, which may reflect the difference in the distance from the hypocenters to the fault trace.

Keywords: Northern part of Ibaraki Prefecture, Earthquake, Surface displacement, Satellite SAR Differential Interferometry, 2.5 dimensional analysis

Recurrence of similar surface ruptures associated with the M 6 earthquakes of 2011 and 2016, northern Ibaraki, Japan

*Yasuo Awata[1], Takashi Azuma[1], Tadashi Maruyama[1]

1. Institute of Earthquake and Volcano Geology, Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology

The Mw 9.0 Tohoku earthquake of 2011 triggered unusual normal-fault-type earthquakes in the southern part of Abukuma mountains, a fore arc mountain of northeast Honshu arc, Japan. Most remarkable earthquake swarm has occurred in the northern part of Ibaraki prefecture with two of moderate earthquakes, Mj 6.1 of March 19, 2011 and Mj 6.3 of December 28, 2016 earthquakes.

We conducted a field survey on the surface ruptures on January 5, 2017, and found a surface ruptures and destruction of artificial structures such as roads and a bridge caused by faulting. These ruptures were found in a 2.5-km-long section with a trend of NNW-SSE along a linear discontinuity of satellite radar interferometry image provide by the Geospatial Information Authority of Japan (2016). At Mochiyama (N36.821, E140.610) in the northern part of the section three ruptures zones cross a paved road at a low angle. We measured the fault displacement at about 15 cm in vertical across the 6-m-wide rupture zone, and 5-6 cm in horizontal-dip component for each of two rupture zones. Some of fissures seem to be older than the 2016 earthquake because those had filled with dirt. Aoyagi et al. (2015) reported that some ruptures appeared associated with the 2011 event at the same location. At the Shin-Koyama bridge site (N36.806, E140.626) in the southern part of the section many of fissures appeared across a prefectural highway rtunning perpendicular to the linear discontinuity of interferometry image. The fissures occurred in a 170 m section of the paved road and the bridge completed in 1993. The total amount of width of those fissures reaches 29 cm. The fault displacement occurred in two steps, because some of new fissures and destructions appeared along the repaired ones. The distribution pattern and amount of displacement are very similar between those two events. Those fissures occurred on both sides of the bridge, suggesting that they are fault origin, not due to landslide. At the 0.5 km southern point of the bridge, new and old minor fissures also appeared on the pavement of a forest road. Along further 3-km-long southern section of the linear discontinuity of interferometry image, 1-2 cm-wide fissures were observed.

Our findings of two steps of surface rupturing suggest that the 2011 and 2016 earthquakes produced the similar surface faulting repeatedly with only 6 years of interval. The ruptures occurred in a Mesozoic granitic batholith where neither of geological and geomorphological faults has mapped. Repeating of 2011 and 2016 small surface faulting might be the characteristics of triggered events on immature fault.

Reference:

1) Aoyagi, Y., Onuma, T., Oku, T. and Sasaki, T., 2015, Proceedings of the Symposium on Fault Displacement Evaluation, 31-38.
2) Geospatial Information Authority of Japan, 2016, http://www.gsi.go.jp/BOUSAI/H28-ibaraki-earthquake-index.html. (Feb. 15, 2017, last access)

Keywords: surface rupture, recurrence of faulting, triggered earthquake, 2016 northern Ibaraki earthquake

Preliminary report of co-seismic surface rupture produced by the 28 December 2016 Hokubu-Ibaraki earthquake, northern Kanto region, Japan.

*Keitaro Komura[1], Koutaro Aiyama[1], Keiichi Ueta[1], Yasuhira Aoyagi[1], Toshinori Sasaki[1], Takahiro Nagata[2], Kazuo Kobori[2]

1. Central Research Institute of Electric Power Industry, 2. Dia consultants

A normal faulting earthquake (Mj: 6.3) occurred at northern Ibaraki, northern Kanto region, Japan, in 28 December 2016 (JMA, 2016). InSAR imaging revealed 2 km length of NW-SE trending crustal offset, maximum ~27 cm of western crustal movement away from satellite and ~6 cm of eastern crustal movement toward satellite (GIAJ, 2016). In the source area, seismicity has abruptly increased since the 2011 off Tohoku earthquake and another moderate (Mj: 6.1) earthquake of normal faulting prior to this event occurred in 19 March 2011. We conducted field survey immediately after the 2016 earthquake to check the surface fault rupture.

