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Education & Research Hub

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2023 年度採択分 九州大学マス・フォア・インダストリ研究所 共同利用研究集会

デジタル化時代に求められる斜面防災の思考法

編集：澤田茉伊

九州大学マス・フォア・インダストリ研究所

MI Lecture Note Vol.96 : Kyushu University

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About MI Lecture Note Series

The Math-for-Industry (MI) Lecture Note Series is the successor to the COE Lecture Notes, which were published for the 21st COE Program “Development of Dynamic Mathematics with High Functionality,” sponsored by Japan’s Ministry of Education, Culture, Sports, Science and Technology (MEXT) from 2003 to 2007. The MI Lecture Note Series has published the notes of lectures organized under the following two programs: “Training Program for Ph.D. and New Master’s Degree in Mathematics as Required by Industry,” adopted as a Support Program for Improving Graduate School Education by MEXT from 2007 to 2009; and “Education-and-Research Hub for Mathematics-for-Industry,” adopted as a Global COE Program by MEXT from 2008 to 2012.

In accordance with the establishment of the Institute of Mathematics for Industry (IMI) in April 2011 and the authorization of IMI’s Joint Research Center for Advanced and Fundamental Mathematics-for-Industry as a MEXT Joint Usage / Research Center in April 2013, hereafter the MI Lecture Notes Series will publish lecture notes and proceedings by worldwide researchers of MI to contribute to the development of MI.

October 2022
Kenji Kajiwara
Director, Institute of Mathematics for Industry

Slope Disaster Prevention in the Digital Era

MI Lecture Note Vol.96, Institute of Mathematics for Industry, Kyushu University
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はじめに

斜面災害は，未だ予測の難しい現象であり，国内外で多大な人的・物的な被害が発生している。気候変動に伴う極端な気象に移行しつつある近年，これまで以上に斜面災害の予測は重要課題となっている。斜面災害の評価は，数理モデルとモニタリングを基礎とする。数理モデルには，地盤の変形や浸透を記述する力学モデルに加え，近年は DX, AI などの活用も試みられている。一方，モニタリングは地盤の変形，間隙水圧，含水量，温度等，崩壊と関係する計測項目は多岐にわたる。計測・通信技術の進歩に伴い，より高精度かつ密なデータの取得が可能になってきている。数理モデルの妥当性検証には計測データが不可欠であり，また計測データの補完や将来予測には数理モデルが不可欠である。両者の進歩によって，斜面災害の予測は実現される。

本研究集会は，九州大学マス・フォア・インダストリ研究所 2023 年度女性研究者活躍支援研究および国際地盤工学会 ATC1 の支援を受け，九州大学伊都キャンパス IMI オーディトリアムにて，2023 年 11 月 20 日 13:00-15:30 に開催された。数理モデルおよびモニタリングによる斜面災害の予測技術と管理・対策に関する最新情報の共有と，異分野および産官学の間のネットワーキングを目的とする。会場に加えて Zoom を併用したハイブリッド形式で実施し，国内外から 36 名が参加した。参加者は，地盤工学，砂防学，数学，情報学，環境工学等を専門とし，主な所属は，大学，民間企業（建設関連），法人研究機関であり，25%が女性であった。

Chandan Ghosh 氏（National Institute of Disaster Management, India）による講演，”Bioengineering measures for slope stabilizations by vetiver grass system”，では，植物根を活用した斜面の補強法とインドでの実践例について紹介があった。北田奈緒子氏（GRI 財団）よる講演，”Regarding ground risk assessment based on topographical and geological features”，においては，地形および地質学的観点から斜面災害リスクの高い地盤について解説があった。酒井直樹氏（防災科学技術研究所）による講演，”Challenges in disaster response using slope monitoring with ICT”，においては，地震後の熊本県のフィールド等での IoT センサや AI を使用したモニタリング事例の紹介があった。徳久晶氏（株式会社ケイズラブ）による講演，”Full-scale field experiment of debris flow and its generation mechanism”，では屋外での大規模な斜面崩壊実験と不織布を用いた対策工の効果について説明があった。吉川高広氏（名古屋大学）による講演，”Application of three-phase elastoplastic finite deformation analysis to slope failure problem during rainfall”，では，不飽和地盤を対象とした構成モデルを用いた数値解析による降雨時の斜面の安定性評価と，熱海の土砂災害への適用・崩壊メカニズムについて解説があった。澤田茉伊氏（東京工業大学）による講演，” Geotechnical approaches for preservation of openly exhibited Geo-relics damaged by rainfall infiltration”では，降雨で崩壊した遺構斜面の

再現解析に基づく原因究明と修復・展示の手法について紹介があった。これらの講演に対して，会場およびオンラインの参加者から多数の質問が寄せられ，活発な議論が行われた。学生や若手研究者からの質問も多く，次世代の研究につながる情報共有の場を提供し，本研究集会の目的を達することができたと考える。

他に，講演者の Chandan Ghosh 氏については，11 月 22 日に防災科学ランチタイムセミナーでの講演，11 月 18 日, 19 日, 26 日にそれぞれ東京都市大学，九州大学，Asian Institute of Technology の研究者らと地盤防災に関する意見交換を実施した。

謝辞 : 当研究集会を開催するにあたり，九州大学マス・フォア・インダストリ研究所より多大なるご支援を賜った。また，国際地盤工学会 ATC1 および CREST2023 SDGs 委員会より，企画・広報の協力を得たので，ここに謝意を表する。

研究代表者　澤田　茉伊
東京工業大学　環境・社会理工学院
2024 年 2 月

2023年度九州大学マス・フォア・インダストリ研究所 共同利用・共同研究　女性研究者活躍支援研究-研究集会(I)

デジタル化時代に求められる斜面防災の思考法

Slope Disaster Prevention in the Digital Era

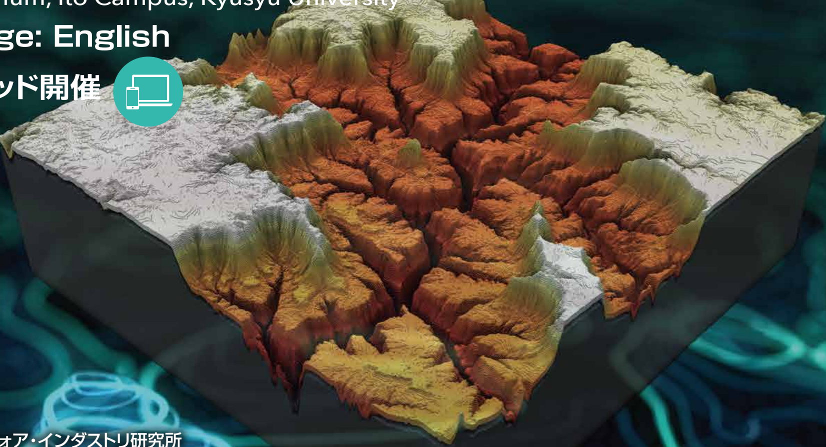
2023 11.20 MON 13:00-15:30

参加無料
事前申込制

九州大学 伊都キャンパス
IMIオーディトリアム
IMI Auditorium, Ito Campus, Kyusyu University

Language: English

ハイブリッド開催



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九州大学マス・フォア・インダストリ研究所
Institute of Mathematics for Industry, Kyushu University

講演者

Prof. Chandan Ghosh,
National Institute of Disaster Management, India

北田 奈緒子(GRI財団)
Dr. Naoko Kitada, Geo-Research Institute, Japan

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Dr. Naoki Sakai, National Research Institute for Earth Science and Disaster Resilience, Japan

徳久　　晶(株式会社ケイズラブ)
Dr. Aki Tokuhisa, K's Lab Inc., Japan

吉川　高広(名古屋大学)
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九州大学 KYUSHU UNIVERSITY
Institute of Mathematics for Industry Kyushu University
Joint Research Center for Advanced and Fundamental Mathematics-for-Industry
文部科学大臣認定「産業数学の先進的・基礎的共同研究拠点」
九州大学マス・フォア・インダストリ研究所

…開催日：2023/11/20〜2023/11/20

デジタル化時代に求められる斜面防災の思考法｜2023a019

カテゴリー：イベント　タグ： 女性研究 研究集会I …

プログラム

11月20日（月）13-16時

- 13:00 – 13:05

開会挨拶
CREST 2023 実行委員会委員長（ハザリカヘマンタ，九州大学教授）

- 13:10 – 14:45

講演
Prof. Chandan Ghosh（National Institute of Disaster Management, India）
Bioengineering measures for slope stabilizations by vetiver grass system

北田奈緒子（GRI財団）
Regarding ground risk assessment based on topographical and geological features

酒井直樹（防災科学技術研究所）
Challenges in disaster response using slope monitoring with ICT

徳久晶（株式会社ケイズラブ）
Full-scale field experiment of debris flow and its generation mechanism

吉川高広（名古屋大学）
Application of three-phase elastoplastic finite deformation analysis to slope failure problem during rainfall

澤田茉伊（東京工業大学）
Geotechnical approaches for preservation of openly exhibited Geo-relics damaged by rainfall infiltration

- 14:45 – 15:15

パネルディスカッション

- 15:15 – 15:30

ネットワーキング

- 15:30

閉会

目　次

Bioengineering measures for Slope Stabilisation

Chandan Ghosh
National Institute of Disaster Management, Delhi, India

The Vetiver Grass Technology (VGT) is a low cost and extremely effective system for soil and water conservation, pollution control, wastewater treatment, mitigation and prevention of storm damage and many other applications. Vetiver can be used in the tropics and semi tropics, and where there are hot summers, and winters that do not include permanently frozen soil conditions. Vetiver, although known as a grass, does possess several tree-like features. It therefore becomes an attractive alternative to trees or shrubs when come to bioengineering applications. Some of the potential applications of Vetiver system across the 100+ countries demonstrate that this plant, even though originated in India, needs extensive research and developments. The presentation highlights are:

- Landslides scenario – highlighting ineffective/inadequate drainage/stabilisation measures that leads to progressive failure
- Hill widening by cutting hills that causes man-made landslides
- Live landslide hotspots where inappropriate technologies lead to failure
- Landslides prevention measures by conventional slope stabilisation methods, such as gravity retaining walls and modern techniques using geosynthetics where a combination with bioengineering measures ensures sustainability
- Important hill roads where slope stabilization measures are taken with extremely high cost but bio-engineering measures ensuring better safety with low or no cost
- Vetiver grass – it's origin, properties and potential for erosion and landslide control
- Successful Application of Vetiver grass where conventional or many other methods failed
- Application of Vetiver grass – giving examples of successful and failed application many countries. It's rather a permanent, low maintenance solution. Vetiver grass is a perennial plant, which provides a permanent solution with little or no maintenance
- Guidelines for Vetiver application siting several examples of landslides hotspots exclusively or in combination with conventional slope retaining structures
- Vetiver grass supports local economies and Vetiver projects are labor intensive so they employ locals, especially in rural areas. Vetiver foliage may be harvested for thatching, fodder, composting or other purposes where biomass is required
- Vetiver is non-competitive and Roots grow vertically downwards. Vetiver does not compete with adjacent plants
- Vetiver has been shown to have very few pest or disease problems. Vetiver can check weed invasion too. It can block the spread of other grasses including the world's worst creeping grasses.

References

[1] Vetiver Network International. URL
http://vetiver.orghttp://vetivernetinternational.blogspot.in/
[2] Hawaii-Pacific Weed Risk Assessment. URL:
http://www.botany.hawaii.edu/faculty/daehler/WRA/full_table.asp

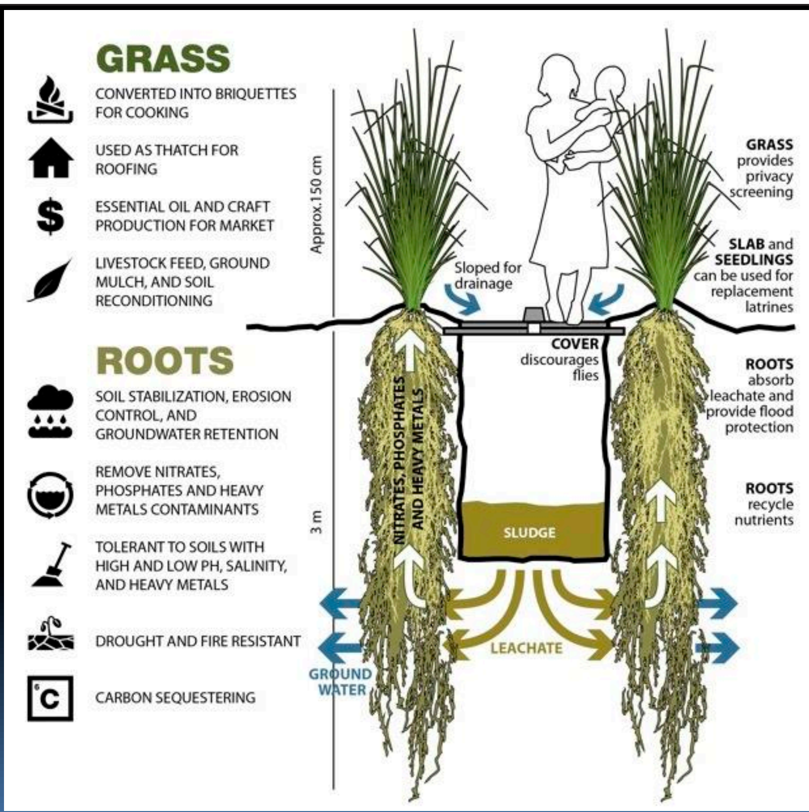
BIOENGINEERING MEASURES FOR SLOPE STABILIZATION

