今，なぜ，地表地震断層の調査・分析・災害評価を問うか
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.

キーワード：活断層、地表地震断層、断層変位
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

2時期レーザ計測データを用いた2016年熊本地震による阿蘇カルデラ周辺の地表変位の計測
Estimation of ground displacements around Aso-Caldera caused by the 2016 Kumamoto Earthquake, with the differential LiDAR DEM analysis

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　平成28年熊本地震に伴い，熊本県阿蘇地域では広域的地殻変動が観測された．本研究では阿蘇カルデラ地域の地表面変位を，航空レーザ計測地形データを用いた数値地形画像解析手法によって面的に計測した．その結果，阿蘇カルデラ内の北西側地域では，隆起傾向と共に北方向への水平変位が認められた．カルデラ内の南西側地域では，隆起傾向と共に南西方向への水平変位が認められた．また中央火口丘付近から西方のカルデラ縁にかけては，沈降傾向と共に西方への水平変位が認められた．さらに，カルデラ西端の立野付近においては，顕著な右横ずれの変位が認められると共に，カルデラ外輪山の山上に，東西方向の延長をもつホルストグラーベン状の地変が認められた．一方，阿蘇谷の低地では，傾斜方向に2～3m移動する長径短径1～2.5km程度の領域が局所的に認められた．

　阿蘇カルデラ西方に位置する布田川断層帯から断続する地表部の右横ずれを示す亀裂は，カルデラ内の黒川左岸河陽付近から北東方向約3㎞付近まで確認されている．本研究の解析結果から，地表面変位の向きが系統的に変化する幅広い境界が，さらにその北東側延長のカルデラ縁付近まで連続していることがわかった．

キーワード：2016熊本地震、DEM差分解析、航空機レーザ計測、画像マッチング解析
Keywords: the 2016 Kumamoto Earthquake, Differential DEM Analysis, LiDAR, Image matching analysis
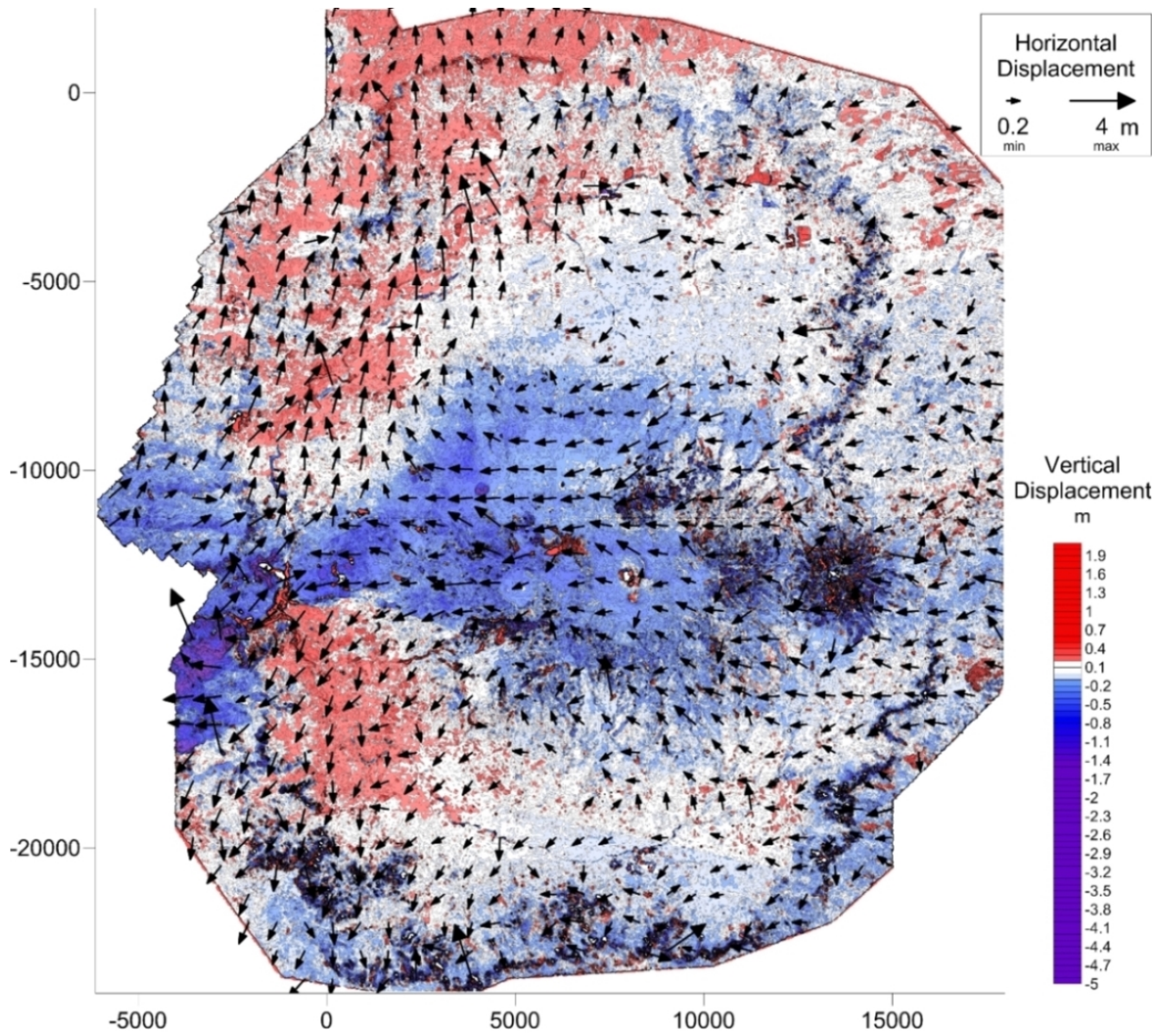
Fig.1 Ground displacements around Aso–Caldera by 2016 Kumamoto Earthquake,Japan
Coordinate System JDG2000/Japan Plane Rectangular CSⅡ

平成28年熊本地震と茨城県北部の地震から再考する短い活断層の評価
Clues to evaluate short active fault learnt from the 2016 Kumamoto and Ibarakiken-hokubu, Japan, earthquakes

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　Ｍ７前後の内陸地震は必ずしも既知の活断層で発生しない．このことは，Ｃ級活断層問題（浅田，1991），短い活断層の評価（例えば，島崎，2008）として，長期評価の課題として何度も取り上げられてきた．実際に，活断層分布から予測されるＭ７以上の地震数よりも，1923年以降に観測された地震数が２倍程度多いことが示されている（遠田，2013）．そのため，長さ20km程度の断層が多数伏在しているか，その一部がわずかに「短い活断層」として地表に顔を出していることを前提とした検討が進んできた．本発表では，平成28年に発生した熊本地震と茨城県北部の地震の事例から，この前提と異なる考え方を提案したい．