We recognized intermittent open cracks along with the InSAR offset. These cracks occurred from northern Mochiyama-area (N36°49′20", E140°36′36") to southern upstream of Koyama-dam (N36°47′54", E140°37′45") and it has ~3.4 km of total length. The distribution of open cracks located at upstream of valley and tip of ridge in right bank (south-west side) of Mochiyama-river between Mochiyama-area and Tomioka-area. In Mochiyama-area, surface rupture of the 2011 earthquake was also suggested by field survey on deformation zone across the asphalt road and leaned trees on its extension (Aoyagi et al., 2015). We observed a clear expansion of the deformation zone (distribution and crack width) after the 2016 earthquake. Additionally, we found fault zone just under small crack at southern tip of trace. The fault zone has ~40 cm width of fault gouge zone consisting of at least two layers of fault gouge. Sharp fault surface (N6°W strike, 67°W dip) recognized along with fault gouge zone may be latest slip surface because colluvium that covers fault surface is deformed. Fault striations (72°NNW rake) recognized inferred latest slip surface are consistent with the 2016 fault-plane mechanism. We concluded these intermittent cracks are tectonic surface rupture by these observations.

Aoyagi Y., T. Onuma, T. Oku, and T. Sasaki (2015): Fault displacement evaluation by InSAR for the recent moderate earthquakes in Japan. Proceedings of the Symposium on Fault Displacement Evaluation, I-5, pp.31-38 (in Japanese).

Geospatial Information Authority of Japan (GIAJ), 2016, Information of earthquake in northern Ibaraki prefecture. http://www.gsi.go.jp/BOUSAI/H28-ibaraki-earthquake-index.html (in Japanese).

Japan Meteorological Agency (JMA), 2016, Earthquake report of Northern Ibaraki prefecture, 28 December, 2016. http://www.jma.go.jp/jma/press/1612/28a/kaisetsu201612282345.pdf (in Japanese).

Keywords: coseismic surface rupture, InSAR, fault zone

Study on the Evaluation Method for Fault Displacement: Probabilistic Approach Based on Japanese Earthquake Rupture Data - Principal fault displacements along the fault-

*Naoko Kitada[1], Naoto Inoue[1], Masao Tonagi[2]

1. Geo-Research Institute, 2. Kozo Keikaku Incorporated

The purpose of Probabilistic Fault Displacement Hazard Analysis (PFDHA) is estimate fault displacement values and its extent of the impact. There are two types of fault displacement related to the earthquake fault: principal fault displacement and distributed fault displacement. Distributed fault displacement should be evaluated in important facilities, such as Nuclear Installations. PFDHA estimates principal fault and distributed fault displacement. For estimation, PFDHA uses distance-displacement functions, which are constructed from field measurement data. We constructed slip distance relation of principal fault displacement based on Japanese strike and reverse slip earthquakes in order to apply to Japan area that of subduction field. However, observed displacement data are sparse, especially reverse faults. Takao et al. (2013) tried to estimate the relation using all type fault systems (reverse fault and strike slip) so in this time, we try to estimate distance-displacement functions each strike slip fault type and reverse fault type especially add new fault displacement data set.
To normalized slip function data, several criteria were provided by several researchers. We normalized principal fault displacement data based on several methods and compared slip-distance functions. We normalized by maximum displacement rate, normalized by mean displacement rate. The normalized by total length of Japanese reverse fault data did not show particular trend slip distance relation. In the case of segmented data, the slip-distance relationship indicated similar trend as strike slip faults. We will also discuss the relation between principal fault displacement distributions with source fault character.
According to slip distribution function (Petersen et al., 2011), strike slip fault type shows the ratio of normalized displacement are decreased toward to the edge of fault. However, the data set of Japanese strike slip fault data not so decrease in the end of the fault. This result indicates that the fault displacement is difficult to appear at the edge of the fault displacement in Japan.
This research was part of the 2014-2015 research project ‘Development of evaluating method for fault displacement ‘ by the Secretariat of Nuclear Regulation Authority (NRA), Japan.

Keywords: fault displacement, PFDHA

Evaluation of earthquake source fault length from active fault and subsurface information

*Naoto Inoue[1], Naoko Kitada[1], Takashi Kumamoto[2]

1. Geo-Research Institute, 2. Graduate School of Natural Science and Technology, Okayama University

In a strong ground motion prediction, the evaluation of fault length is important because fault dimension provides the size of an earthquake. The Headquarters for Earthquake Research Promotion published Regarding the revised Methods of evaluating active fault in 2010. This method estimates the subsurface fault based on the combination of active fault and subsurface information, such as geological structure and geophysical information. We evaluated lengths of Japanese inland earthquakes, according the above mentioned methods. The estimated fault length in mature active fault zone were similar or longer than that of the earthquake source fault inferred from strong ground motion inversion. On the contrary, the estimated fault length in immature fault zone were shorter than that of inverted results.
This research was part of the 2014-2016 research project ‘Improvement for uncertainty of strong ground motion predictio ‘ by the Secretariat of Nuclear Regulation Authority (NRA), Japan.