Resilient India - Disaster Free India

Prof. Chandan Ghosh, PhD(IIT-K), Dr. Engg (Japan)
http://disasterresilientindia.blogspot.in/
https://www.facebook.com/chandan.ghosh.9887117
https://twitter.com/cghosh24
Email: cghosh24@gmail.com

Context

- Geotechniques that we think we know off about Landslides
- Unpredictability domain of landslides occurrences and limitations for Early Warning
- Modelling and interpretations – not many vying with Nature
- Nature-based slope mitigation – our perceptions falling apart and miles to go
- Bio-engineering for landslides mitigation- case examples



Source: Can. Geotech. J. 58: 1915–1927 (2021) dx.doi.org/10.1139/cgj-2020-0626

Study: Monotonic and cyclic behaviour of root-reinforced sand..

the friction angle upon extension increased significantly by approximately 10° (from 41.9° (bare specimen) to 51.5° (rooted specimen)) at a low confining pressure of <100 kPa

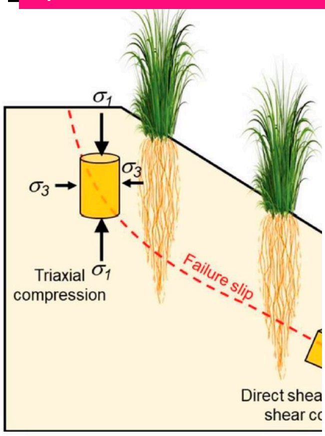
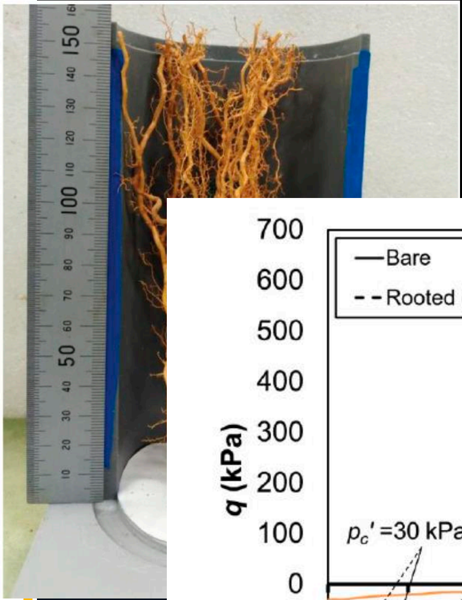
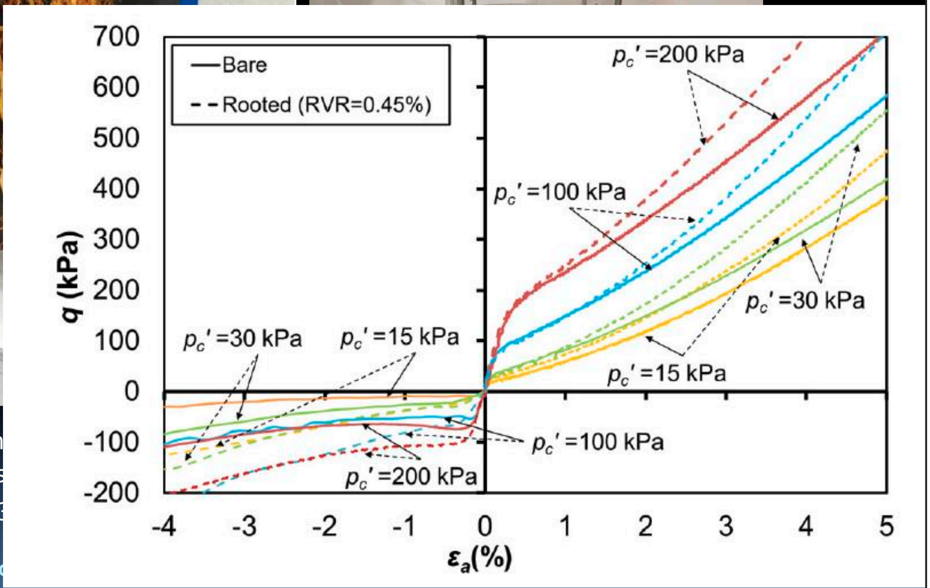


Table 1. Index properties of Toyoura sand.

Index properties	Value
Specific gravity, G_s	2.65
Maximum void ratio, e_{max}	0.977
Minimum void ratio, e_{min}	0.597
Particle diameter of 10% passing, D_{10} (mm)	0.17
Particle diameter of 30% passing, D_{30} (mm)	0.19
Particle diameter of 50% passing, D_{50} (mm)	0.22
Particle diameter of 60% passing, D_{60} (mm)	0.23
Coefficient of uniformity, C_u	0.92
Coefficient of curvature, C_c	1.35





Undrain
rooted s
c of 15, 3

Sourc
dx.doi.org/10.1139/cgj-2020-0626

Inclined drain pipe – suitably be installed, very simple and no special tech required! How to fit Soil mechanics principles here?

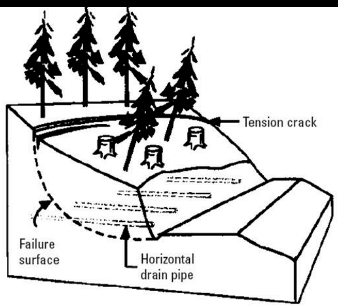
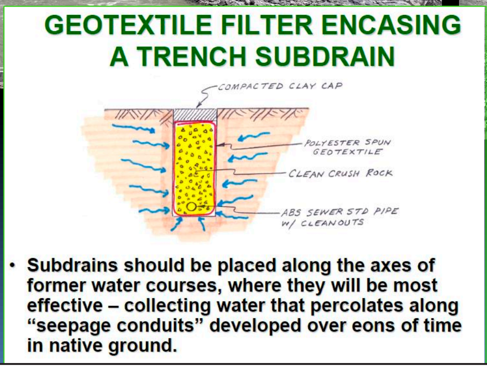


Figure C10. Schematic of drainpipes. (Schematic from Reference 11.) Photograph of drainpipes in a landslide in California, USA, by Andrew Alden.

Such culvert/cross drainage facility creation is time consuming and costly..geotextiles wrap around pipe lines filled with sand-gravel mix is to be designed suiting site conditions, such as amount of rain water/water fall discharge etc.



Reliable & cheaper Alternative to Retaining/breast wall – Vetiver grass

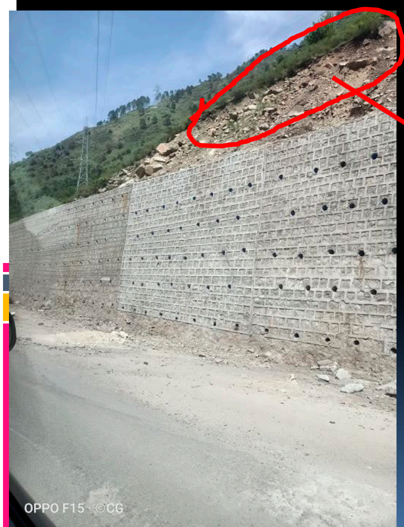
Flyash dump site – stabilization by Vetiver grass, India

Bokaro Steel & Power Plant - Slope stabilization, Soil Erosion control, Water & Air Pollution Mgmt.

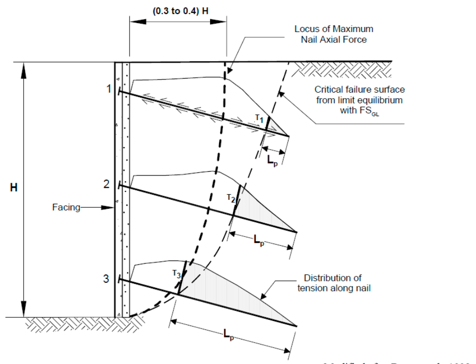
Area – 100 mt. Height x 55 mt. width - 5500 Sq.m

Fly ash mount stabilization & Pollution control by Bioengineering & Green capping

We have similar cut-slope at Ramban-Banihal and these are so easily solved by Vetiver!



Using same age old method–making slope more vulnerable!! Nailed slopes are stable



Modified after Byrne et al., 1998.

Figure 5.14: Schematic Location of Soil Nail Maximum Tensile Forces.

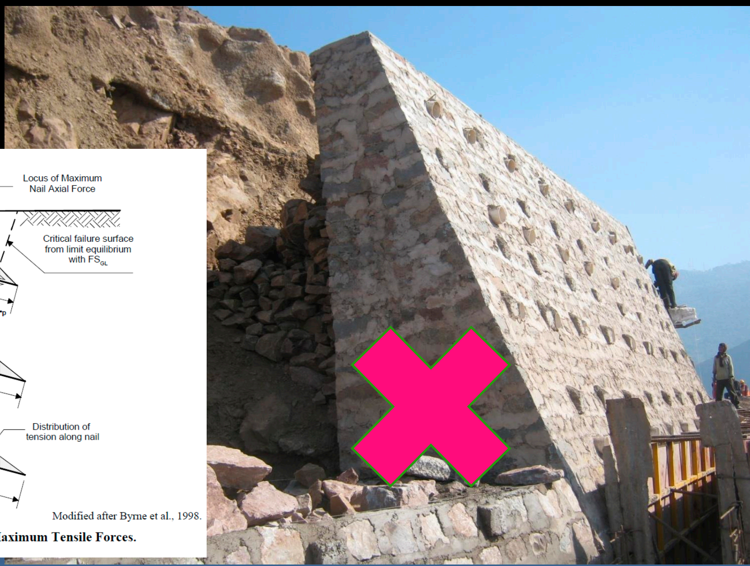


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Table 1: Applicable bioengineering techniques and their effects. Modified from: (Source: Dhital, 2013; Howell, 2001).

S.No.	Suggested method of Bioengineering	Description	What kind of effects is obtained?
1.	Planted grass lines (horizontal)	Rooted cuttings are planted in lines across the slope	Provides surface cover Reduces runoff speed Catches debris and protects the slope
2.	Planted grass lines (diagonal)	Rooted cuttings are planted in lines running diagonally across the slope	Effects similar to (1) Drainage of surface water
3.	Grass seeding	Grass seeds sown directly on the site	Easy vegetation of larger, rocky, and steep slopes
4.	Shrub and tree planting	Shrubs and trees are planted at regular intervals on the slope	Reinforces and anchors the slope Increases slope stability as they grow
5.	Brush layering	Woody cuttings are laid across the slope following the contour	Prevents the development of rills Strong barrier to trap debris Reinforces the slope Provides drainage

R. Raut & O. T. Gudmestad, *Int. J. of Design & Nature and Ecodynamics. Vol. 12, No. 4 (2017)* 423

Table 1: (*Continued*)

S.No.	Suggested method of Bioengineering	Description	What kind of effects is obtained?
6.	Palisades	Similar to brush layering, but the cuttings are planted	Effects similar to brush layering
7.	Fascines/Contour wattling	Bundle of live branches laid in shallow trenches being buried by soil	Effects similar to brush layering
8.	Vegetated stone pitching	A combination of dry stone walling where vegetation is planted in the gaps	Provides a very strong form of armouring
9.	Live check dams	Large woody cuttings planted across a gully following the contour	Catches debris Armours and reinforces gully floor
10.	Vegetated bamboo crib walls	Specialized form of gravity retaining structure using on-site fill material	Immediate protection Provides long-term advantages of slope stabilization

Flyash dump stabilization by Vetiver

Failure cases …due to post plant care..using water for 2-3 weeks

Not caring enough after vetiver grass plantation

How fast Vetiver grows? What's

Conventional structural work and vetiver planting in progress, November 2012

Same site totally stabilized, May 2014

Bio-engg. Solution paradigm

- Composting / decompose organic compound
- **Waste water treatment**
- Remove Bad odour and sterilized harmful bacteria
- Agriculture and gardening
- Absorption of toxic gas like Methane and Hydrogen Sulphide(H_2S)
- Filling Up Dissolved Oxygen
- Controlling Temperature and pH
- Absorption and Chelation of heavy metal and toxic organic compounds

Industries:

- Sewage Processing Area
- Process marine sewage
- Animal Waste
- Poultry Farm Sewage
- Human Waste
- **Chemical Industrial Sewage**
- **Service Water Processing**

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Use of Vetiver

- Traditional medicine
- Roots as water flavouring agent
- Root mats for door, window screens during summer for cooling effect
- For desert coolers in summer in North India
- As eco-friendly soil binders
- Roots for preparing Sharbat (sherbet) or soft drink during summer, especially in North India
- Socio-economic life of the rural population in India
- Dried roots for scenting clothes
- Dried culms as brooms and for thatching
- Pulp of the plant for paper and straw board

THE VETIVER GRASS- CHARACTERISTICS

- **Grows under extreme and wide range of condition**
- **Long Living Perennial Grass**
- **Air temperatures: Sub zero to >55° C**
- **Soil pH from <3 to >10**
- **Annual Rainfall 200 mm to > 6,000 mm**
- **Tolerant to high toxicity**
- **Few Pests and diseases**
- **Powerful (75 MPa root strength) and deep root system**
- **Can withstand upto 5 months of submergence.**
- **Non competitive and non invasive**

Thanks

Regarding ground risk assessment based on topographical and geological features

Naoko KITADA
Geo-Research Institute, Japan

日本列島は，４つの地殻プレートが会合した場所で形成された「島弧」であり，非常に複雑でバリエーションに富む地質が観察される地域である．そのため，構成する岩種や岩盤が風化して形成される土砂は地域によって鉱物組成が異なる．特に糸魚川‐静岡構造線を境として，東側（東日本）と西側（西日本）の地質や地形は大きく異なる．東側では中新世以降の火山岩類が広く分布し，時間経過とともに変質して不安定な土塊は地滑りや崩壊を発生させる．一方西側では，白亜紀に瀬戸内海を中心に花崗岩が大規模に貫入した．それらが風化してマサ化した土砂は，豪雨時の土石流などを発生させる．また，西南日本に分布する中央構造線を境に南側では「付加体」と呼ばれる海洋プレート起源の岩石が分布する．

これらの地質のバリエーションは地域性のある地形を構成すると同時に，気候（特に降雨など）による変質，岩石風化による土砂の生成が地域毎に異なることから，地質リスクも地域によって異なる原因となる．よって，地域の地質と地形を知ることと，それによって発生する地質リスクを理解することは土地利用時には重要なポイントとなる．

事例として，東日本の日本海側を中心に分布する「グリーンタフ」は前述の火山岩類の一部が変質して生成した緑泥石がリスク要因となり，地すべりや崩壊を発生させる．一方，西日本に分布する中央構造線付近では，広範囲に分布する断層破砕帯部において岩盤が脆く破砕あるいは粘土状のガウジなどに変化していることがリスク要因として，地すべりや崩壊の発生が高い．花崗岩地域のうち，花崗岩貫入の外縁部地域では急冷に伴う節理（亀裂）の発達が風化変質を促進してマサ化が進み土石流や崩壊を発生させる要因となる（千木良・加藤，2023）．付加体地域においては，層状の堆積岩が傾動していると，谷筋に沿って層理面が流れ盤になった場合，崩壊や地滑りを発生させる要因が高い．

いずれにおいても，地質の特徴や成り立ちを十分に把握することによって，地質特性からリスクを予測することが可能であること，リスクを予測できれば，リスクを回避するための調査や設計，工法を選択して，安全な構造物が建設できる．災害や建設工事のトラブルを事前回避するためには，これらの地質学や地形学などの知識を活用することが大切であり，理学と工学の融合（協働）作業が必要であると考える．

参考文献：

千木良雅弘・加藤弘徳（2023）：花崗岩の冷却割れ目と岩体の内部構造，日本応用地質学会令和５年度研究発表会講演論文集，p61-62.

