

## 学 位 論 文 要 旨

学位論文題目	Observation and Evaluation of Surface Deformation in Complex Landslide Slope of Bobonaro in Timor-Leste by using Remote Sensing (リモートセンシングによる東ティモール・ボボナロにおける複雑な地すべり斜面の地表面変状の観測および評価)
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### Research Background and Objectives

After gaining independence on 20 May 2002, Timor-Leste's policies have focused on alleviating poverty and addressing the immediate needs of the people, consolidating security and stability, and providing a foundation for the nationhood through the building of state institutions. Following the approval of the Timor-Leste Strategic Development Plan, in 2011, many projects related to the infrastructure started, including the construction of large sections of roads and bridges. However, it has not achieved enough due to unexpected ground deformation in mountain areas that is seriously affecting road constructions, etc. The geomorphology and geoenvironment of the country have led to continuous ground deformation, frequent landslides, flash floods and flooding events during the rainy season, thus disrupting the land transport system by destroying bridges and washing out roads. This situation has led to direct and indirect negative impacts on the activities and safety of the people, and consequently, has delayed the ongoing development, wasting the resources and time. In order to design roads and other infrastructures under such difficult conditions, it is important to know the present and future ground conditions. Continuous monitoring is a significant method for detecting the ground deformation and providing essential information to realize the effective design. The problem arises of "How can ground deformation be monitored in extensive areas, which are generally located in mountain areas that are difficult to access? Satellite-based remote sensing has recently been applied to monitor displacement in extensive areas. In addition, Unmanned Aerial Vehicle (UAV) photogrammetry has been applied to detect and characterize the ground surface deformation in detail alongside field observations.

The purpose of this dissertation is to develop a method for detecting ground deformation by making full use of these remote sensing technologies. To achieve that, the following four objectives are listed.

1. To apply the Differential Interferometry Synthetic Aperture Radar (DInSAR) to detect and evaluate the recent ground surface deformation since 2007 in complex Landslide Slope in Bobonaro.
2. To employ Unmanned Aerial Vehicle (UAV) Photogrammetry for detecting the detailed deformation.
3. To discuss about the relation of the ground deformation with the earthquake and hard rainfall event's
4. To find the people's consciousness and preparedness about geo-disasters.

#### Analysis Data

ALOS1 PALSAR1 and ALOS2 PALSAR2 datasets were provided by the Japan Aerospace Exploration Agency (JAXA). The first dataset, composed of 22 SAR images collected from PALSAR1, covered the period from 2007/01/22 – 2011/02/02. The second dataset, composed of 13 SAR images collected from PALSAR2, covered the period from 2015/02/10 – 2019/04/02.

A high-resolution orthomosaic and DEM were collected on 19 August 2017 by employing Small UAV Photogrammetry DJI Mavic Pro.

The earthquake data downloaded from the United States Geological Survey (USGS) Earthquake Catalogue covered the two periods of study.

Timor-Leste rainfall data has not been well recorded since 1974. To overcome this unavailability of rainfall data, it was necessary to use the data published by the Climate Forecast System Reanalysis (CFSR) of the National Centers for Environmental Prediction (NCEP), covering the period from January 2007 to February 2011. For the second period, a HOBO ground station rainfall data logger, with a resolution of 0.2 mm per tip, was installed 2 km from the study area. The data collection was conducted from 07/03/2017 until 02/04/2019 partially covering the second period.

#### Dissertation structure

This dissertation is divided in six chapters:

##### Chapter 1:

Presents a) the background and motivation of the study, b) exposition of an essential literature review related to the ground deformation and landslide monitoring techniques, starting from the conventional methods to the recent and common uses portable and automated devices c) aims of the dissertation, d) references.

##### Chapter 2:

Presents essential information of the study location such as a) Overview of the country related to geology, geomorphology, topography, soil, hydrography, rainfall pattern, soil erosion and tectonic, b) information about Bobonaro region related to geographical location, lithology and topography, c) historical of the ground deformation since 1918, d) type and mechanism of the ground deformation and landslide e) description about the study area and the recent evidences of the ground deformation impact, f) references.

##### Chapter 3:

In this chapter is presented the results of questionnaire survey to identify the consciousness and preparedness regarding geo-disasters in Timor-Leste. The theme of this chapter is connected with chapter 1 and matches with the fourth objective of this dissertation. The result presents that, the majority of people have experienced geo-disasters. Consequently, their consciousness about geo-disasters considered high. However, their preparedness is very low. To overcome this situation

is very important to introduce the soft countermeasure method through education by introducing the knowledge about the prevention and reduction of nature and man-made disasters in the school curriculum.

#### Chapter 4:

In this chapter is presented the study about factor triggering landslides in Timor-Leste. This chapter is relates to chapter 2 and 5. The theme of this matched with the third objective of this dissertation. The recent landslides triggered by rainfall occurred on 17 January 2018 clearly show that high precipitation events do not trigger landslides. On the other hand, the landslide occurred after it rained for four consecutive days with a gradual increase from 4.2 mm/hour, to 10.2 mm/hour, to 13.6 mm/hour and to 17.8 mm/hour on the day of the landslide occurrence. The earthquake triggering factor, although it is of low magnitude, which is responsible for the topographical change of the ground level. However, these two landslide triggering factors might possibly act together or simultaneously.