　１）2016年４月16日1:25に発生した熊本地震（M7.3）：
　2016年熊本地震（M7.3）では，既知の日奈久断層北東部と布田川断層に概ねそって約30kmの地震断層が出現した（例えば，Kumahara et al., 2016）．しかし，InSAR解析画像による干渉縞の不連続などから，主要地震断層帯以外にも200個所以上で小断層変位が検出された（Fujiwara et al., 2016）．その拡がりは主要地震断層帯から約15km遠方にまで及ぶ．特に，阿蘇外輪山西方では40以上の東西走向の小断層からなる断層群（10km x 10km程度の範囲）が顕著な上下変位を示した．個々の変位は正断層とみられ，変位量は最大40cmにもおよぶ（Fujiwara et al., 2016）．これらの一部は，鞍岳断層群として新編日本の活断層（活断層研究会，1991）などに記載されていた．また，同様の誘発小変位は熊本市街にも認められ，北西－南東走向の既存の断層崖（水前寺断層）にそって出現していることが確認されている（Goto et al., 2017）．阿蘇外輪山では余震はほとんど認められず，非地震性のすべりである．一方で，水前寺断層沿いには5km以浅の小規模な余震が集中する．

　２）2016年４月16日3:03に発生した熊本地震の余震（M5.9）：
　InSAR解析画像にもとづく現地調査から，主要地震断層帯の北東端から約10km北東に位置するJR宮地駅付近に地震断層を確認した．この地震断層は，北東－南西に約２.5kmにわたって延び，最大上下変位約10cm，右横ずれ変位が5cmをともなう．本震破壊域との距離から本震時の地震断層とは考えにくく，直後の多数の余震のうち，約１時間半後の３時３分に発生したM5.9の地震（深さ７ｋｍ）で出現したと推定される．日本の地震断層のなかでは最小Mとみられるが，InSAR画像がなければ見落としていたであろう．

　３）2011年３月19日茨城県北部の地震（M6.1）と2016年12月28日茨城県北部の地震（M6.3）：2016年12月28日の地震では，InSAR解析によって北西－南東走向の長さ約３ｋｍの干渉縞の不連続が確認され，西側が低下する正断層が推定されている．直後の現地踏査でも，最大５ｃｍの西側低下と約10cmの水平東西伸張が確認されている（小俣・杉田，2017；粟田・吾妻，2017）．InSAR解析に基づく断層モデルから推定される断層下端の深さは４ｋｍ程度であり，地震発生層下端まで延びない．また，この地震断層は2011年３月19日にも変位したことが確認されており（Aoyagi et al., 2015），同じ短い断層がわずか約６年間隔で繰り返し変位したと考えられる．この２つの地震によって約30cmの水平伸張が計測されている（粟田・吾妻，2017）．

　以上のことから，１）短い活断層は必ずしも単独でM7地震を起こさず，大きな活断層の活動に付き合って変位し，その繰り返しによって断層変位地形が形成される可能性があること，２）Ｍ６前後のやや小規模な地震であっても長さ５ｋｍ以下，10-20cm程度の変位を持つ地震断層を伴い，その動きの繰り返しによって短い活断層が形成される可能性があること，が示唆される．

　文献：浅田　敏（1991）活断層研究，9，1-3；Aoyagi et al. (2015) Hokudan International Symposium

on Active Faulting 2015 abstract; 粟田泰夫・吾妻　崇
（2017）https://www.gsj.jp/hazards/earthquake/ibaraki2016/report20170105.html；Fujiwara et al.,
EPS (2016), 68, 160; Goto H. et al., EPS (2017) in press；活断層研究会（1991），東京大学出版
会，437pp；Kumahara et al. (2016) JpGU2016 abstract；小俣雅志・杉田律子
（2017）http://jsaf.info/jishin/items/docs/20170105144457.pdf；島崎邦彦（2008）活断層研
究，28，41-51；遠田晋次（2013）地質学雑誌，119，105-123；地震調査委員会資料

2016年熊本地震に伴う地表地震断層のごく近傍における地震動特性について

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

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　2016年4月16日に熊本地震(Mw7.0)地震が発生した．この地震では広範囲に地表地震断層の出現が確認されている．地表地震断層近傍で多くの建物被害が発生したが，地表地震断層ごく近傍に限定すれば，断層変位に起因する建物被害は見られるものの，地震動に起因した建物被害は軽微であったと思われる事象が多い．これは，2011年福島県浜通り地震など既往地震の建物被害調査でも報告されている（例えば，久田・他，2011）．このような断層近傍の地震動を説明するために，本研究では地表地震断層のごく近傍における地盤構造を把握することを目的として，益城町下陳における余震観測，南阿蘇村河陽および益城町福原・下陳の地表地震断層の極近傍で常時微動による単点観測とアレイ観測を実施した．単点及びアレイ観測点は地表地震断層を横切るように配置し，H/Vスペクトル及び位相速度分散曲線から断層直上とその周辺の地盤構造の違いを確認した．本発表では，これらの結果から断層近傍の地盤構造と地震動の関連性について考察する．

　久田・他(2011): 日本地震工学会論文集，第12巻，第4号(特集号)，pp.104-126.

動力学的断層破壊シミュレーションに基づく断層極近傍の強震動の評価手法の提案

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

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　我が国では、通常の強震動予測（例えば、地震調査研究推進本部，2016）では、表層の下の地震発生層に位置している断層からの地震動しか考慮していない。しかしながら、内陸地震では断層極近傍における強震動に対して表層に位置している断層からの地震動が影響を与える可能性がある。そこで、本研究では、鉛直横ずれ断層と逆断層を対象に、表層に位置する断層からの地震動が強震動に与える影響を評価する方法を提案した。

　本方法では、三次元有限差分法による動力学的断層破壊シミュレーションで得られた断層面上のすべり速度時間関数を用いて、波数積分法により地震動を計算した。例示のため、地震動の計算は断層トレースから50mと2kmの地点で行った（本稿では50mの場合のみを示す）。断層モデルは25kmの長さで、表層の厚さが3km、地震発生層の厚さが15kmで、断層面にすべり弱化則を組み込んだ。断層モデルは、地表や地中の断層のパラメータに関する3つの経験的関係式（松田，1975；入倉・三宅，2001；壇・他，2001）を拘束条件として、設定した。

　鉛直横ずれ断層の結果では、断層トレースから50mの地点において、断層全体による地震動の断層直交成分の80〜90%が地震発生層に位置する断層による地震動であった。また、断層平行成分はほぼ100%が表層に位置する断層による地震動であった。断層トレースから50mの地点においては、周期0.5〜6秒で、断層直交成分の方が断層平行成分より大きくなった。