Regarding ground risk assessment based on topographical and geological features

Naoko KITADA

(Geo-Research Institute)

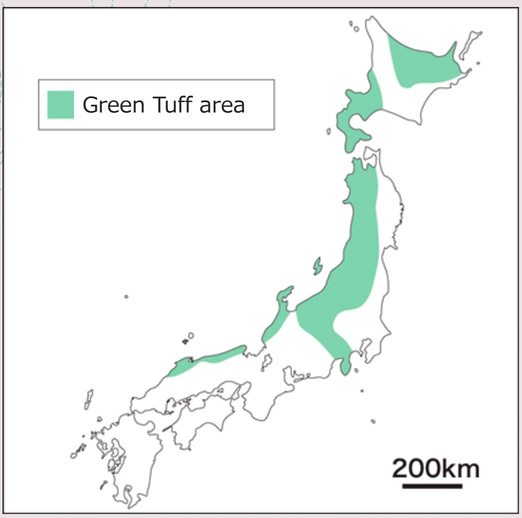
Areas at risk of disaster from a geological perspective

Characteristics of the constituent strata and rock bodies

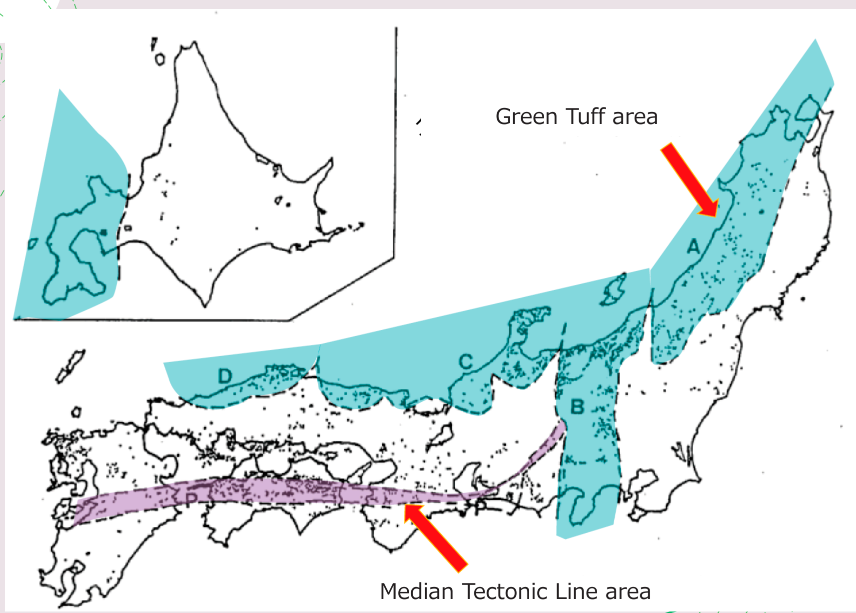
⇒ Characteristics of constituent minerals, characteristics of strata composition

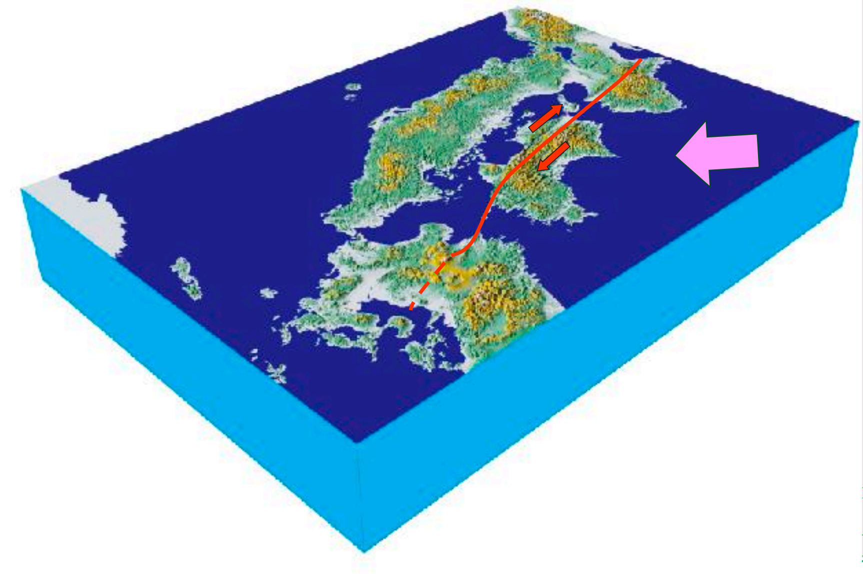
Tends to be susceptible to chemical and physical changes such as alteration due to water-rock reactions

- Volcanic debris (pumice, volcanic ash, etc.) ⇒ Altered and turned into clay
- Granite ⇒ Weathered and mashed
- Fault ⇒ Clay at the fractured part
- Bedding surface ⇒ Collapse due to flow bed

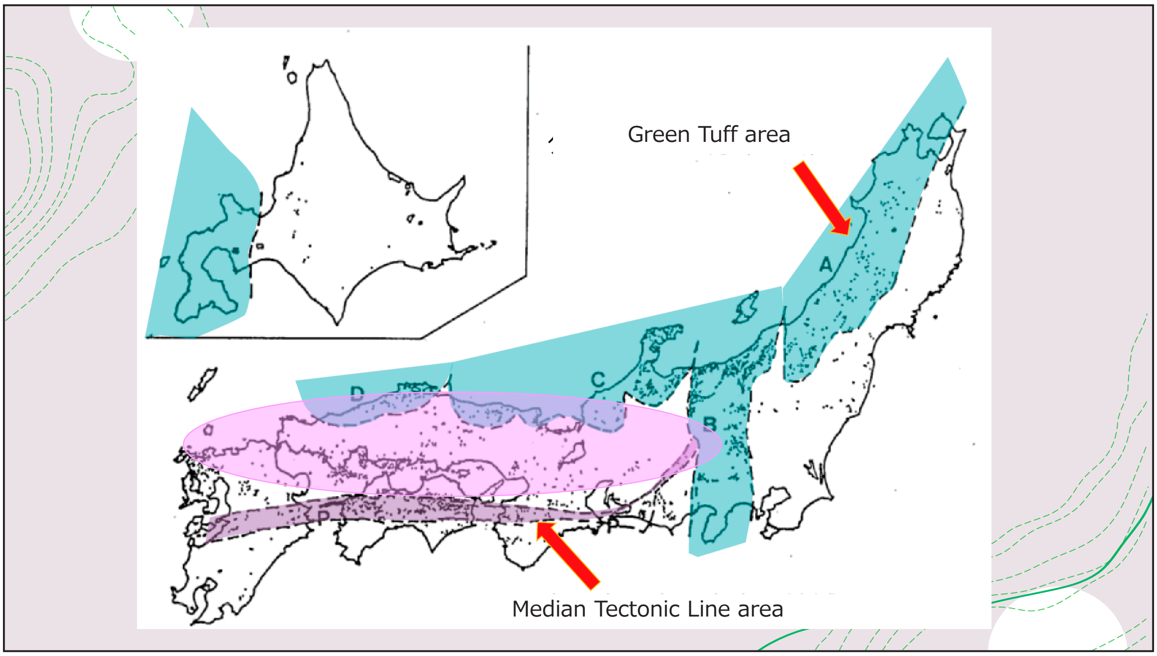


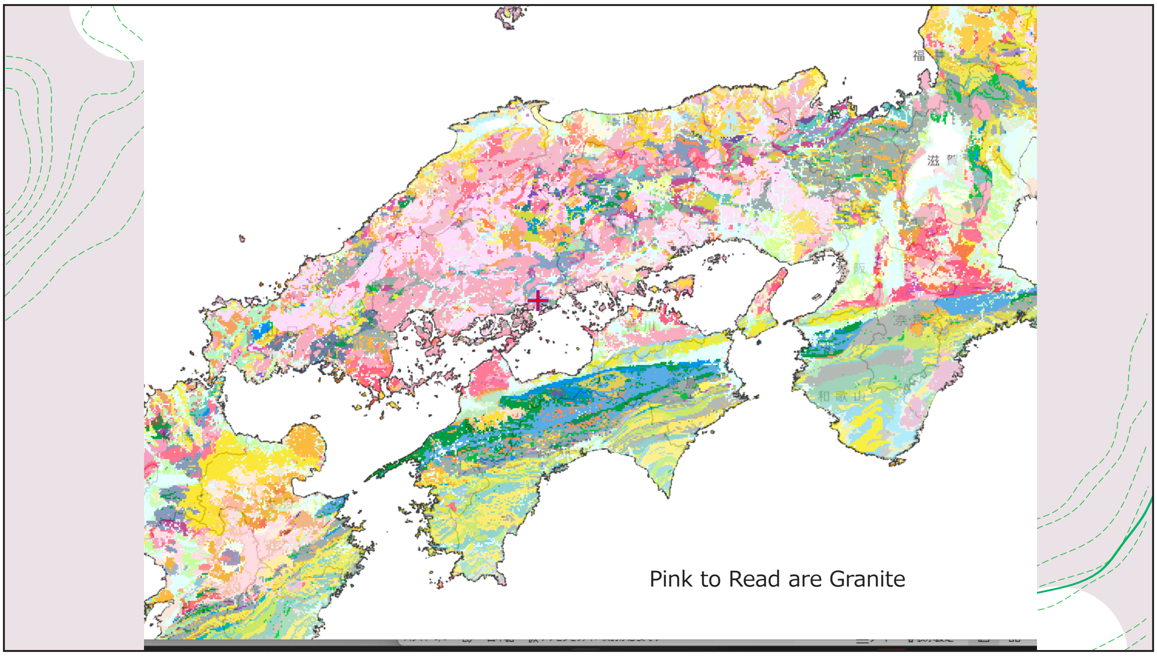
+ Most of the volcanic rocks produced by submarine volcanic activity during the Miocene Neogene period are green in color, so they are called "green tuff." ⇒ The pyroxene amphibole in the ejecta has been chemically changed to chlorite (clay mineral).





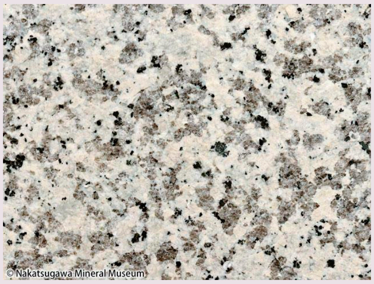
At the fractured part of the fault, the bedrock becomes fine-grained and turns into clay.