Keywords: fault length, active fault, earthquake source fault

Investigation of off-fault displacement

*Naoto Inoue[1], Naoko Kitada[1], Yasuhiro Matsumoto[2], Tsutomu Takahama[2], Tonagi Masao[2], LUIS ANGEL DALGUER[3], Kojiro Irikura[3]

1. Geo-Research Institute, 2. KOZO KEIKAKU ENGINEERING Inc., 3. Aichi Institute of Technology

Discontinuous distributed fault displacements occur around the primary surface rupture in the earthquake. Evaluation of off-fault displacement is important for mitigation of fault displament hazards. There are two types of off-fault displacement in the view point of a prediction problem. The displacement does not occur only on the active fault, but also off the active fault. Petersen et al. (2011) introduced mapping accuracy for the strike-slip fault. We estimated the mapping accuracy of several Japanese earthquakes at distinct fault side, i.e. hanging-wall/foot-wall by measuring distances between active fault traces and primary surface ruptures. Based on estimation of the mapping accuracy of strike-slip fault, narrow bell-shaped displacement profile across the active faults was inferred. On the contrary, wide bell-shaped displacement profile was estimated and the center shifted to the foot-wall side, in the case of the reverse-fault. The other off-fault displacement is the displacement on the secondary faults. This type of displacement of reverse fault focuses on the hanging-wall. These differences are important to estimation of fault displacement hazard.

Acknowledgments: This research was part of the 2014-2016 research project ‘Development of evaluating method for fault displacement‘ by the Secretariat of Nuclear Regulation Authority (NRA), Japan. A part of displacement data was used from Kagohara et al. (2007), which was partly supported by the Grant-in-Aid for Scientific Research (no. 17200053) by Ministry of Education, Science, Sports and Culture.

Keywords: fault displacement hazard, secondary fault

Study on the evaluation method for fault displacement: Deterministic evaluation approach based three step considerations.

*Tonagi Masao[1], Tsutomu Takahama[1], Yasuhiro Matsumoto[1], Naoto Inoue[2], Kojiro Irikura[3], LUIS ANGEL DALGUER[3]

1. KOZO KEIKAKU Engineering Inc., 2. Geo-Research Institure, 3. Aichi Institute of Technology

Fault displacement hazards are very important to enhance seismic safety of nuclear installations. In Japan, important nuclear facilities must be installed in the ground where there is no risk of displacement. And also IAEA Specific Safety Guide (SSG) -9 provides guidelines and procedures for assessing the potential for fault displacement (capability) at or near the site for both new and existing nuclear power plants. Under such background, we are investigating the possibility of evaluation by both deterministic evaluation method and probabilistic evaluation method as to whether or not fault displacement occurs on the ground surface when earthquake occurs.
In this paper, we focus on fault displacement and introduce the concept of deterministic evaluation methods for fault displacement.

We are planning to evaluate fault displacement will occur on the ground surface due to earthquake occurrence by the following three steps.
step1) Construction characterized source models. We will construct a characterized source models that can reproduce strong ground motion near the seismic source with for less than period of 10 seconds.
step2) Consider conduct dynamic rupture simulation with each parameter of the characterized source model constructed in step 1 as input. By dynamic rupture simulation, evaluate the permanent displacement appearing on the ground surface due to the displacement of principal fault. (In step 2, consider calculation area that wide area including the principal fault is taken into both the depth direction and the horizontal direction.)
step3) in step3, targeting a very narrow range of the ground surface (ex. few hundred meters to several kilometers), we consideration a very soft and discontinuous nature of the surface, evaluate displacement by numerical analysis method represented in the finite element method, or the like. In this study, we have conducted a combination of the finite element method (FEM) and the particle method (SPH) method for the analysis method.

In accordance with the above flow, we conducted a tentative analysis for the 1999 Chi-Chi earthquake and compared displacement of observation records and analysis result.

This research was part of the 2016 research project ‘Development of evaluating method for fault displacement ‘ by the Secretariat of Nuclear Regulation Authority (S/NRA), Japan.

Keywords: deterministic approaches, characterized source model, dynamic rupture simulation, subsurface rupture simulation