　鉛直横ずれ断層と同じ方法で、逆断層についても計算を行った。その結果、断層トレースから50mの地点において、周期3秒以下で断層全体による地震動の断層直交成分の100%が地震発生層に位置する断層による地震動であること、周期3秒以上で地震発生層に位置する断層による地震動が断層全体による地震動の約70%に減少していることがわかった。断層平行成分では、表層に位置している断層による地震動と地震発生層に位置している断層による地震動は同程度であることがわかった。断層トレースから50mの地点においては常に断層直交成分のほうが断層平行成分よりも大きくなった。
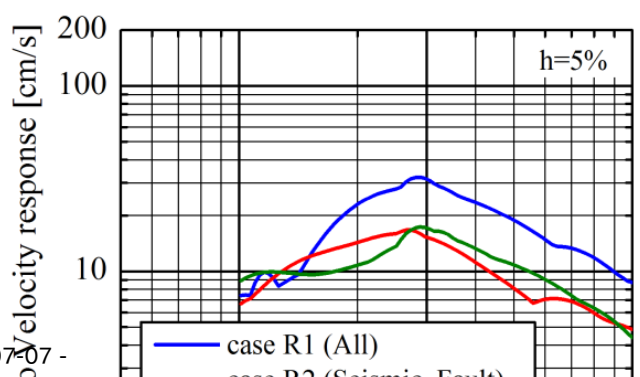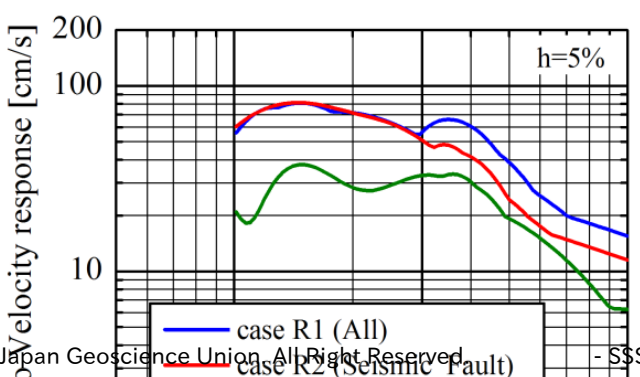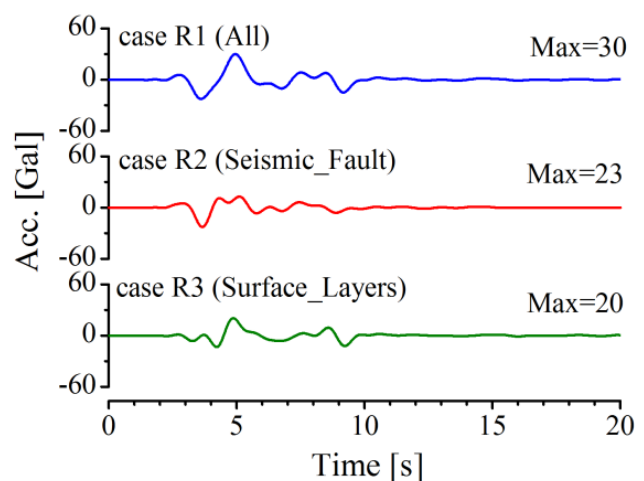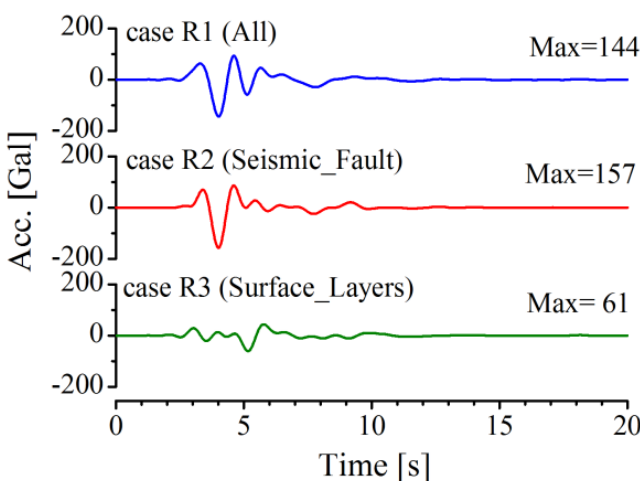
キーワード：強震動、断層極近傍、動力学的断層破壊シミュレーション
Keywords: strong motions, close fault, dynamic simulation
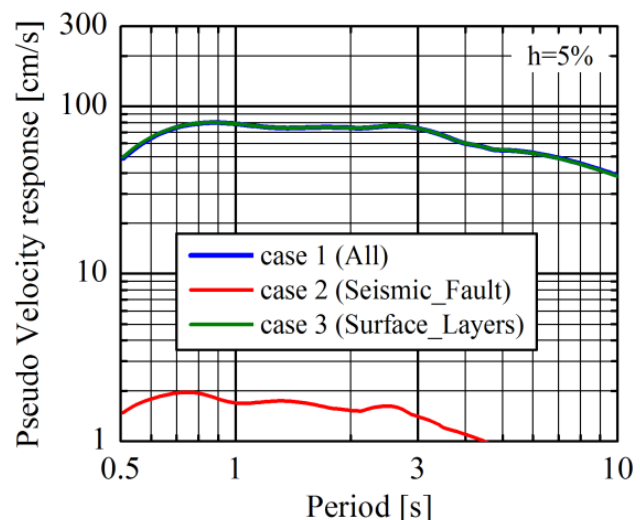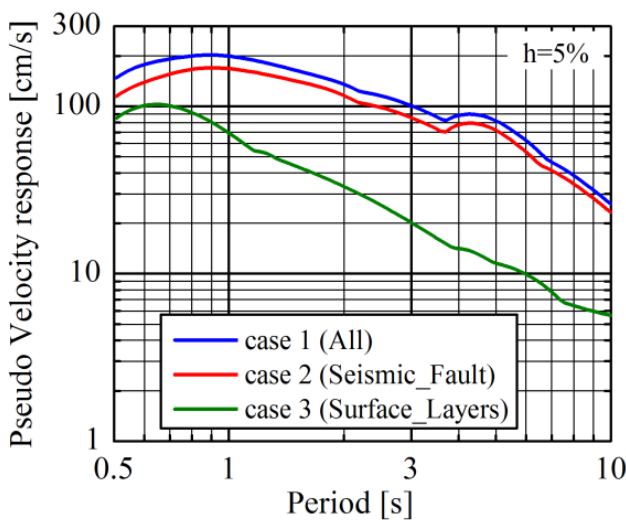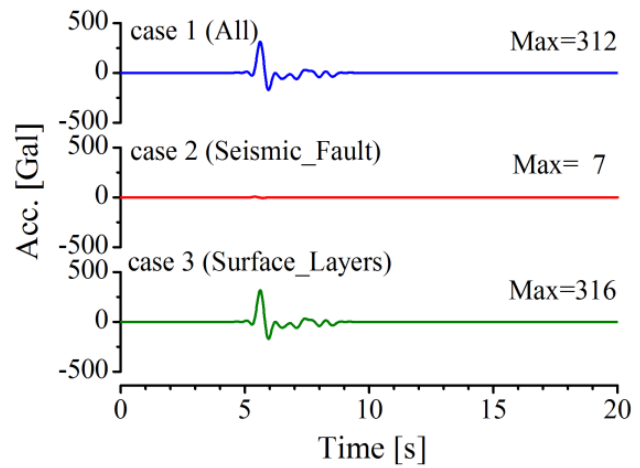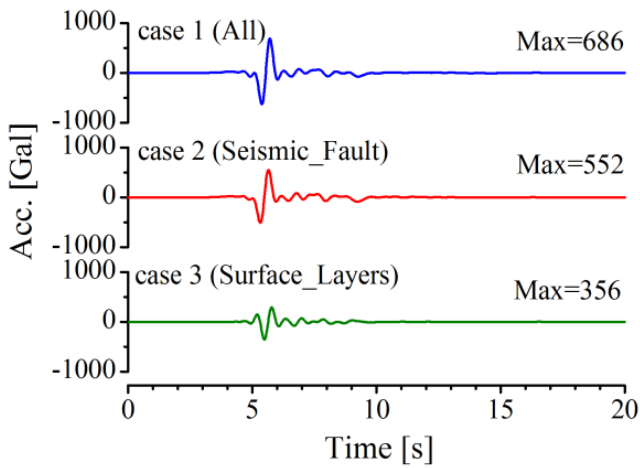
(a) fault normal component   (b) fault parallel component

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.