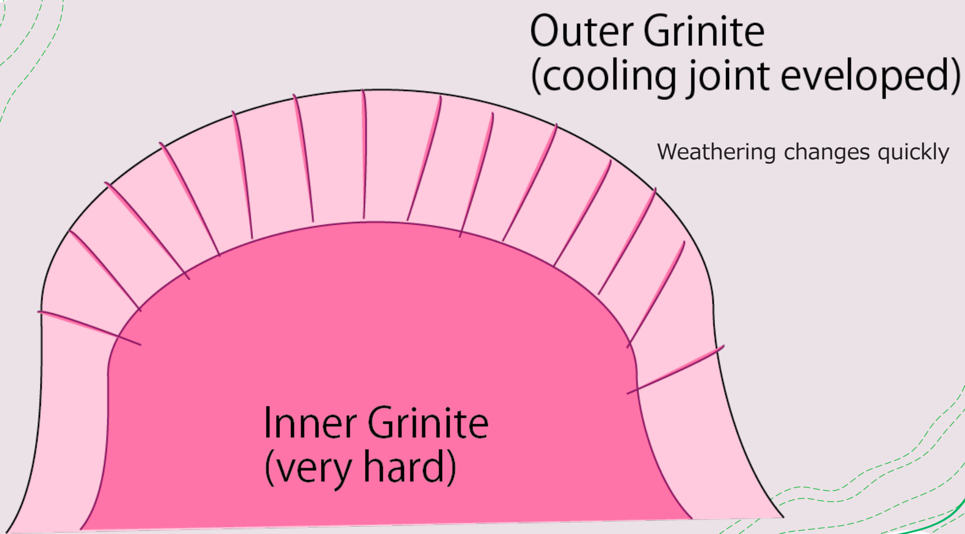

Green Tuff area
A
B
C
D
Median Tectonic Line area

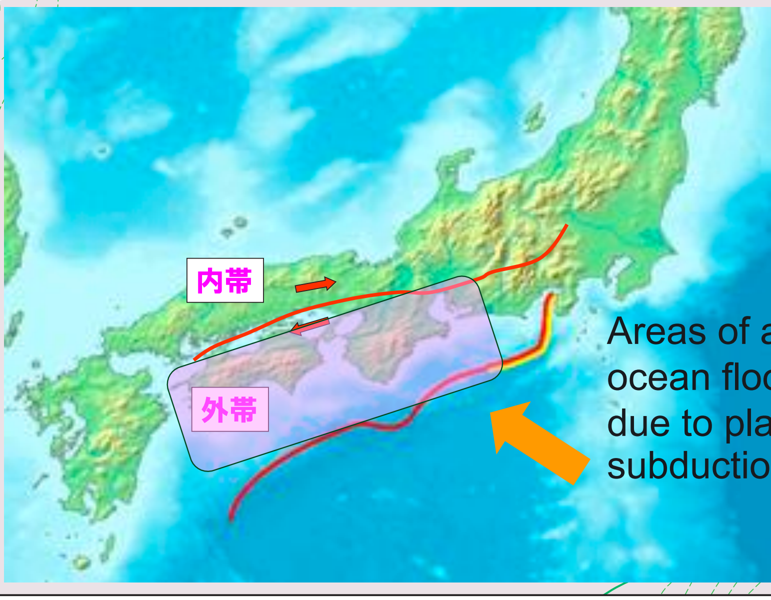

Pink to Read are Granite

Granite

+ Weathered granite is brittle and will crumble into pieces if you hit it with a hammer.

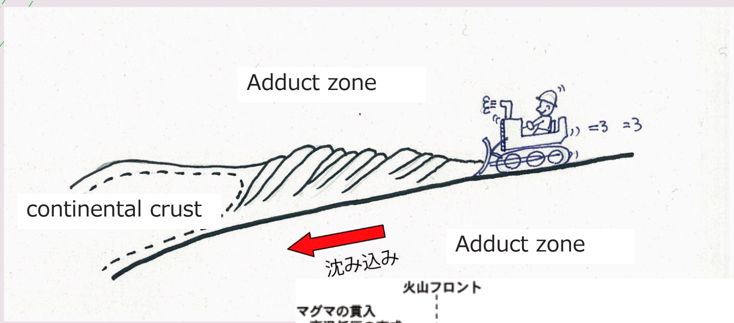




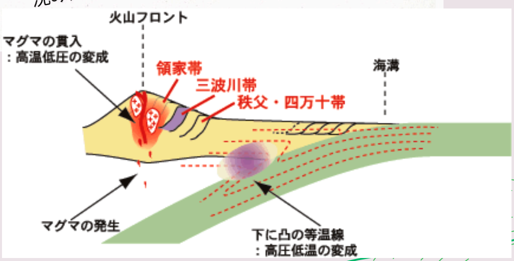


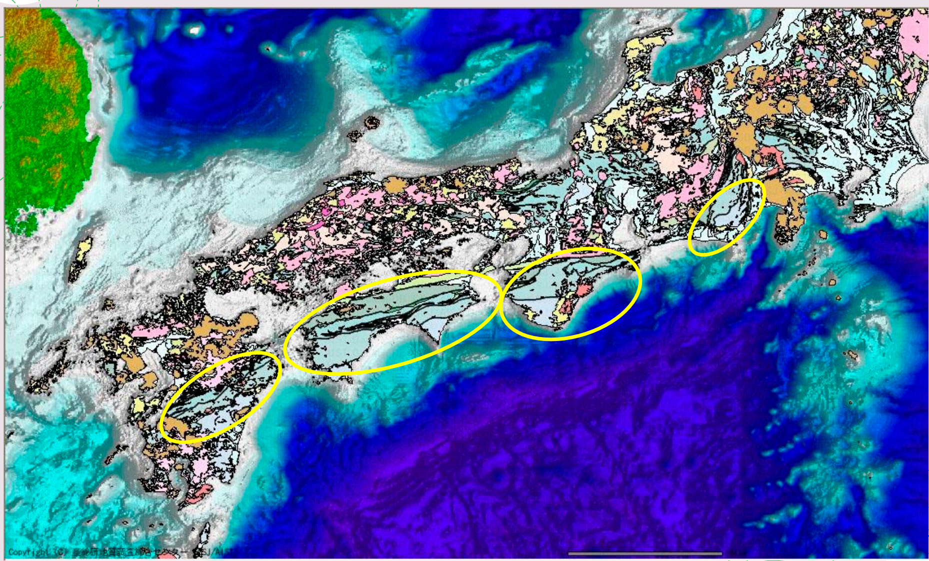
Areas of accretion of ocean floor sediments due to plate subduction

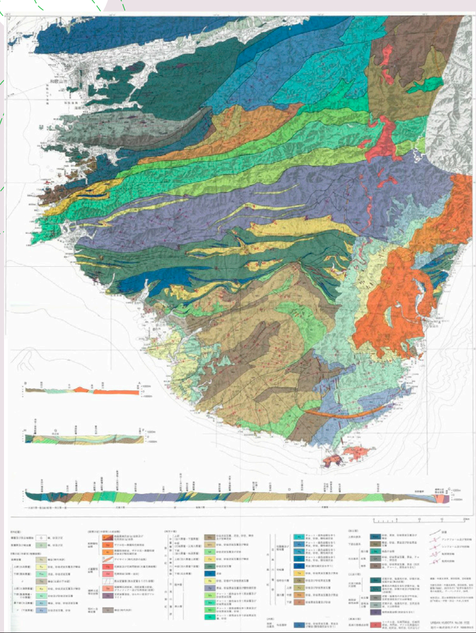
Geological characteristics of the Kii Peninsula - it's "accretion" !

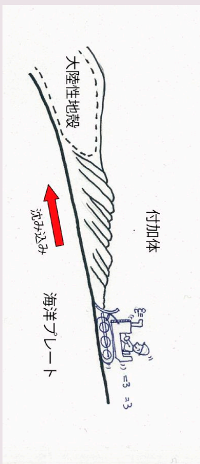


Adduct zone





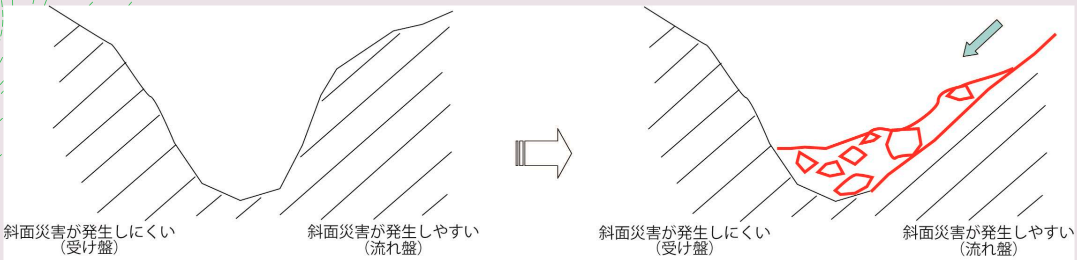




<Characteristics>

Distributed in a band
EW ～ ENE-WSW

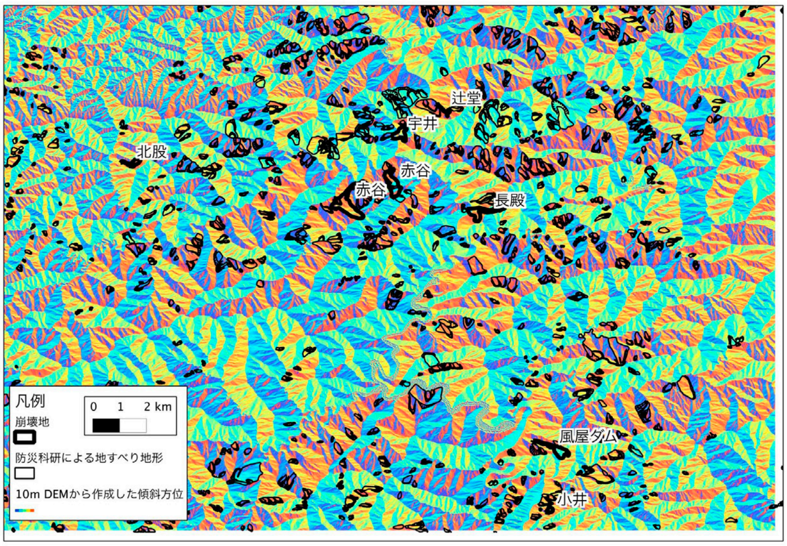
四万十帯の地質図（中屋他，1999）



receiving board

flow board

流れ盤と受け盤の図と特徴



Slope direction and landslide of strata created from 10m DEM
Warm color:flow board. Cool color: receiving board

conclusion

- It is important to understand geological and topographical features.
- Disasters occur due to natural phenomena such as meteorological phenomena and earthquakes, and the ground and geological conditions of the area where the disaster occurs are important points.
- When planning a city, it is important to understand and consider geological risks in advance.

Challenges in disaster response using slope monitoring with ICT

Naoki SAKAI

National research Institute for Earth science and Disaster resilience(NIED), Japan

In our country, natural events such as earthquakes, tsunamis, heavy rain, floods, landslides, and volcanic eruptions present various risks, intertwined with social conditions like complex value chains, advanced land use, and an aging population. Particularly in recent years, there are concerns about widespread disasters caused by major earthquakes and extreme rainfall, along with the possibility of secondary disasters post-event, making disaster response and regional recovery increasingly complex.

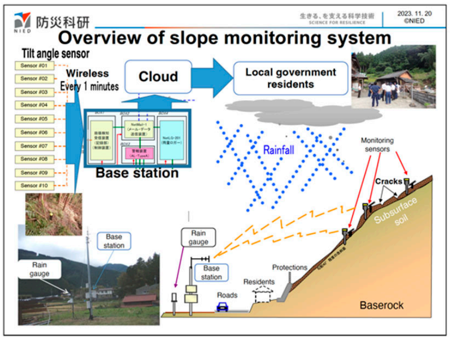


Fig. 1 Overview of IoT slope monitoring system

In the field of disaster prevention and mitigation, a close collaboration between the physical sciences, engineering, and social sciences is necessary. Although hazard research has led to more detailed maps, a method for collaboratively solving the subsequent steps of risk assessment and enhancing municipal response capabilities was lacking. One problem was the lack of a "unified disaster situation awareness" among professionals from various fields, which led to unclear methods of concrete cooperation. However, with the recent advancements in IoT (Internet of Things), measurements have become more accessible, making it easier to digitalize the previously analog world of human intuition and experience, and to understand changes in real-time. Specifically for landslide it is shown in Fig. 1. Such technological innovation has unified and visualized phenomena, disasters, and social activities, enabling the "unified disaster situation awareness."

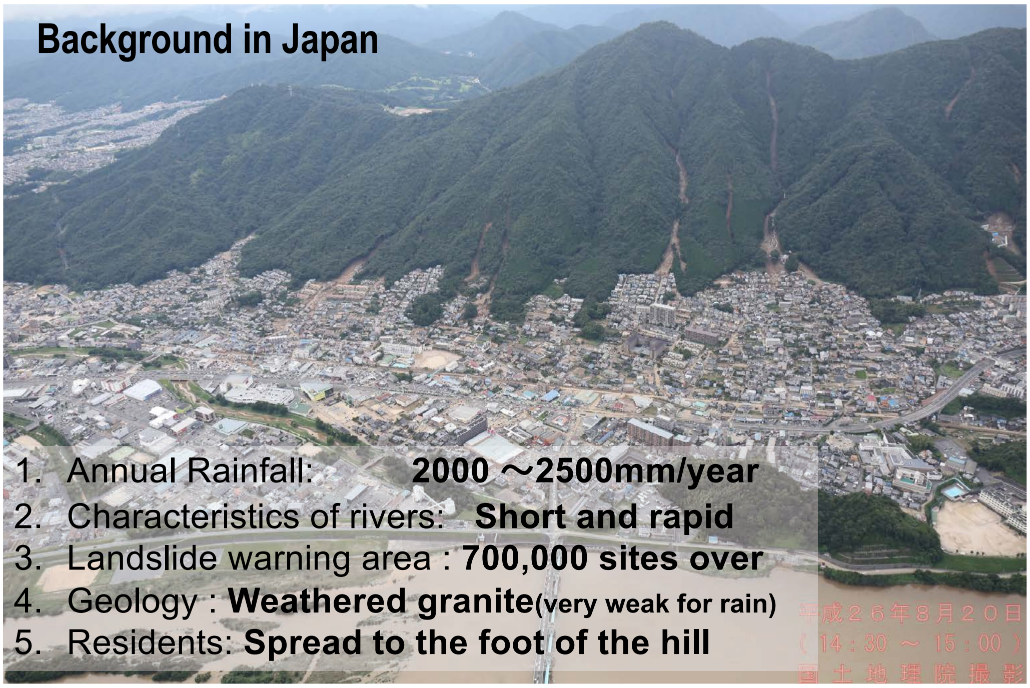
To improve the resilience of local communities, it is crucial to have a flow of visualization of the current situation → decision-making → action. To seamlessly connect these steps, visualization enabled by IoT, AI, and Big Data technologies is necessary, and initiatives should be led by the private sector to foster inter-field collaboration.

