Introduction to the session on the surface ruptures during earthquakes

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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

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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

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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

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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

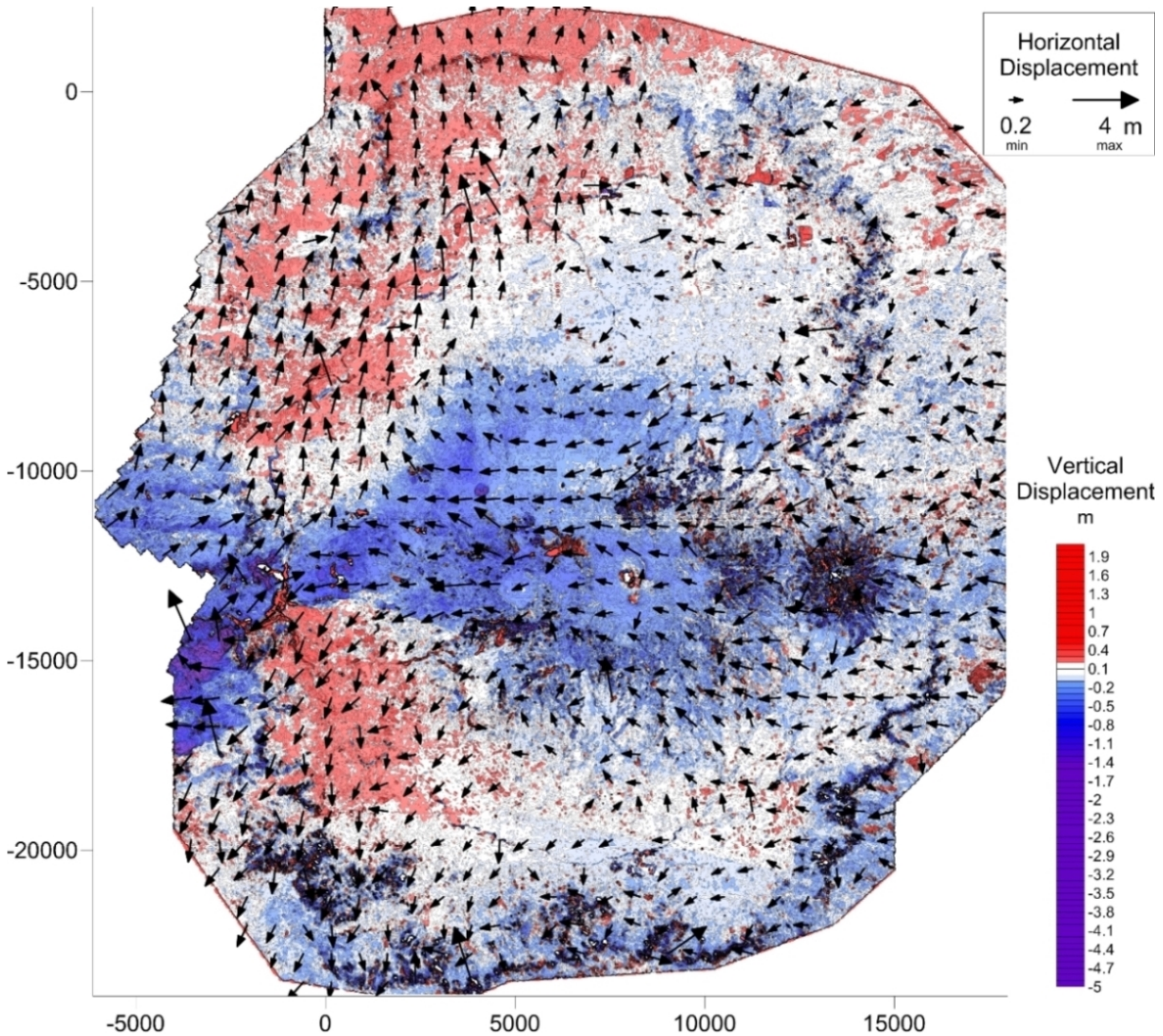

Fig.1 Ground displacements around Aso-Caldera by 2016 Kumamoto Earthquake,Japan

Coordinate System JDG2000/Japan Plane Rectangular CS II

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

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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

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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