#### Chapter 5:

In this chapter the main results of this study are presented. This chapter discussed about: a) the application of Differential Interferometry Synthetic Aperture Radar (DInSAR) for screening usual and usual ground deformation behavior in extensive areas, b) the application of Unmanned Aerial Vehicle (UAV) Photogrammetry for mapping and for detecting ground surface deformation in detail. Both methods have an advantage that they do not require any sensors. This chapter relates to chapter 1, 2 and 4. The theme of this chapter matched with the first, the second and the third objective of this dissertation. The LOS displacement results, clearly showed the trend in the ground surface deformation during the two periods of study. UAV photogrammetry data is useful to perform a detailed interpretation of the ground deformation morphology, the direction of the ground movement, and measurements of the ground surface features with centimeters order of accuracy. The combination of DInSAR and UAV present good coherence. The LOS displacement time-series showed that the time occurrence of the ground deformation, earthquake sequences, and periodic rainfalls are notably related.

#### Chapter 6:

Provide the conclusions of this research and recommendations for future work.

#### Final remarks

It states that the four goals raised at the beginning of this paper have been achieved. Furthermore, it was proved that the combination of the proposed methods would be an effective method for detecting ground deformation in areas where the surveying cannot be performed.

(様式 9 号)

## 学位論文審査の結果及び最終試験の結果報告書

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<p>【論文審査の結果及び最終試験の結果】</p> <p>東ティモールの山間部では沈下やすべりなど想定外の地盤変動によって道路工事等が度々影響を受けている。申請者は、国土基盤情報が整備の途上で、広範な現地測量が困難な同国では、差分干渉 SAR (DInSAR) や無人航空機 (UAV) による観測が有効であると着想し、地震後の降雨により侵食と地すべりが多発している同国西部のボボナロ地域を対象に DInSAR と UAV を組み合わせた観測・解析によって斜面変状の経時変化がどの程度まで解明できるかを検討した。本研究の成果としては、東ティモールの地形・地質・気象の条件の下、雨季に起こる複雑かつ継続的な地盤変状を検出する目的に対して、提案された方法の組み合わせは測量が不可能な地域において非常に有効な方法であることが示された点である。今後、他の地域での適用を進めれば、同国のインフラ整備事業の前進に役立つと考えられる。</p> <p>本学位論文では、これらの成果を以下の 6 章にまとめている。</p> <p>第 1 章では、研究の背景と目的を述べた。また、既往の研究結果を整理・要約した。</p> <p>第 2 章では、調査地域の地質、地形、降雨・地震発生状況、植生等を述べたうえで、過去の斜面変状、地すべりの形態を概観した。</p> <p>第 3 章では、住民の災害に対する意識や準備状況を確認するために実施したアンケート調査結果と考察を述べた。その結果、大多数の住民が地盤災害を経験していることがわかった。また、地盤災害に関する住民の意識は高いものの、住民の地盤災害に対する準備を軽視する傾向があることがわかった。</p> <p>第 4 章では、東ティモールにおける地すべり発生の誘因について検討した結果を述べた。その結果、地すべりの発生には降雨だけでなく小規模地震でもその原因になりうることを示</p>	

唆された。

第 5 章では、ボボナロ地域の DInSAR の解析結果に基づいて 2007 年以降の斜面変状の経時変化を分析し、UAV ならびにトータルステーションによる測量結果と比較検討したところ、これらの手法は複雑な様相を呈す斜面変状のモニタリングに有効であることが示され。また、この地域の斜面変状は地震イベントによって引き起こされ、数ヶ月あるいは数年後の降雨が斜面変状の継続的な進展に寄与した可能性があることを指摘した。

第 6 章では本研究の結論を総括し、展望を述べた。

公聴会における主な質問内容は、1) 東ティモールにおける本研究手法の展開、2) インフラ整備の政策決定における技術的な役割、3) 斜面防災ならびに道路維持コスト縮減への本研究手法の活用、4) 地域住民の被災実態と防災意識の乖離、5) 東ティモールにおける本研究手法の普及とスキルアップに対する方策などに関するものであり、いずれの質問に対しても発表者からの確かつ十分な回答がなされた。

以上より本研究は独創性、信頼性、有効性、実用性ともに優れ、博士（工学）の論文に十分値するものと判断した。

論文内容及び審査会、公聴会での質問に対する応答などから、最終試験は合格とした。

なお、主要な関連論文の発表状況は下記のとおりである。（関連論文：計 4 編）

- 1) B. H. Martins, M. Suzuki, P. E. Yastika, N. Shimizu: Ground surface deformation detection in complex landslide area - Bobonaro, Timor-Leste - using SBAS DInSAR, UAV and Field Observations, *Geosciences*, 10 (6), 245; <https://doi.org/10.3390/geosciences10060245>, 2020.
- 2) B. H. Martins, M. Suzuki, T. Eguchi, N. Tamkuan, M. Nagai: Factors triggering landslides in Timor-Leste, *Proceedings of the 4th International Conference VIETGEO 2018 - Geological and Geotechnical Engineering in Response to Climate Change and Sustainable Development of Infrastructure*, pp.421-430, 2018.
- 3) B. H. Martins, M. Suzuki, T. Eguchi, N. Tamkuan, M. Nagai: Ground subsidence induced by shallow earthquake in Timor-Leste, *Proceedings of the ISRM Specialized Conference and 8th Conference of Croatian Geotechnical Society Geotechnical Challenges in Karst*, pp.205-210, 2018.
- 4) B.H. Martins, M. Suzuki: Geo-disasters consciousness and preparedness of the people in Timor-Leste, *Proceedings of Technical Forum on Mitigation of Geodisasters in Asia*, P.0005, pp.19-22, 2019.