The initiatives mentioned above highlight the importance of a trans-disciplinary approach (TDA), with a particular emphasis on decision-making based on information underpinned by scientific evidence. If we can establish and standardize these concepts, it will be possible to expand Japan's ICT-based disaster prevention technologies to the world.

Challenges in disaster response using slope monitoring with ICT

Dr. Naoki SAKAI **(sakai@bosai.go.jp)**
Deputy director, Storm flood and landslide division,
National Research Institute for Earth Science and Disaster Resilience (NIED)

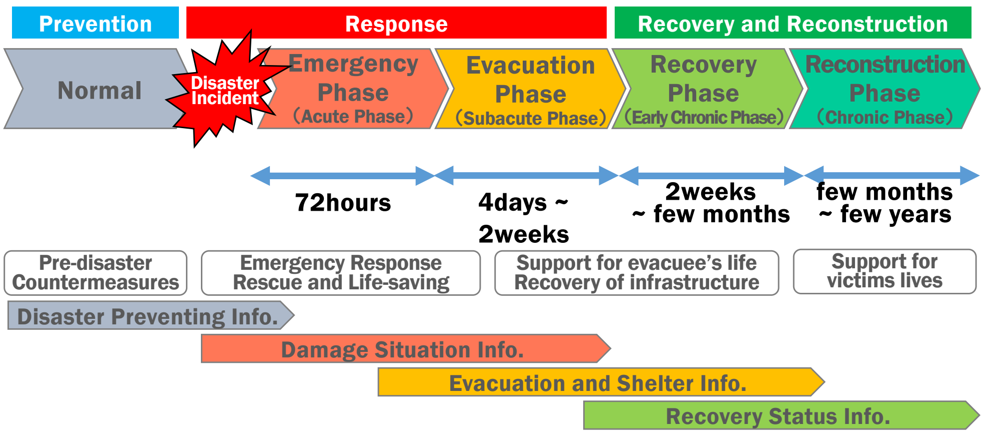
Background in Japan

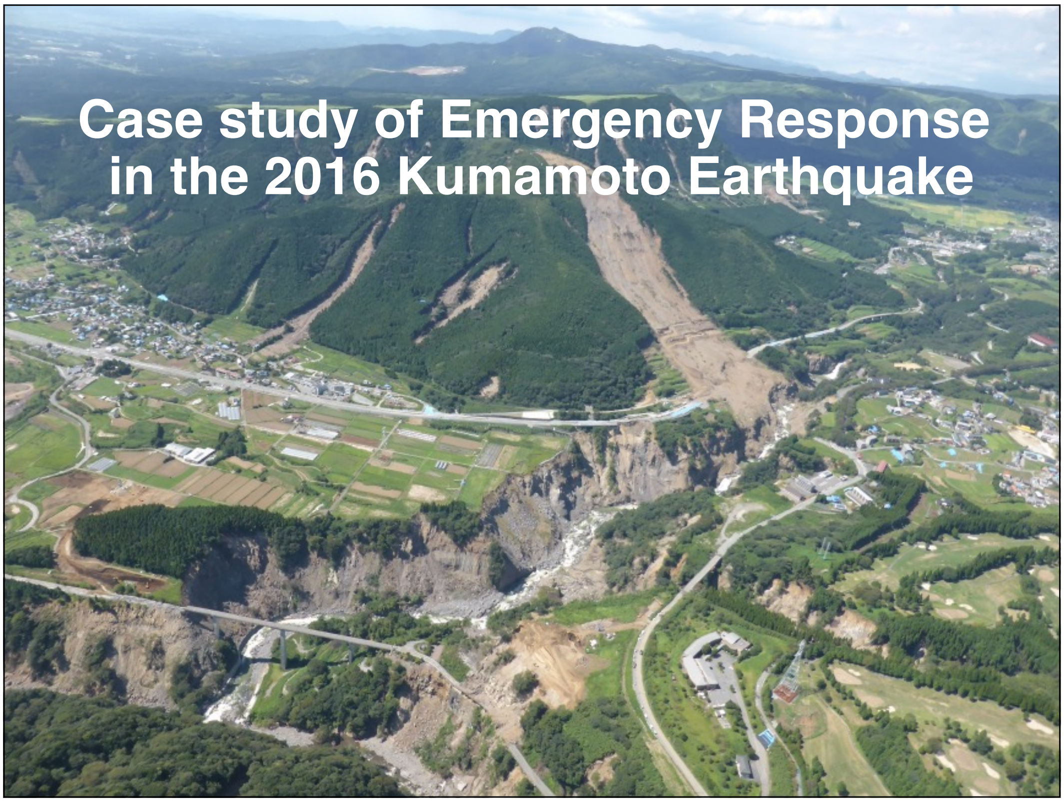


1. Annual Rainfall: **2000 ～2500mm/year**
2. Characteristics of rivers: **Short and rapid**
3. Landslide warning area : **700,000 sites over**
4. Geology : **Weathered granite(very weak for rain)**
5. Residents: **Spread to the foot of the hill**

Disaster Response and Information

- Disaster response activities need appropriate information.
  - Disaster Preventing Information: Hazard maps, Evacuation maps, etc.
  - Damage Situation Information: Collapsed buildings, Casualties, Damaged infrastructures, etc.
  - Evacuation and Shelter Information: Location of shelters, Evacuees, Logistics, Water supply, etc.
  - Recovery Status Information: Recovery of lifelines, food supplies, roads, telecommunications, etc.





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If rains, Residents are safe or not?

西原村、集団移転提案へ

熊本地震 活断層付近の7地区

熊本地震の本震で震度7に襲われた熊本県西原村が、被害の大きい7地区に集団移転を提案する方針を固めた。付近に活断層が通っていることなどから、将来的に住むのが難しいと判断したためで、6月1日に住民説明会を開く。その後、地区ごとの住民の意向を確認し、同意が得られれば移転候補地の選定に入る。

熊本地震で、集団移転について検討しているのが明らかになったのは初めて。

村によると、対象は大切畑や古閑、布田、風当などの計約150世帯。大部分が山の斜面やふもとに家屋が立っていて、全壊か大規模半壊した家が多く、高齢化も進んでいる。各地区は活断層付近にあり、再び地震が起きればさらに家屋が倒壊する危険性がある。複数の地区に山すそがかかる大峯（標高409㍍）の山肌の一部に亀裂が入り、村は将来的に住むには危険と判断した。

村は国の補助が得られる「防災集団移転促進事業」の仕組みを使う考えで、住民

……と話した。（北崎礼子、吉田啓）

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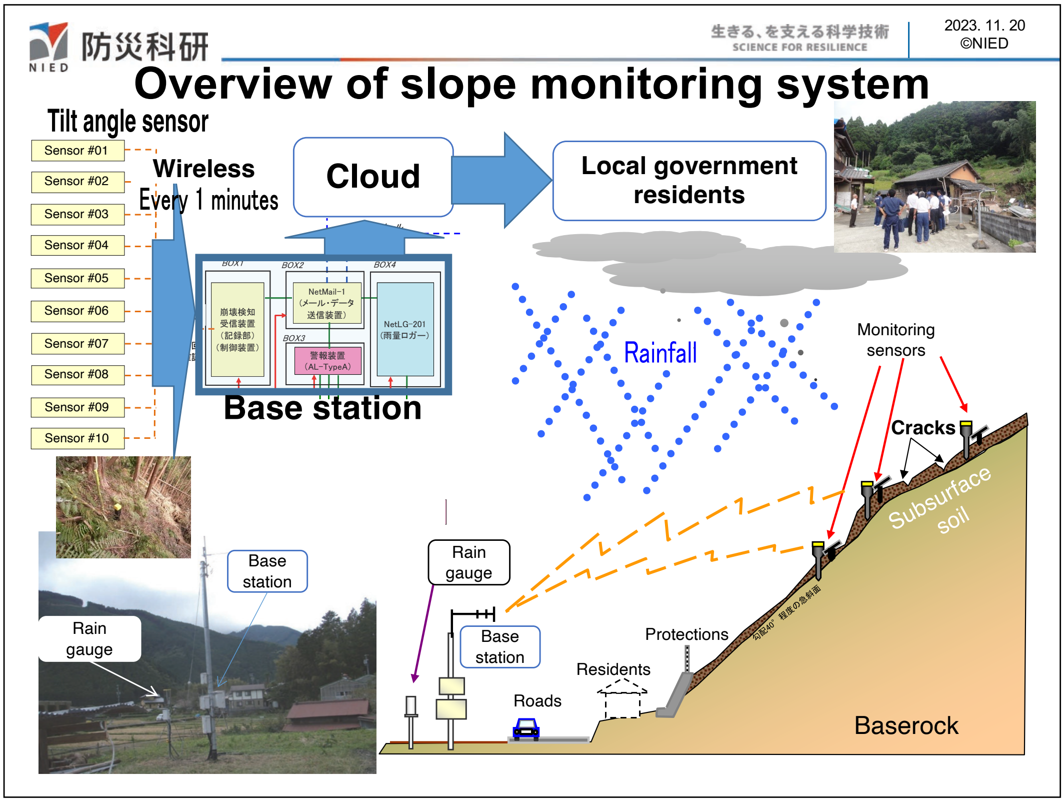
How to monitor the slope near resident area

7



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Overview of slope monitoring system
Tilt angle sensor
Sensor #01
Sensor #02
Sensor #03
Sensor #04
Sensor #05
Sensor #06
Sensor #07
Sensor #08
Sensor #09
Sensor #10
Wireless
Every 1 minutes
Cloud
Local government
residents
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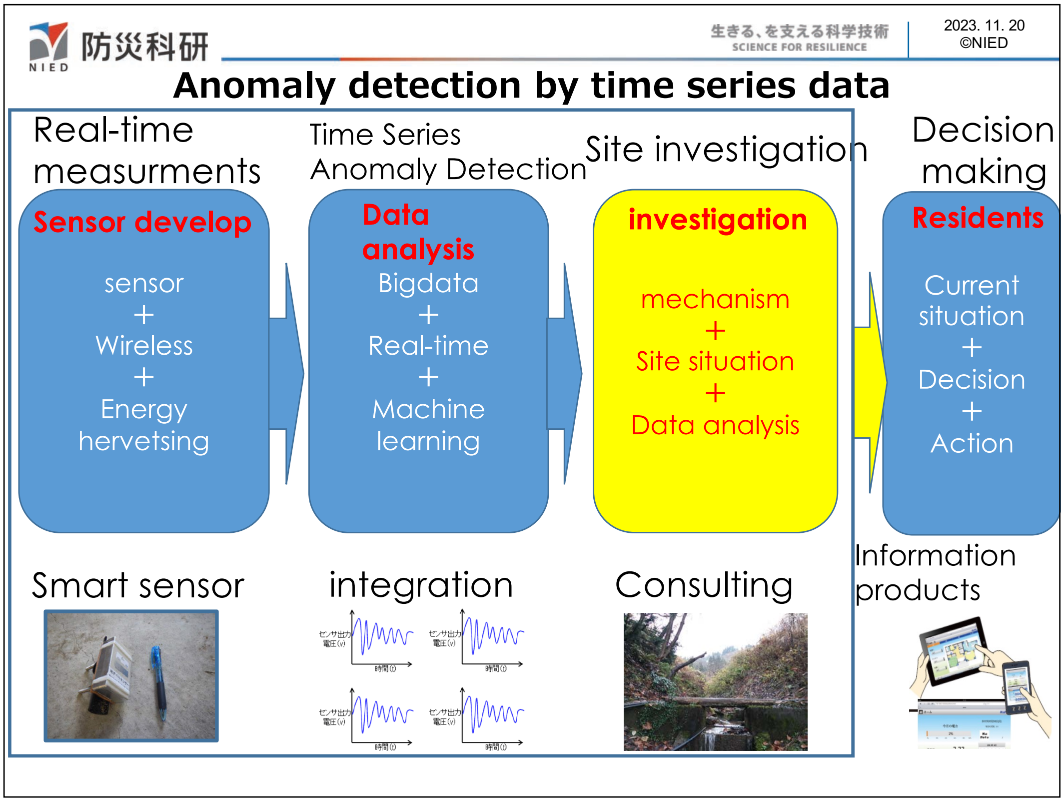
Protections
Residents
Roads
Baserock



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Anomaly detection by time series data
Real-time
measurments
Time Series
Anomaly Detection
Site investigation
Decision
making
Sensor develop
sensor
+
Wireless
+
Energy
hervetsing
Data
analysis
Bigdata
+
Real-time
+
Machine
learning
investigation
mechanism
+
Site situation
+
Data analysis
Residents
Current
situation
+
Decision
+
Action
Smart sensor
integration
Consulting
Information
products

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Monitoring slopes with IoT sensor system

IoT sensor:
MeMS type accelerometer

For residents during raifall:
Slope monitoring delivered information that the slope is not active now.