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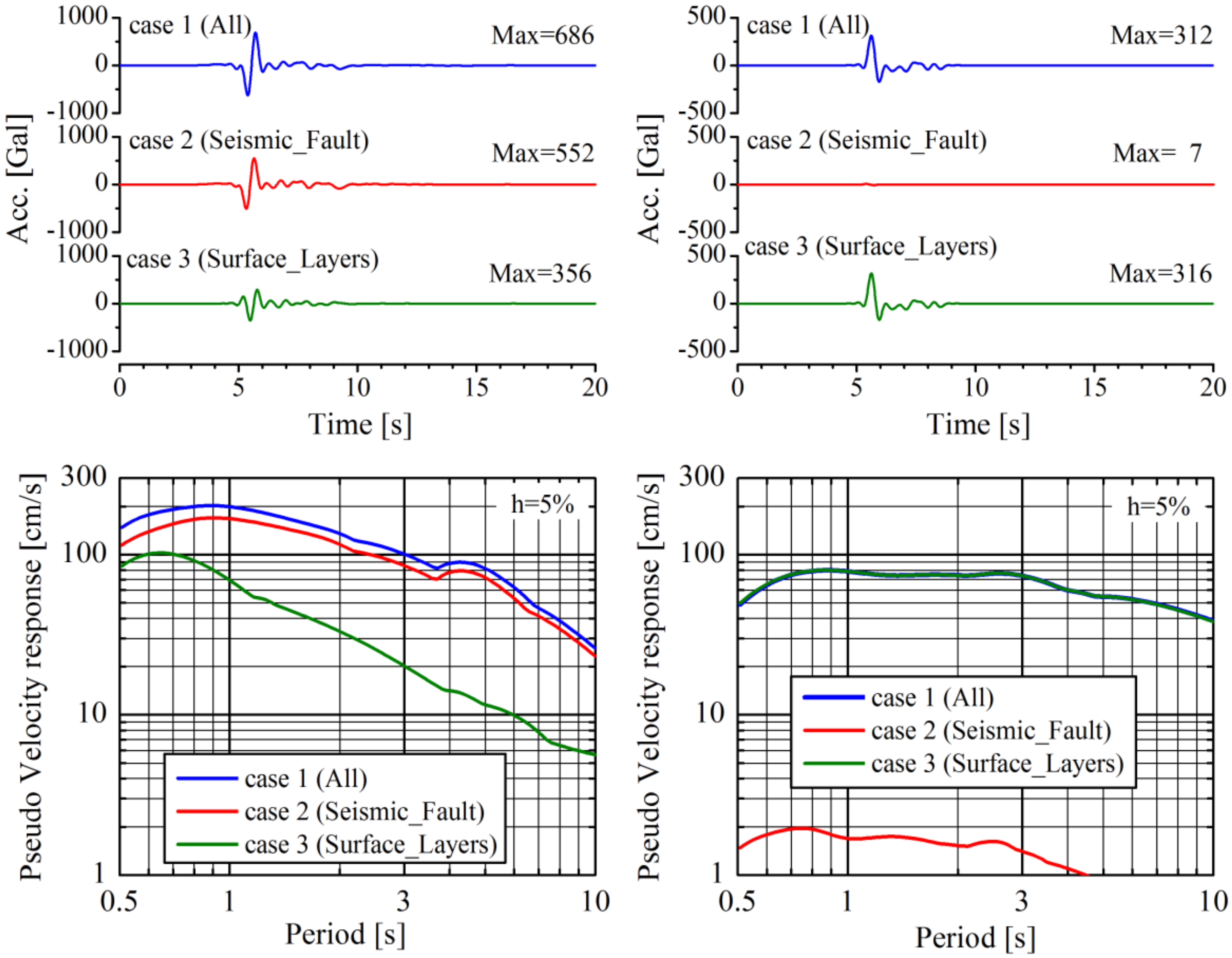
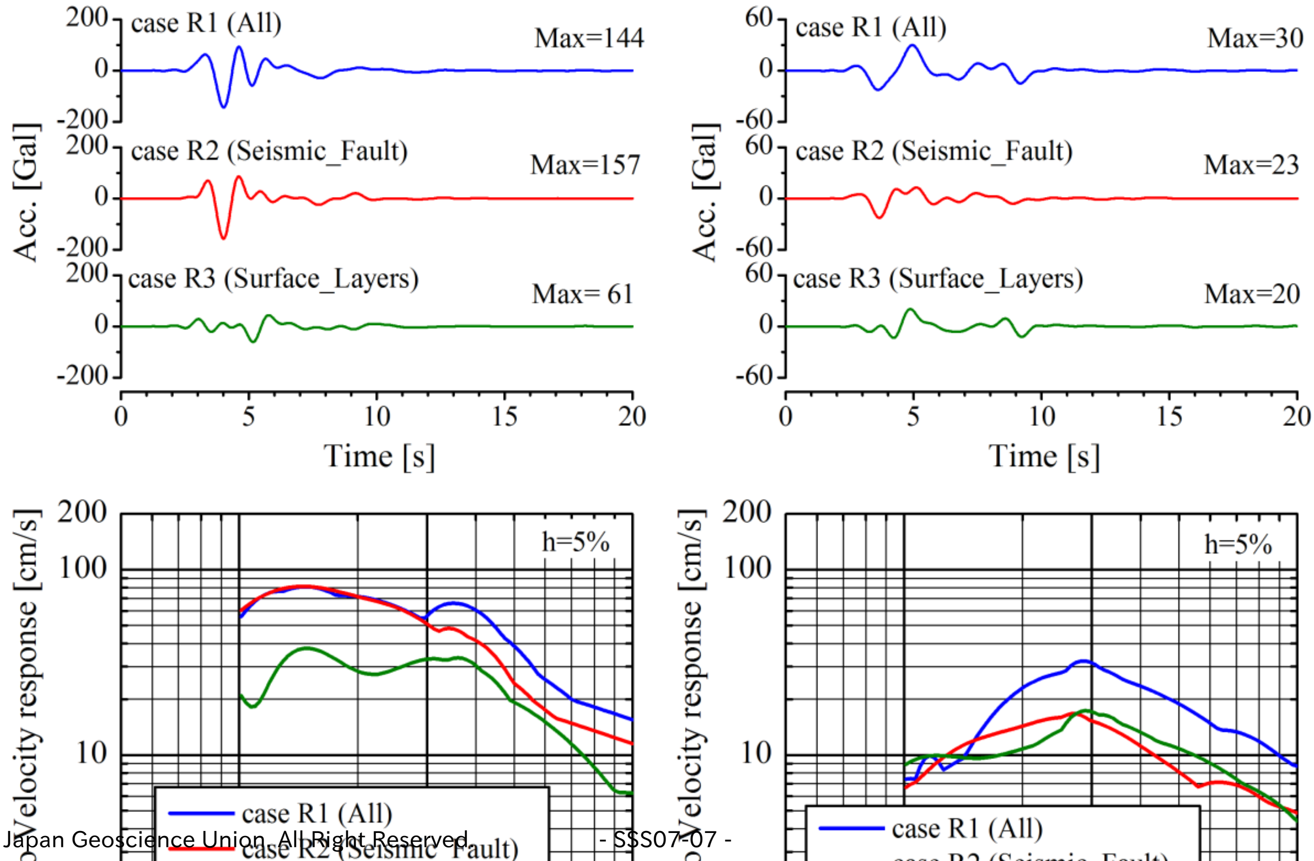
In Japan, only the seismic waves radiated from the fault in the seismogenic layer under the surface layers are considered in the usual strong motion prediction (e.g., Headquarters for Earthquake Research Promotion, 2016). However, in the inland crustal earthquakes, the seismic waves radiated from the 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