リスク評価のための断層変位ハザード解析
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.

キーワード：断層変位、決定論的、確率論的、確率論的断層変位ハザード解析
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.

キーワード：確率論的断層変位ハザード解析、副断層、発生確率
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.

キーワード：活断層、断層変位、地表地震断層、活断層評価
Keywords: active fault, fault displacement, surface fault, active fault evaluation

地震断層近傍での高密度死者分布
High density distributions of victims of inland earthquakes in the vicinity of the faults

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　2016年4月16日に起きた熊本地震の本震（M7.3）は、阿蘇カルデラの西側出口の阿蘇大橋付近から宇土市付近に至る布田川断層の滑りによって生じた地震であった。この本震の2日前の4月14日の夜には前震(M6.3)が起き、最大震度7に達し、死者9人を出した、やはり布田川・日奈久断層の滑りによる地震であった。16日の本震による死者は、41人に達した。このうち、自宅付近で死亡した37人については、地震発生後9日が経過した25日までの「熊本日々新聞」の紙面に、各自宅の住所（丁目まで）が掲載された。筆者は、熊本日々新聞東京支局（丸ビル7階）で地震後３週間までの同紙を購入し、死者の自宅住所の記事を抜き出してその位置を地図上に求めプロットを行った。本震発生は16日の午前1時25分であったので、大部分の死者は自宅で就寝中に発生したものと推定される。プロットの為の北緯東経の町丁目の中心位置を採用した。真の自宅位置と誤差は200m以内と推定される。図１は、このようにして得られた本震による死者37人の発止位置を図１の三角印で示した。大部分の死者は、布田川断層からその北側（上盤側）3kmの幅の帯状の地域の内部に集中して生じていたことが分かる。断層の下盤にあたる断層線の南側にはほとんど死者は生じていない。この地震（前震・本震・余震を含め）による全壊家屋は約8000軒を数えるがその分布は、断層から約20km隔たった町村にまで広域に及んでいる。しかし死者の発生分布は、家屋被害分布よりもはるかに分布の集中が著しいのである。監視カメラの映像によると、断層線にごく近い益城町などでは、地震発生後僅か２〜３秒以内に木造家屋の全壊は完了しており（熊本日々新報社談）、中に住んでいた人は、揺れを感じた後、ほとんど何もする間もなく落ちてくる天井や壁、家具などの下敷きになったと考えられる。断層線から離れた位置では、家屋は最終的には全壊しても、それに至るまでに数秒から10秒以上の時間が経過して「ゆっくり倒壊」しており、中にいた人は机の下に潜り込む等の緊急措置をおこなう時間的な余裕があったために圧死を免れたものであろうと推定される。

　図２は昭和2年(1927)に京都府北部に起きた北丹後地震（M7.3）による起震断層の位置と、当時の町村毎の、各全人口に対する死者の数（％）を丸記号の大きさで表したものである。この地震では郷村断層と、これと共役な関係にある山田断層がすべったが、この2個の断層線にごく接近した位置にある峰山や四辻などで、大きな死者率を示しており、断層線から離れると急速に死者率が下がっているのが読み取れる。家屋倒壊率で同様の図を描くと、倒壊率の高い町村は断層からと遠い位置にも分布していて、断層線が際だつ様な分布は示さない。

　歴史事例として、安政元年(1854)六月十五日に発生した伊賀上野地震の集落別死者率を描いてみた。この地震の死者に関しては伊賀上野城下の万福寺の過去帳（「新収日本地震史料　補遺」のp941）が伊賀上野城下の街区ごと、また郷村（郊外地区）の集落ごとの死者数を載せている。このほか、津城下の「嘉平次来状」、伊勢相可の「西村三郎右衛門」などの記録が当時の街道筋の宿場の死者数を載せている。これらに基づいて、伊賀上野とその周辺の集落毎の死者率の分布を図示すると図3が得られる。いっぽう、松田ら(1982)は、安政伊賀上野地震は上野城下の市街地の北側を東西に走る木津川断層の滑りによるものであるとした。図３には、木津川断層（本断層・副断層）の位置も合わせて描いた。やはり、断層にごく接近した集落で、もっとも死者率が大きくなっている様子を読み取ることが出来る。

　以上、過去に発生した内陸の断層滑りによる地震３例では、断層線にごく接近した位置で、死者率が大きくなることが示された。その分布の断層付近での集中度は、家屋の被害分布などより鮮明に現れる。ことに断層にかたむきがある場合、上盤側に当たる地域で死者数密度度が大きくなる。この事実は、歴史事例において、どの断層の滑りによる地震であるかが不明の事例について、起震断層がどれであるかを判断するのに役立てることが出来るであろう。

キーワード：2016年熊本地震、1927年北丹後地震、安政伊賀上野地震、死者密度、断層線と死者分布
Keywords: The 2016 Kumamoto Earthquake, The 1927 North Tango Earthquake, The 1854 Iga Ueno Earthquake, motallity distribution, mortallity distribution and fault lines
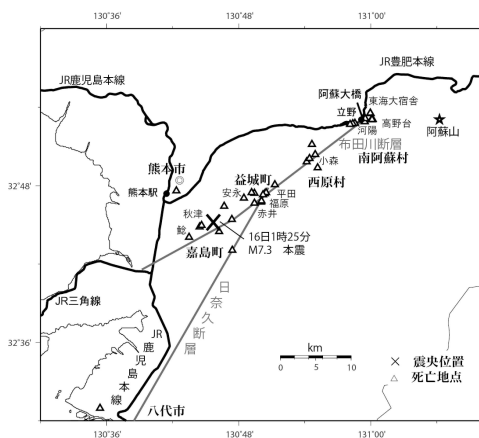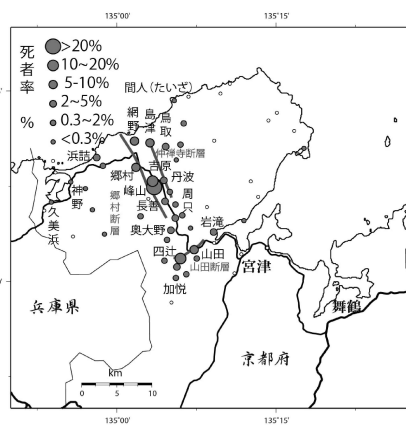