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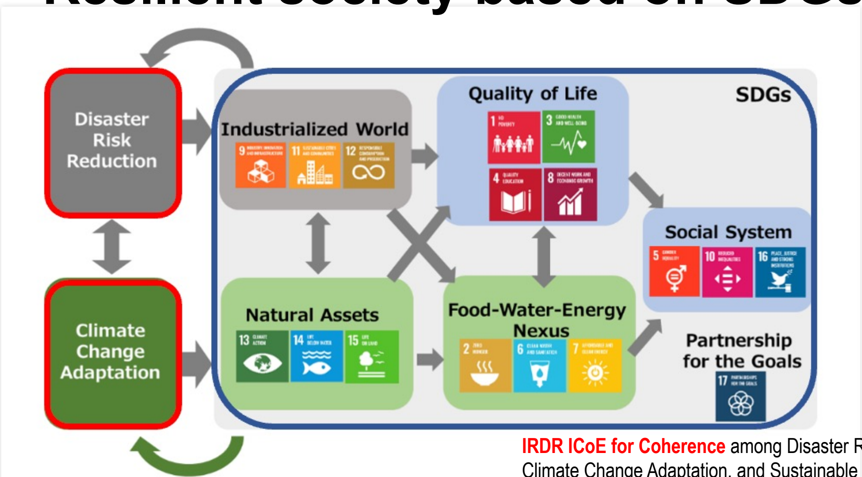
Resilient society based on SDGs



IRDR ICoE for Coherence among Disaster Risk Reduction, Climate Change Adaptation, and Sustainable Development.
International activities require the "integration of knowledge" in related fields.
https://www.bosai.go.jp/jhop/icoe.html
https://www.irdrinternational.org/

- Quality of life
- Climate Change adaptation
- Disaster Risk Reduction
- ICT and DX(Digital Transformation)

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Challenges for local monitoring using ICT

- In 2018, this area is huge damaged with many debris flows along the valley.
- Installing equipment based on the requirements of the residents with IoT/AI.
- providing real-time landslide risk information with a hydorological simulation.
- Using 3D-point cloud data to keep the safe infrastructures.

Landslide don’t occur often, Aim to realize the build back better with a quality of life. 12

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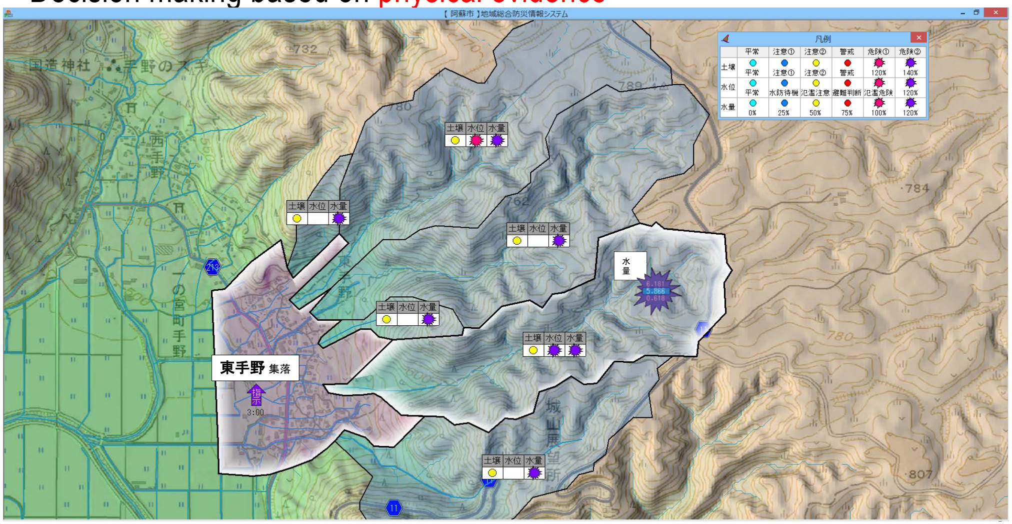
Community-based landslide risk assement system

- Monitoring of slope condition in local community by IoT sensor and AI
- Warning sign by hydrological simulation of small river basin
- Decision making based on physical evidence



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Guidelines for the implementation of a community-based landslide early warning system (ISO22328 Security and resilience — Emergency management)

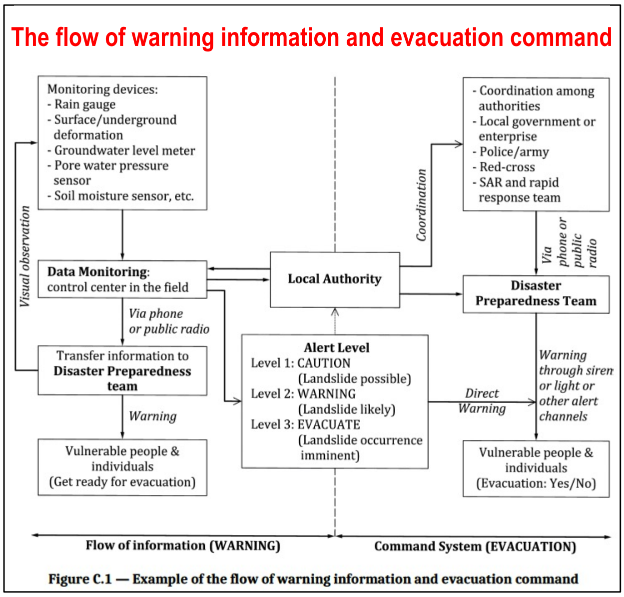
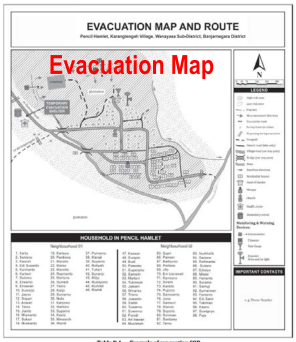
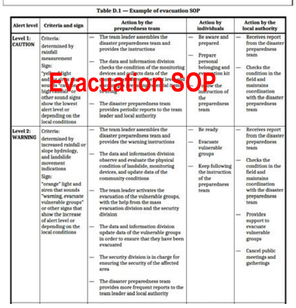


Figure C.1 — Example of the flow of warning information and evacuation command





https://www.iso.org/obp/ui/en/#iso:std:iso:22328:-2:dis:ed-1:v1:en

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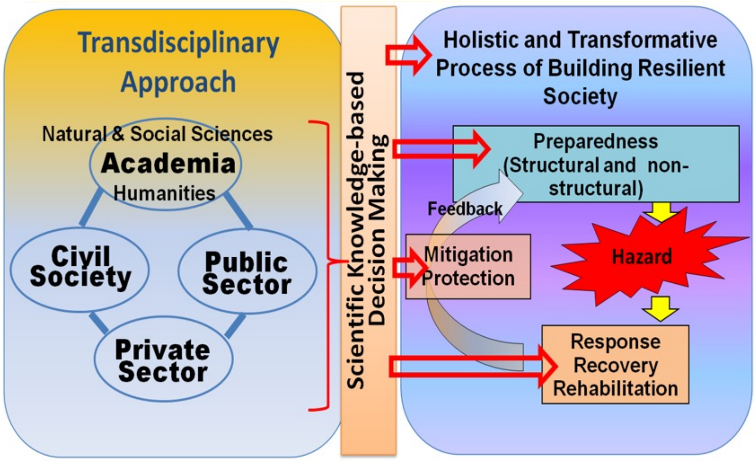
Resilient strategy by TDA



Co-Design, Co-Produce, Co-Deliver, Co-Implement

From Japanese Society of Civil Engineering

Fig.1. Transdiciplinary approach (TDA) to aid in active use of scientific knowledge for decision making

Industry-Academia-Government Collaboration

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Think globally, Act locally!

Deputy Director,
Storm, Flood and Landslide Research Division
Deputy Director-General,
Center for Advanced Research Facility
(Large-scale rainfall simulator)

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- **Universiti Tenaga Nasional(UNITEN)**, Institute of Energy Infrastructure, Ajunct Professor
- http://www.facebook.com/nsakai0505
- http://jp.linkedin.com/pub/naoki-sakai/55/8b8/43/

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SCIENCE FOR RESILIENCE

Earthquakes, tsunami, volcanoes, violent winds, heavy rains,
snowstorms, floods, and landslides are
natural threats that will always exist.
However, at NIED, we believe that disasters can be reduced.
Therefore, we are constantly developing technologies and strategies
to prepare for and respond to disasters.
With better prediction, smarter prevention, and faster restoration,
we aim to protect lives and livelihoods for a sustainable future.

防災科研 NIED

Full-scale field experiment of debris flow and its generation mechanism

Aki Tokuhisa
K's Lab. Inc., Japan

1. Introduction

In the heavy rainfall in the district of Chugoku, north Kyushu, Japan on 21 July, 2009, a lot of debris flows occurred around the boundary between Yamaguchi City and Hofu City. These debris flows appeared on a rocky mountain where bedrock was exposed. The bedrock is weathered, the scree is thinly distributed on the ridgeline, and the soil and its granularity are not consistent, which clearly led to marked irregularities in water permeability. In this paper, for the purpose of clarifying the Rainfall infiltration and failure mechanism of source head in Masado slope, we performed FEM analysis that reproduced these characteristics. In addition, a full-size experimental model slope was created, and a rainfall experiment was conducted under the conditions where a bare ground surface slope and the non-woven filter were laid.

2. Full-scale field experiment

Our observations of the slope during the experiment were as follows.

a) Gully erosion

Immediately after rainfall hit the exposed slope, water flowing on the surface eroded a shallow gully in the lower part of the slope.

b) Boiling collapse

As the rainfall continued, the interstitial water pressure in the bedrock increased. When this exceeded the weight of the clumps higher up, we saw the deep trench collapse. We refer to this as a boiling collapse. The boiling collapse was especially notable on the lower part of the slope.

c) Slope failure conditions

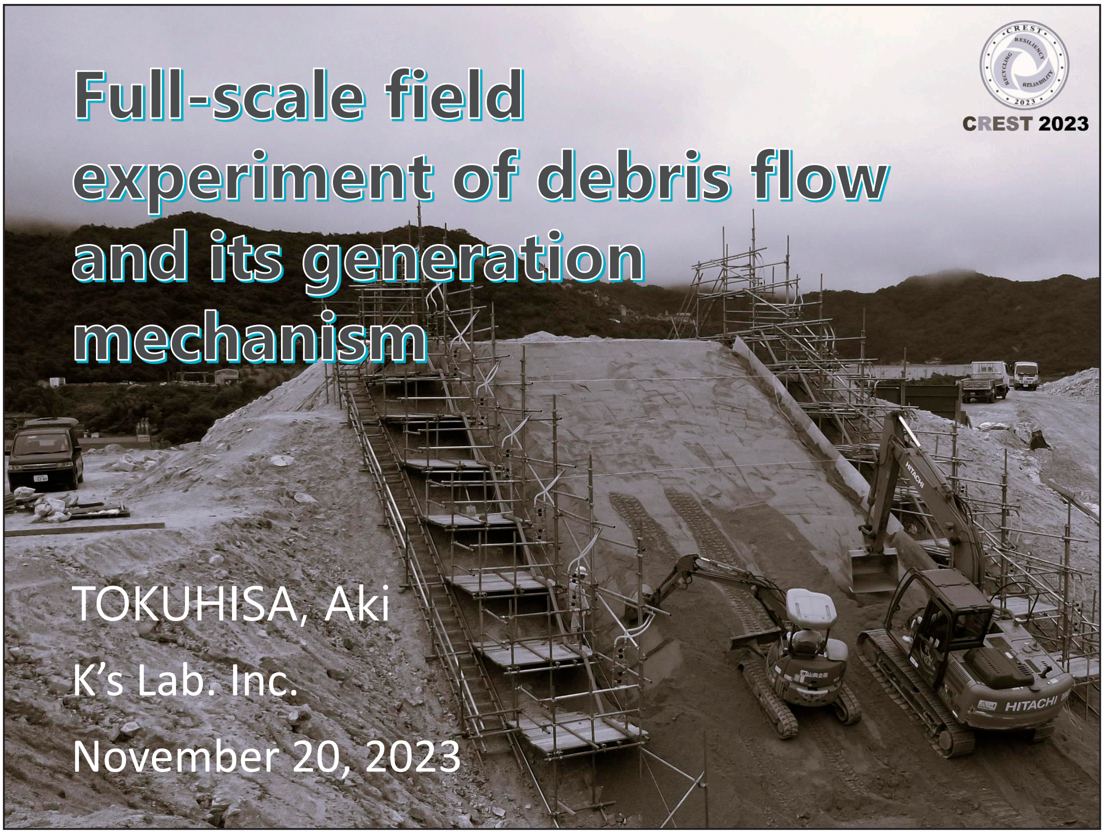
As time passed, the downstream part eroded and the overall slope balance broke down. In some cases, the collapse was such that clumps travelled downstream roughly 10 m. We believe that debris flow occurs when this collapsed soil swells to the point that it flows on the surface water draining downstream.

3. Seepage Flow Analysis by FEM

Where the high-permeability layer was distributed, seepage flow was an order of magnitude higher than in the other cases with high-permeability layers, regardless of whether topsoil was present, and we calculated the increase in pressure head over time. Further, the pressure-head value in the high-permeability zone increased steadily. When we calculated a safety factor F, we found the safety factor F at 11:30, the time of the second round of rainfall was less than 1.00. This analysis is in agreement with the time the debris flow occurred.

4. Conclusions

A comprehensive examination of the two results shows that the presence of a high permeable coarse grained layer between Masado layer and impermeable bed rock layer causes a sharp rise in pore water pressure at lower part of the slope due to the effect of underground penetration and groundwater funnel flow. The flow has become clear that the occurrence of boiling causes the collapse. Moreover, the expected effect of non-woven filter which control the seepage in heavy rain was confirmed.



Full-scale field experiment of debris flow and its generation mechanism

CREST 2023

TOKUHISA, Aki
K's Lab. Inc.