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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

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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

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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

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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

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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 earthququkes 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

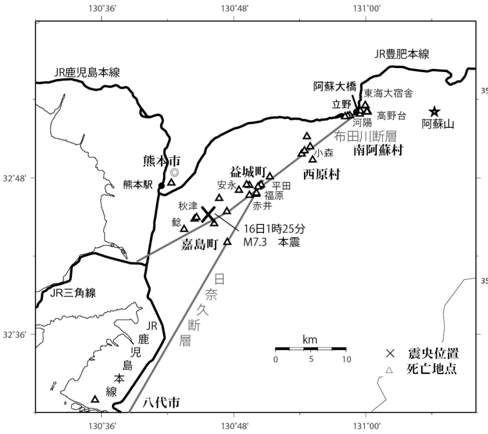

図１　2016年4月16日熊本地震の死者発生地点

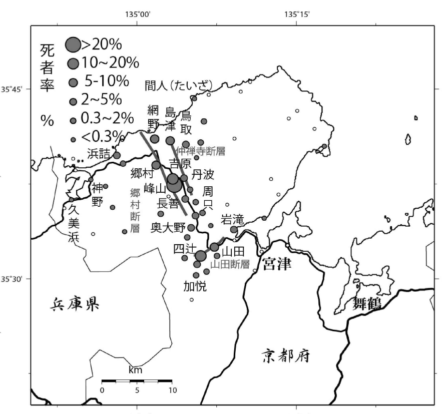

図２　1927年（昭和2年）北丹後地震の町村別死者率

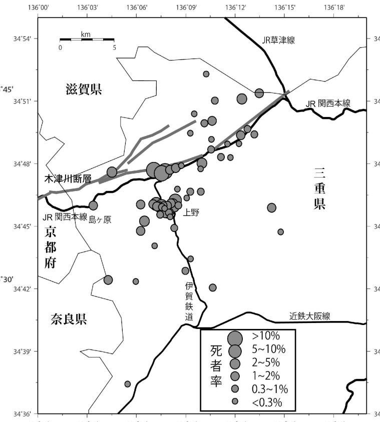

図３　安政元年(1854)6月15日伊賀上野地震の集落別死者率

Surface Rupture and Structural Damage

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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

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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

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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

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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