図1　2016年4月16日熊本地震の死者発生地点
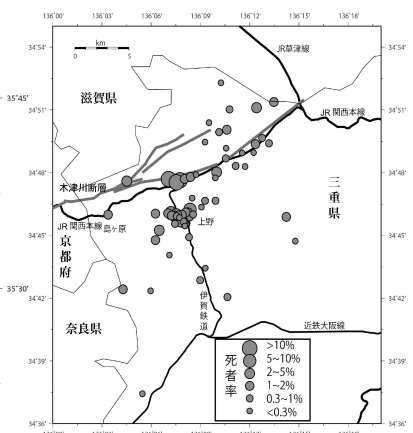

図2　1927年(昭和2年)北丹後地震の町村別死者率

図3　安政元年(1854)6月15日伊賀上野地震の集落別死者率

地表地震断層と建物被害
Surface Rupture and Structural Damage

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　平成28年（2016年）熊本地震では、震度7が同じ場所で2度観測され、益城町において建物被害が集中し、布田川・日奈久断層帯の活断層とほぼ同じ位置に20km以上にわたって地表地震断層が出現した。地表地震断層がこれほど長い距離にわたって活断層とほぼ同じ場所で観測されたのは、大変稀な現象である。

　熊本地震のように地表地震断層が出現した場合に、その断層運動によって建物が被害を受けることも想定されるが、活断層と同位置に地表地震断層が出現するのは近年では数少ない事例であることからもわかるように、地表地震断層がどこに出現するかを事前に特定することは非常に難しいことと考えられ、活断層が存在する地域では、活断層の位置を詳細に調べることよりも、活断層と地中の震源断層との関係や断層運動によって形成された盆地構造との関係を把握できるような、深い地盤構造が把握できる地盤調査が重要となる。1995年兵庫県南部地震のように、地表地震断層が認められなかった神戸市域において、震源断層と盆地構造の特性とその位置関係から建物被害が集中したことが、その重要性を証明している。ただし、地表地震断層の変位量が詳細に分かっている場合、震源断層での食い違い量との関係を把握することにより、まだ地震が起こっていない活断層の変位量と想定される震源断層での食い違い量を把握するために貴重な情報となる。

　一方、断層の変位量が建物に被害を及ぼすのではないかという指摘もあるが、基礎の設計・施工によって問題になることも考えられるが、断層変位が非常にゆっくりとしたものだった場合、建物が引き裂かれるよりも断層変位が建物によって拘束されるため、倒壊をするような被害にならない。熊本地震においても、益城町役場北の断層変位が生じた辺りでは断層が建物の下を通っていても外見上は建物への影響は認められなかった。ただし、地表地震断層のずれの速度がはやい場合はこの限りではないと考えられる。従って、地表地震断層が建物に被害を及ぼすかどうかを調べるには、地表地震断層がずれる速度を観測することが重要である。そして、地表地震断層のずれの速度と震源断層の破壊過程もしくは表層地盤の特性との関係を把握することが建物被害との関係を論じる上で重要となると考える。

キーワード：地表地震断層、建物被害、震源断層
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.

キーワード：地上レーザ測量、SfM多視点ステレオ写真測量、無人航空機、点群、DEM、亀裂
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

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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 $M_w 8.7$, 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

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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

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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
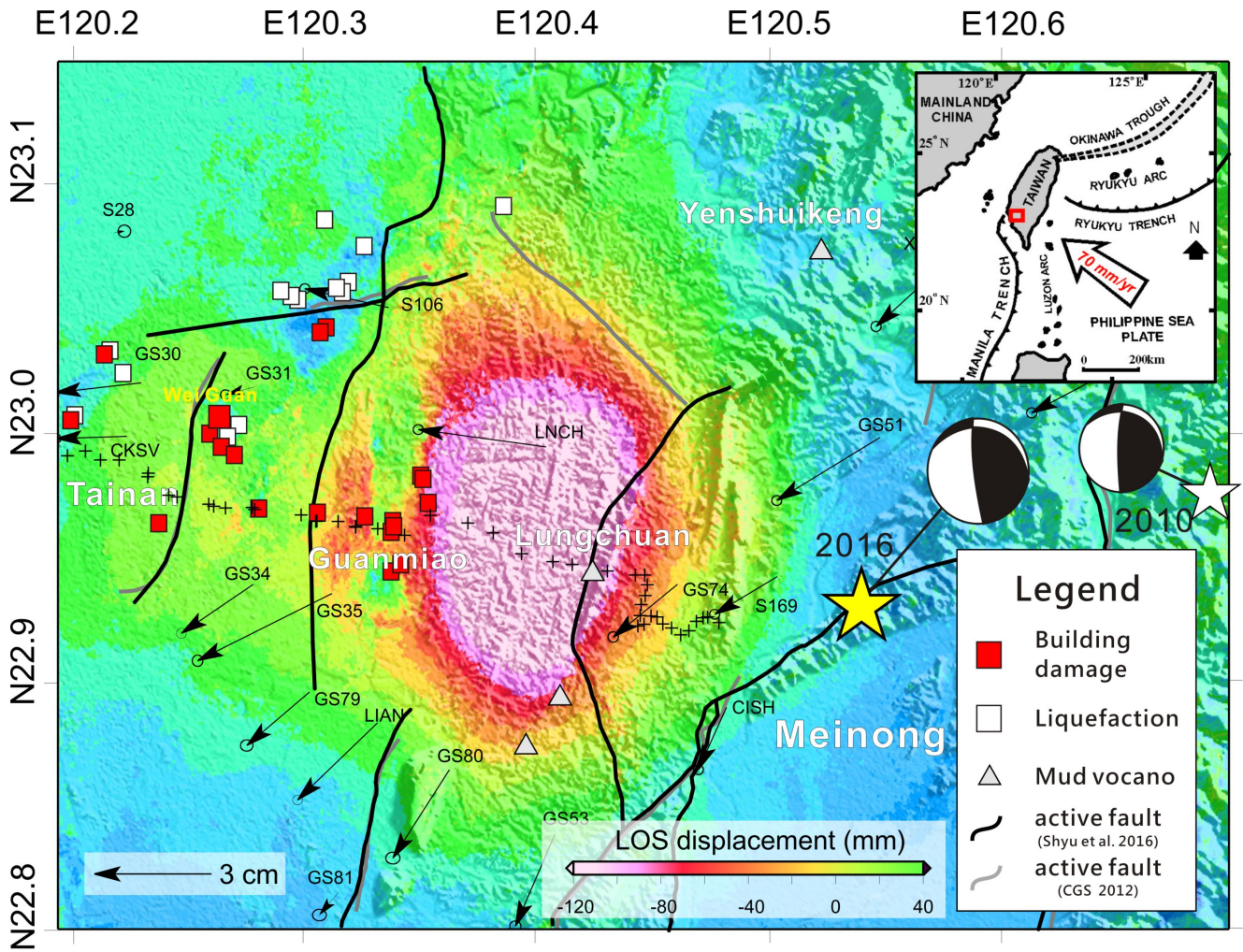
SAR干渉画像に現れた阿蘇外輪山北西部の地表変位の現地検証とその解釈
Field survey and interpretation of the surface linear ruptures in northwest of the outer rim of the Aso caldera emerged on SAR interferogram