November 20, 2023

Introduction

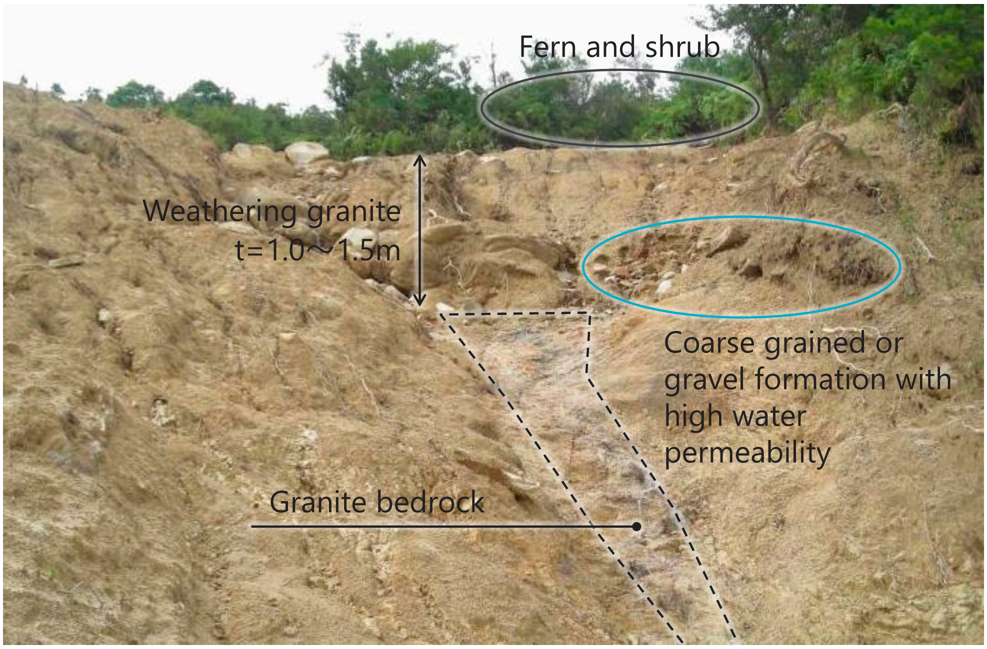
Torrential rain disaster in July 2009 in Chugoku and northern Kyushu.

2

Introduction

3

Characteristics of debris flow source head

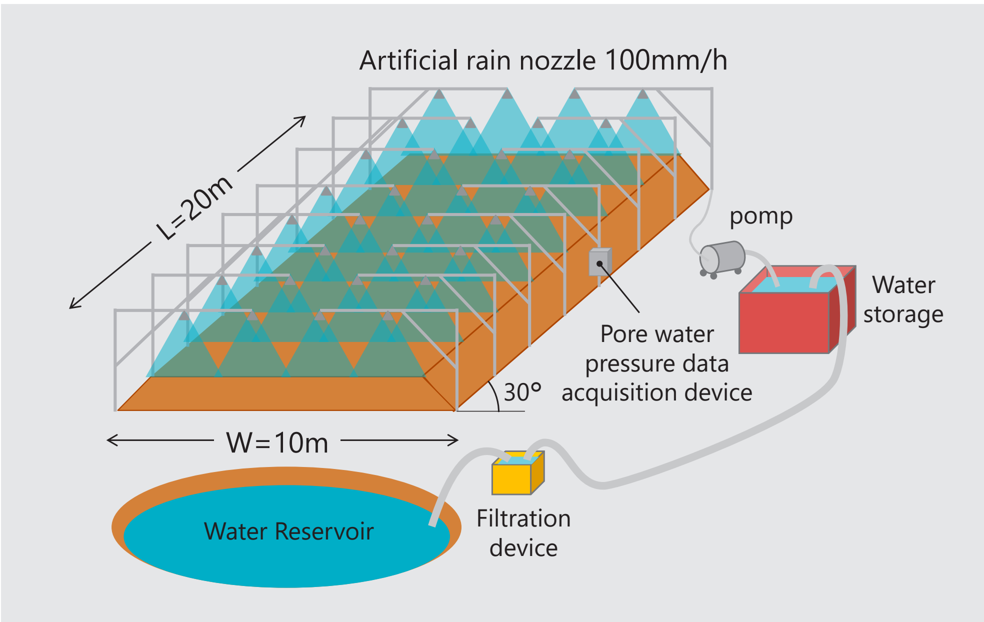


4

The Experiment Model Slope

5

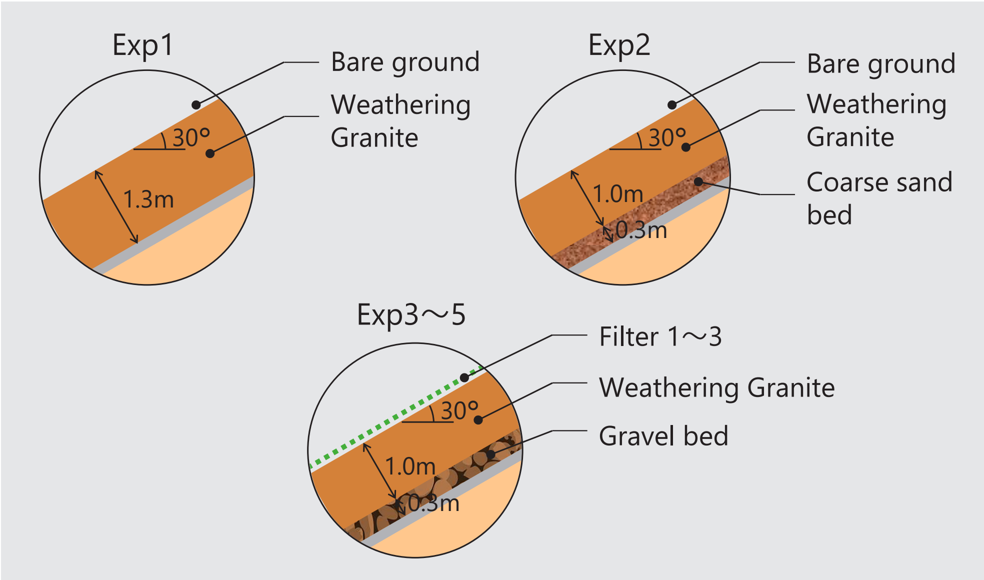
Build up the Experiment Model Slope



6

Condition (1/3)

Composition of experimental embankment



7

Condition (2/3)

Nonwoven filter：slope erosion prevent function

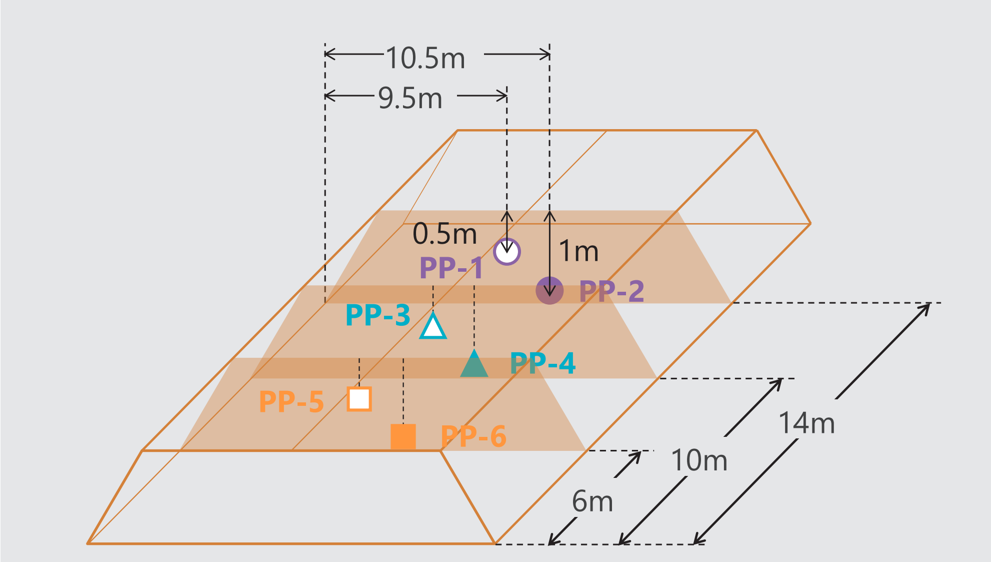
Can be planted by buried seeds and flying seeds

Exp No.	condition	thick (mm)
3	Filter 1	7
4	Filter 2	12
5	Filter 3	20

8

Condition (3/3)

Pore water pressure gauge：Exp 2～5



9

Experimental results | Exp1,2

Events observed in the slope during the experiment

On the bare ground slope, shortly after the beginning of rainfall, shallow grooved **gully erosion** occurred in the lower slope due to surface water.

Exp2
Rainfall 10min.

10

Experimental results | Exp1,2

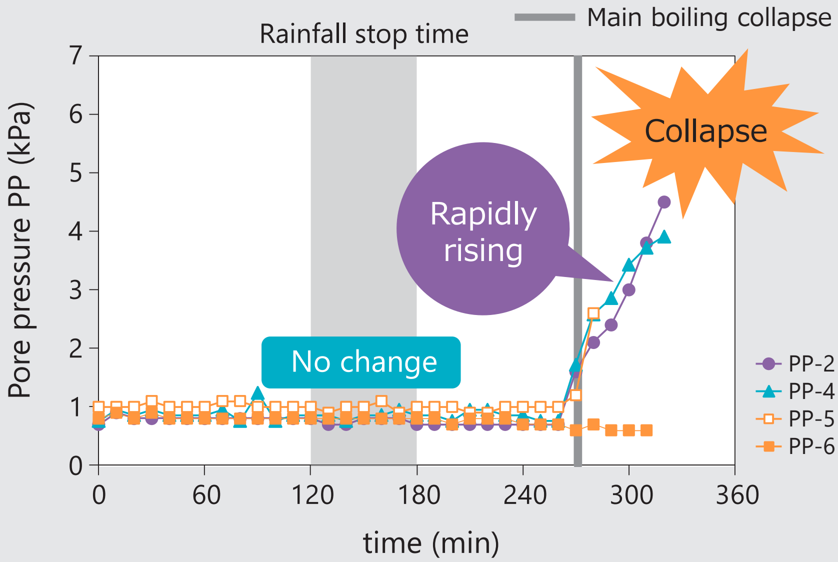
A deep, 20-30 cm wide grooved collapse (**boiling collapse**) occurred when the rainfall continued, the pore water pressure in the ground increased and the upper soil cloth weight was exceeded.

Exp2
Rainfall 271min.

11

Experimental results | Exp1,2

Exp2 Bare ground



12

Experimental results | Exp1,2

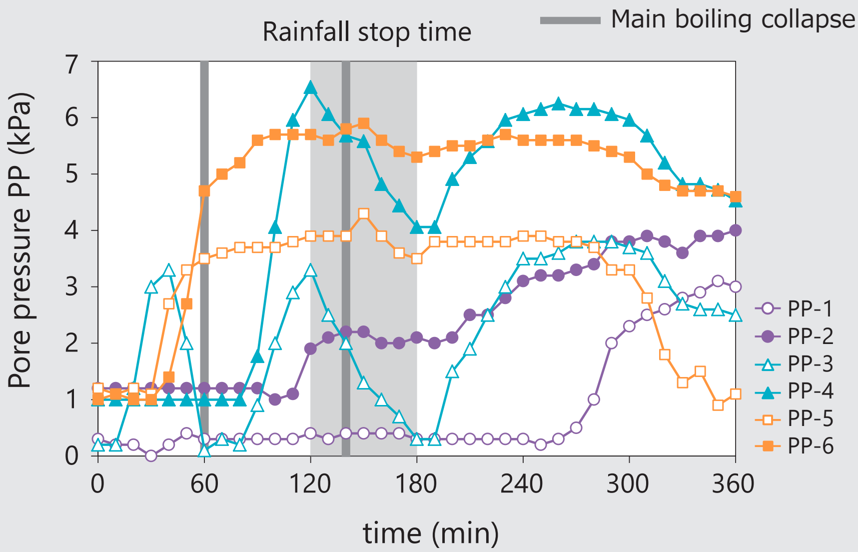
13

Experimental results | Exp1,2

14

Experimental results | Exp3-5

Exp4 Filter2



15

Experimental results

The penetration of rainfall due to difference in constituent layers

2 hours from the start of rainfall

Exp1

Exp2

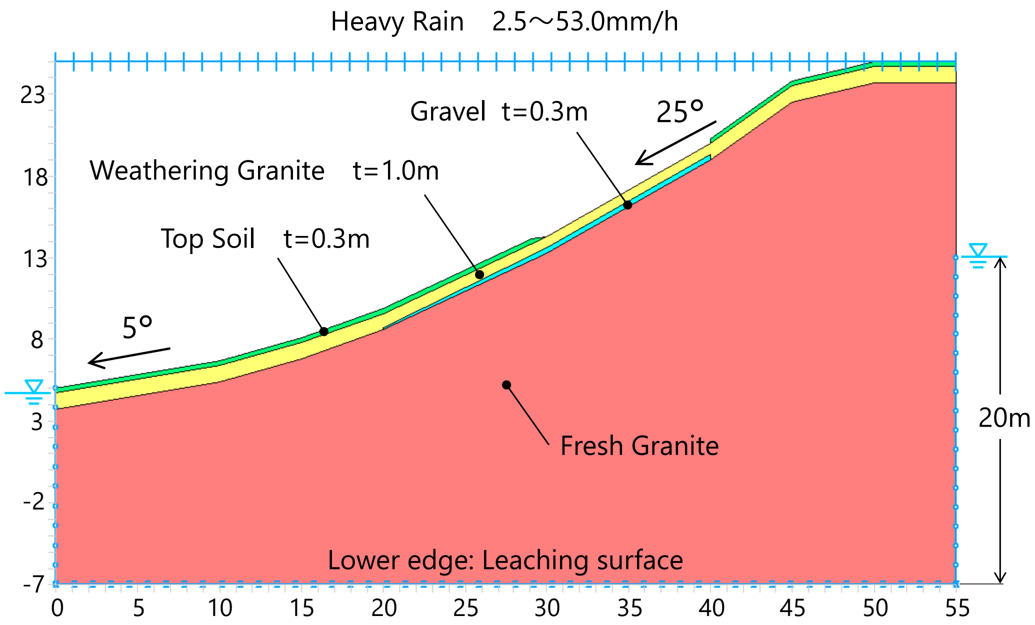
Exp3

Exp4

Exp5

16

Analysis Methods, Models, and Cases

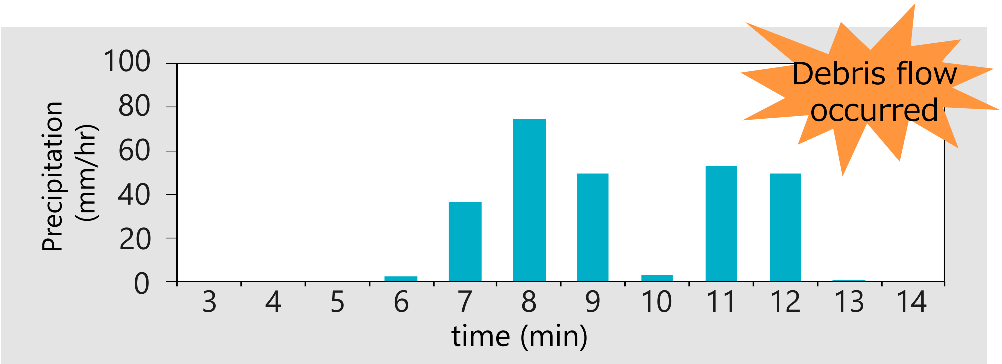


17

Boundary condition

Rainfall waveforms on July 21, 2009 in "AMeDAS (Yamaguchi)".