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　ALOS-2データを用いたSAR干渉解析により確認された熊本地震に伴う小さな地表変位を示す線状の位相不連続のうち、阿蘇外輪山北西部に多数認められた概ね東西走向の長さ数kmの線状の位相不連続については、3次元地表変位量成分の解析（森下ほか2016）により、北部は南落ち、南部は北落ちの最大30cm程度の垂直変位を示しており、地震に伴う応力場の変化により二次的に生じた南北方向の伸張に伴う半地溝状の正断層群的な変動を示していると解釈されている（Fujiwara et al. 2016、藤原ほか2016）。

　これらの位相不連続が現れている地点の現地調査を行ったところ、多数の不連続線上で地表変位を確認した。いずれも、走向はおおむね東西、開口幅、落差ともに最大30cm程度で、少なくとも数10m以上直線状に連続する。変位の向きは場所によって異なるが、すべて位置、走向、変位の向きはSAR干渉解析による分析ときわめてよく整合するものであった。地表地震断層と判断されかねない形状的特徴を示すものもあった。

　地形との関係については、先行研究（九州活構造研究会1989，中田・今泉2002）において鞍岳断層群として示されている活断層上に、変動地形学的に推定された変位方向と一致して現れているほか、地形的には断層地形とは認められない位置に現れているものも多い。本地域は阿蘇山の火山活動に伴う火砕流や噴出物が厚く堆積しており、それらに埋もれた構造の活動が誘発されているとも考えられる。

　地震に伴う応力の変化や地震動により既存の構造が誘発された受動的な変動、いわば「お付き合い」地表変動は、SAR干渉解析により地表の変位が面的かつ詳細に把握できるようになって以降、多く報告されている。これらは、報告のあった地震のみに特徴的に現れたわけではなく、もともと地震に伴って普遍的に発生していたかもしれない。これまで報告されている地表地震断層や、トレンチで認定されるイベントにも、このような受動的変動が含まれている可能性があり、活断層の活動履歴の評価に対する問題提起と考えるべきであろう。

キーワード：SAR干渉解析、地表変位、誘発変動、お付き合い変動
Keywords: SAR interferometry, surface ruptures, triggered displacement, accompanied displacement

2016年熊本地震における詳細な地形データを用いた地震断層の三次元変位解析事例

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

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　平成28年(2016年)4月16日1時25分に熊本県で発生したM7.3の地震（以下、熊本地震）では、阿蘇市から御船町にかけて地表地震断層の出現が確認されている。これらの地盤変状を面的・定量的に把握するため、筆者らは、この地震直前（4月15日15時-19時20分）と直後（4月23日10時14分-11時53分）の2時期に実施した航空レーザ計測データを用いた検討を進めてきた。

　複数時期の地形データを比較する手法としては、メッシュデータを用いた標高差分が一般的である。しかしながら、今回の地震断層のように大きな水平変位を伴う場合、水平成分と垂直成分の見極めが難しい。

　そこで、航空レーザ計測により取得された点群データを用い、3次元の変位ベクトルを計算する手法について検討した。複数の点群間で位置合わせを行う一般的な手法としてICP (Iterative Closest Point)手法がある。これは、2つの点群間の最近傍点を対応点として求め、対応点の距離を縮小する幾何変換を推定する処理を繰り返すことで、マーカ等がなくても自動的な位置合わせを可能とするものである。本検討では、さらに点群の構成する面と面の距離も最小化することも考慮した手法（CCICP: Classification and Combined ICP）を採用した。

　益城町三竹北方付近にモデル地域を設定し、CCICP手法を適用した。図に示す。水平方向の変位をベクトルの向きと大きさで、鉛直方向の変位を色分けで示している。この結果より、木山川低地の南北端に沿う東西方向の2条の右横ずれ断層と、北西−南東方向にのびる左横ずれの共役断層が確認できた。また、南側の山地部では隆起方向、北側の台地部では沈降方向である。断層が分岐する付近では、局所的に水平移動成分がほとんどない場所もあること等が明らかとなった。

キーワード：航空レーザ、活断層、2016年熊本地震、ICP手法
Keywords: LiDAR, Active Fault, 2016 Kumamoto Earthquake, Iterative Closest Point algorithm
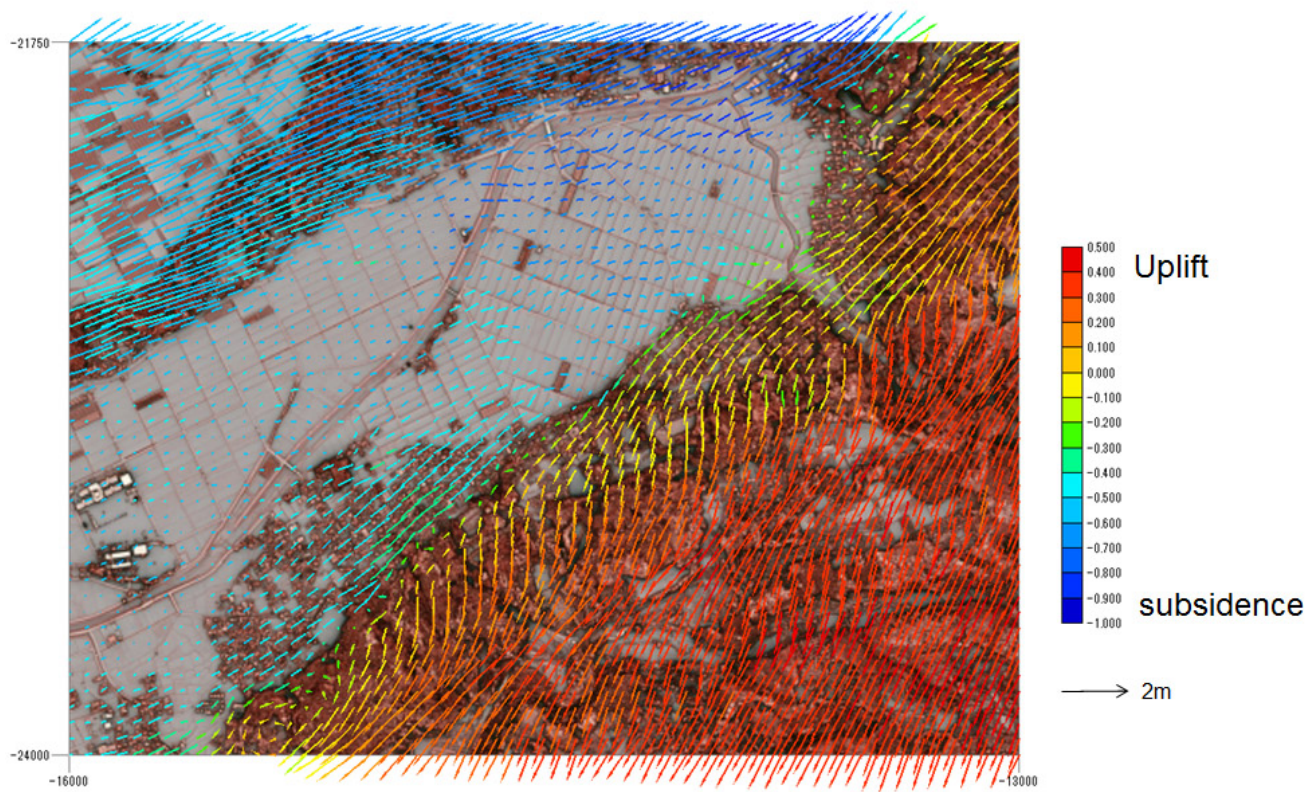
Rupture features of the 2016 Mw6.2 Norcia earthquake and its possible relationship with strong seismic hazards

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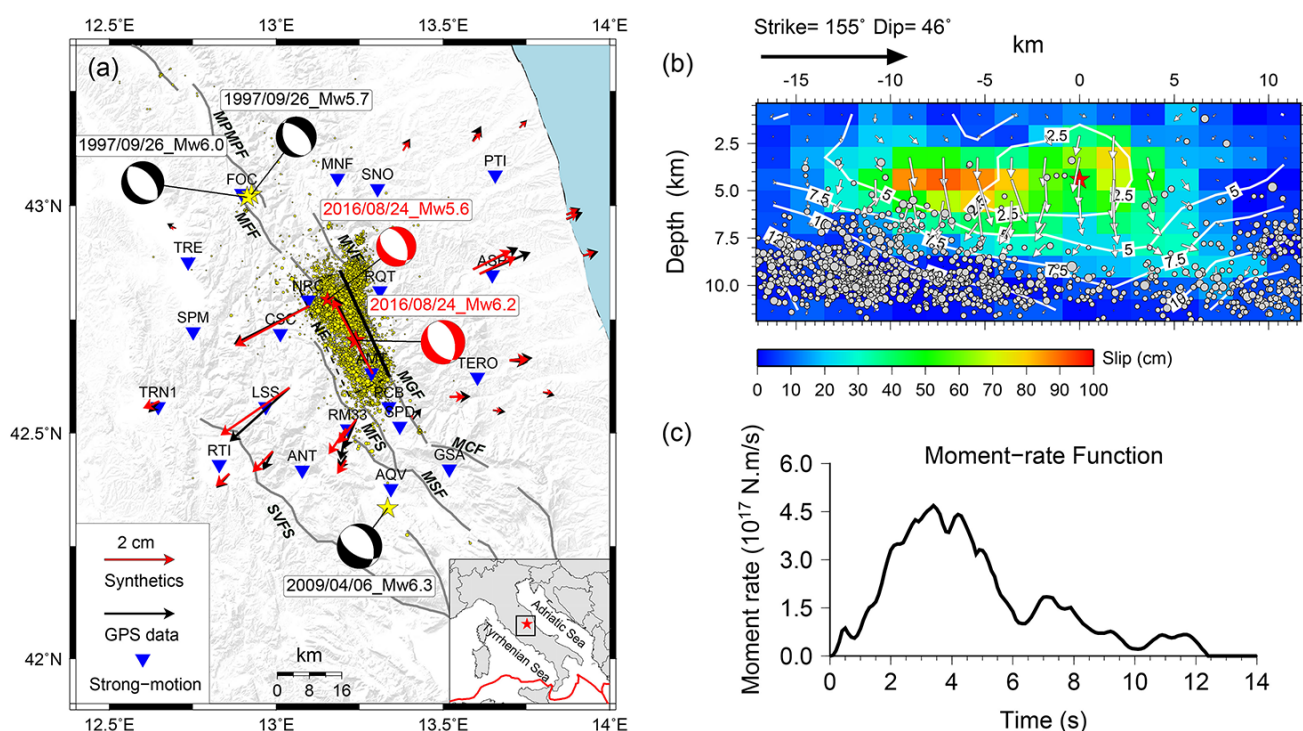
An example of slip on a capable fault: Near-field co-seismic deformation of the 30th October Central Italy earthquake (6.6 Mw) measured using low-cost GNSS

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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

2016 Kaikoura (New Zealand) M7.8大地震におけるHundalee断層帯の変動と被害調査
Co-seismic offsets and damage associated with the Hundalee Fault during the 2016 Kaikoura, New Zealand, M7.8 earthquake

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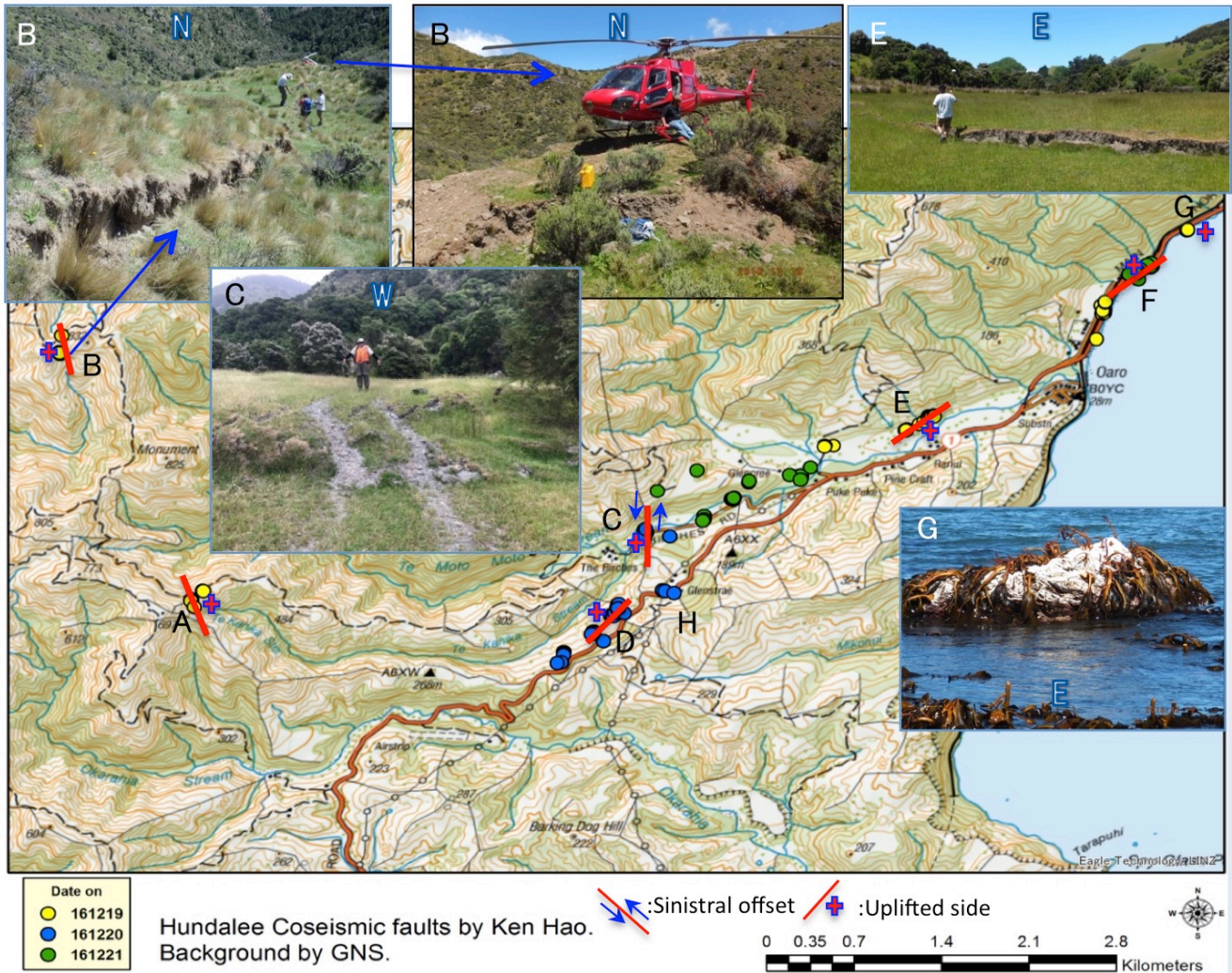
According to the updated survey results of the multi-institutional research team (GNS, 2016), the Hundalee Fault was one of more than 12 individual faults that collectively ruptured during the earthquake.

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

キーワード：カイコウラ地震、現地調査、地震断層、ニュージーランド、Hundalee fault
Keywords: Kaikoura earthquake, field investigation, co-seismic fault, New Zealand, Hundalee fault

Date on
- 161219 (yellow)
- 161220 (blue)
- 161221 (green)

Hundalee Coseismic faults by Ken Hao.
Background by GNS.

:Sinistral offset
:Uplifted side

0 0.35 0.7   1.4   2.1   2.8
Kilometers

平成23年と平成28年の茨城県北部の地震に伴う地表変動の衛星SAR差分干渉解析

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

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　平成23年3月19日と平成28年12月28日に茨城県北部で生じた地震に関して，地震前後のALOS PALSARデータ（平成23年）とSentinel-1 CSARデータ（平成28年）の差分干渉解析を実施し，地表変位量の分布パターンを調査した。2件の地震ともに，北行軌道と南行軌道の干渉ペアが利用可能であり，これらを用いて2.5次元解析を実施して変位量を東西方向と上下方向に分解し，変位の分布パターンを比較した。平成23年の地震前後の干渉ペアは，東北地方太平洋沖地震による広域変位量を含むため，電子基準点データにより広域変位量をシミュレートしてこれを除き，局地変位量を算出した。断層の地表トレースは，平成23年と平成28年でほぼ同一であり，巨視的には，同じ断層が活動した可能性が高いと考えられる。2.5次元解析の結果，上下方向と東西方向の最大変位量の位置は異なることが判明し，その分布パターンから，リストリックな形状を成す断層面に沿う正断層の活動が示唆される。これらの地震に伴い生じた地表変位量は，上下方向・東西方向とも，平成28年の地震のものに比べて平成23年のものが2倍程度大きく，震源から断層の地表トレース付近までの距離の違いを反映しているものと考えられる。震源の深さは，気象庁の発表に基づくと平成23年の地震が約5km，平成28年の地震は約11kmであり，断層の地表トレースからの震央までの距離は，平成23年の地震で約5km，平成28年の地震で約12kmである。

キーワード：茨城県北部、地震、地表変位、衛星SAR差分干渉、2.5次元解析

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

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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)

キーワード：地表地震断層、断層活動の繰り返し、誘発地震、2016年茨城県北部の地震

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

2016年12月28日茨城北部の地震による地表地震断層(序報)
Preliminary report of co-seismic surface rupture produced by the 28 December 2016 Hokubu-Ibaraki earthquake, northern Kanto region, Japan.

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　2016年12月28日に茨城県北部を震源とする地震が発生した。震源の深さは約11 km、地震の規模を示すマグニチュードは6.3で、正断層型と推定されている(気象庁, 2016)。地震直後に公表されたInSARの解析画像によると、北西一南東方向に約2kmにわたって変位の不連続が認められ、西側の地盤が最大約27cm衛星から遠ざかる一方、東側の地盤は最大約6cm衛星に近づくような変動が検出された(国土地理院, 2016)。震源域では、東北地方太平洋沖地震直後から地震活動が活発化し、2011年3月19日にもMj6.1の正断層型の地震が発生している。筆者らは、2016年の地震による地表地震断層の出現の有無を確かめるため、地震直後に現地踏査を実施した。

　踏査の結果、InSARの不連続線に沿って開口クラックが断続的に続くことが確認された。クラックは北端の持山集落(N36°49′20 ", E140°36′36 ")から南に向かって小山ダム上流部の支流(N36°47′54", E140°37′45")の約3.4 kmに渡って出現していることが明らかとなった。持山集落から富岡集落にかけての区間では、持山川の右岸（南西側）斜面に連続性の良いクラックが出現しており、これらの出現位置は谷部で上流側に入り込み、尾根部で先端側に移動する。なお、持山集落では、2011年3月19日の地震の後にも、舗装道路を斜めに横断する南西低下の変形帯が生じており、その延長上の杉が傾斜していることから、地表地震断層が出現したと考えられている（青柳ほか，2015）。今回の地震では、この変形帯（亀裂の分布範囲、個々の亀裂幅）が明らかに拡大していることを確認した。また、断続的なクラックの南端付近で、クラックの直下に断層破砕帯が露出した。破砕帯は幅40cm程度の断層ガウジ帯を伴い、その断層ガウジ帯は少なくとも2枚の断層ガウジからなる層状構造を呈する。断層ガウジ帯に沿っては直線性に富む断層面(N6°W, 67°W)が認められ、崖錐堆積物を変形させていたことから、最新活動面であると思われる。最新活動面では条線(レイク角72°NNW)が認められ、そのセンスは今回の発震機構と調和的である。以上の調査結果を統合すると、今回出現した断続的なクラックは地表地震断層であると考えられる。

　青柳恭平・大沼巧・奥智也・佐々木俊法, 2015, InSAR解析によって検出した小規模な地震断層の最大変位量と長さの関係. 断層変位評価に関するシンポジウム講演論文集，I-5，pp.31-38.
　国土地理院, 2016, 茨城県北部の地震に関する情報.
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キーワード：地表地震断層、InSAR、断層破砕帯
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-

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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.

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

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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.

キーワード：断層長、活断層、震源断層
Keywords: fault length, active fault, earthquake source fault

Investigation of off-fault displacement

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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.

キーワード：断層変位ハザード、副断層
Keywords: fault displacement hazard, secondary fault

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

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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.

キーワード：決定論的アプローチ、特性化震源モデル、動力学破壊シミュレーション、表層の破壊シ
　　　　　　ミュレーション
Keywords: deterministic approaches, characterized source model, dynamic rupture simulation,
　　　　　　subsurface rupture simulation