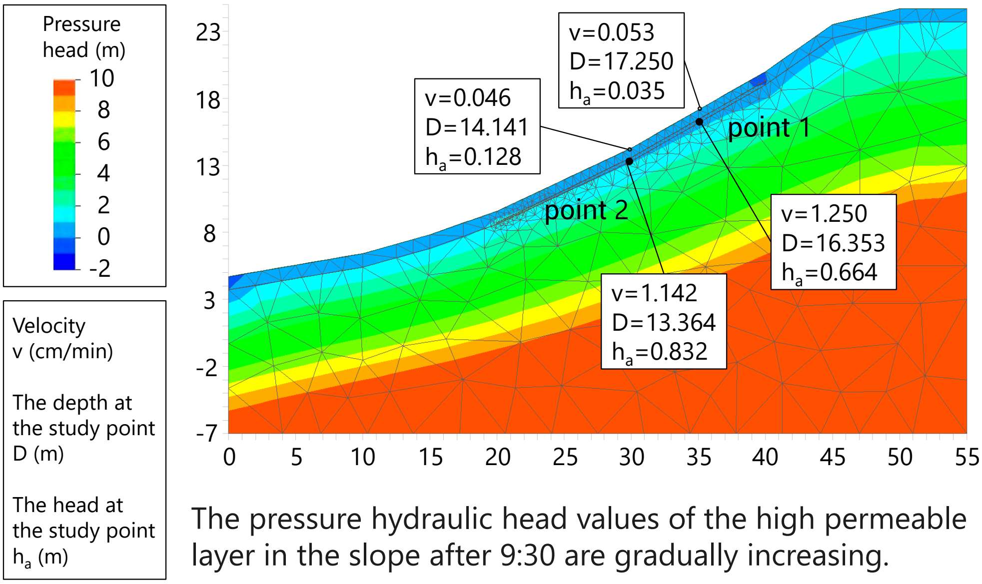
Time	6	7	8	9	10	11	12
Precipitation (mm/hr)	2.5	36.5	74.5	49.5	3.0	53.0	49.5



18

Analysis Results

No top soil with high permeability layer and soil thickness d = 1.0m



The pressure hydraulic head values of the high permeable layer in the slope after 9:30 are gradually increasing.

19

Analysis Results

The safety factor F against boiling at points 1 and 2 was calculated from the following equation.

$$F = \frac{\dfrac{G_s - 1}{1 + e}}{\dfrac{h_a}{D}}$$

G_s : the specific gravity of soil particle = 2.62

e : the void ratio = 0.8

h_a : the head at the study point (m)

D : the depth at the study point (m)

Cases where $F < 1$ No topsoil + high permeable layer

After the first heavy rain 9:30 $F = 1.007$

After the second heavy rain 11:30 $F =$ **0.994**

This coincides with the onset time of the debris flow .

I consider that the flow velocity did not cause seepage failure, but the increased pressure hydraulic head reduced stability.

20

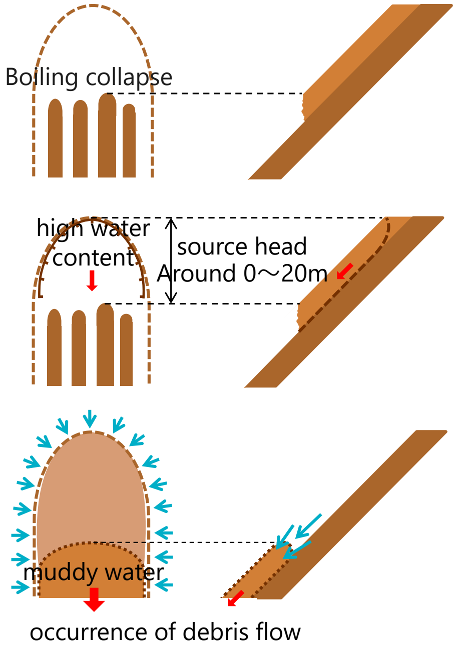
Summary

Collapse of debris flow source head

① Boiling collapse occurs in several locations on the lower part of the slope, causing soil mass to wash away.

② The upper slope is out of balance and collapse occurs around 0 to 20 m at the head of the source. The collapsed sediment entrains the surrounding surface water during flow, resulting in high water content.

③ In addition, surface water increase volume and velocity of the flow, resulting in a debris flow.



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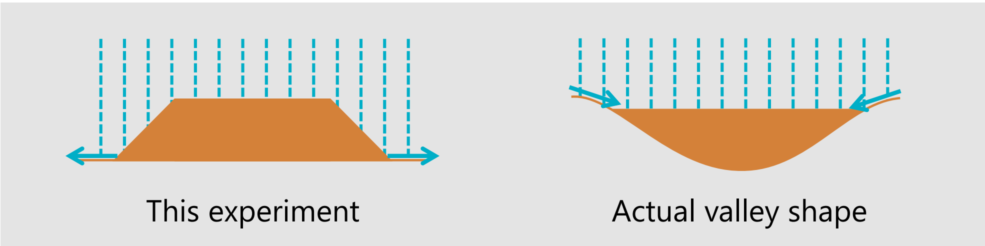
Summary

- The full-scale collapse experiment was conducted to observe the variation of pore water pressure due to the effect of rainfall alone on the slope. The peak time of pore water pressure is considered to be accelerated because the valley topography where debris flows occur is a concave profile and surface water from the surrounding area gets gathering.



- The effectiveness of the non-woven fabric filter in reducing infiltration during heavy rainfall was confirmed, and it is considered to be applicable as a preventive measure against debris flow.

22

Summary

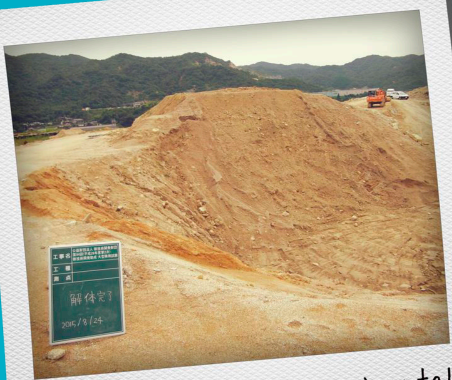
Because the non-woven fabric filter is lightweight and easy to handle, it can be installed at any location and at a lower cost than conventional techniques such as mechanical installation.

Effects of Construction on Sources of Debris Flow and Landslides

- Debris flow and landslides can be controlled.
- The scale of erosion control weirs, etc. can be reduced, and costs and construction period can be shortened.
- Construction prior to erosion control weir construction will prevent landslides during construction.

Enables low-cost debris flow countermeasures

23



Dismantling of the experimental apparatus is completed.

End

24

Application of three-phase elastoplastic finite deformation analysis to slope failure problem during rainfall

Takahiro Yoshikawa

Nagoya University, Japan

Numerous slope and embankment collapses have occurred due to heavy rainfall. Causes of the collapses are considered as reduction of strength due to saturation of unsaturated soil and rise in pore pressure and increase of self-weight due to water absorption. However, the detailed collapse mechanism has not been elucidated. To elucidate the mechanism, soil-water-air coupled elastoplastic finite deformation analysis considering inertia force were conducted. First, numerical simulations on deformation and failure of unsaturated slopes in rainfall model tests were performed. As a result, it succeeded in reproducing the deformation-to-failure behavior of the model slope due to rainfall infiltration. The soil element on the slip surface exhibited "softening behavior with plastic volume expansion" above the critical state line in $p' - q$ skeleton stress space. Next, numerical simulations on Atami embankment collapse on July 3, 2021, were performed. The results showed that a large amount of groundwater flowing into the bottom of the embankment may have caused softening behavior with plastic volume expansion in the soil in that area, leading to the failure of the whole embankment.

References

[1] Akira Asaoka, Toshihiro Noda, Eiji Yamada, Kazuhiro Kaneda and Masaki Nakano, An elasto-plastic description of two distinct volume change mechanisms of soils, Soils Found. 42(5)(2002) 47-57. doi: 10.3208/sandf.42.5_47

[2] Anusron Chueasamat, Toshikazu Hori, Hirotaka Saito, Tomotaka Sato, Yuji Kohgo, Experimental tests of slope failure due to rainfalls using 1g physical slope models, Soils Found. 58(2)(2018) 290-305. doi: 10.1016/j.sandf.2018.02.003

[3] Toshihiro Noda and Takahiro Yoshikawa, Soil-water-air coupled finite deformation analysis based on a rate-type equation of motion incorporating the SYS Cam-clay model, Soils Found. 55(1)(2015) 45-62. doi: 10.1016/j.sandf.2014.12.004

[4] Takahiro Yoshikawa and Toshihiro Noda, Triaxial test on water absorption compression of unsaturated soil and its soil-water-air-coupled elastoplastic finite deformation analysis, Soils Found. 60(5)(2020) 1151-1170. doi: 10.1016/j.sandf.2020.06.010

Application of three-phase elastoplastic finite deformation analysis to slope failure problem during rainfall

Nagoya University Takahiro Yoshikawa

Background

1

Collapse of a road embankment in the 2018 Japan floods
(from Tsuchida and Hashimoto)

2021 Atami embankment collapse
(from Shizuoka Prefecture)

Causes of collapse are considered as

- saturation of unsaturated soil
- reduction of strength due to rise in pore pressure
- increase of self-weight due to water absorption

However, the detailed collapse mechanism has not been fully elucidated.

Background

Prediction of the collapse of slopes / embankments due to rain

A combination of seepage flow analysis and stability analysis is used:
using the stress state obtained from a seepage flow analysis, a stability analysis that determines whether the safety factor exceeds 1 or not, is performed.

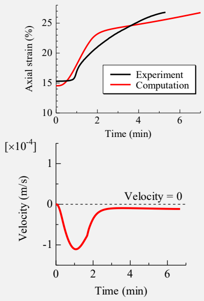
However, it is necessary

- to analyze slopes / embankments
  from deformation to failure caused by seepage
- to use a finite deformation analysis considering geometric nonlinearity
  in order to simulate large deformation behavior from deformation to failure
- to consider inertial forces since failure is accompanied
  by accelerated motion even if the external force is rainfall

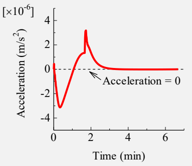
Purpose

Three-phase elastoplastic finite deformation analysis considering inertia force is used to elucidate the collapse mechanism due to rainfall.

Water absorption failure of triaxial specimen

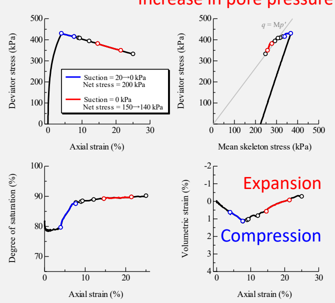


Reproduction of failure behavior accompanied by acceleration



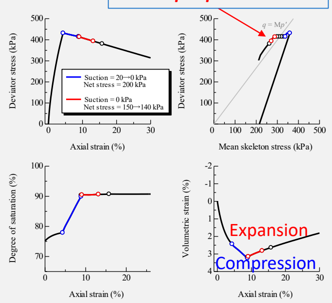
Experiment

— Reduction of suction
— Increase in pore pressure



Analysis

Softening behavior with plastic volume expansion above *q=Mp'*



Application of this analysis method to simulation of a rainfall model test and a real problem

Outline of analysis method

$\boldsymbol{u}$-p^{w}-p^{a} formulation

◆ Eq. of motion

$$\rho \ddot{\boldsymbol{x}}_{\mathrm{s}} = \mathrm{div}\,\boldsymbol{T} + \rho \boldsymbol{b} \quad \Rightarrow \quad \left(\rho \ddot{\boldsymbol{v}}_{\mathrm{s}} + \left[(\rho^{\mathrm{w}} s^{\mathrm{w}} + \rho^{\mathrm{a}} s^{\mathrm{a}})(\mathrm{tr}\,\boldsymbol{D}_{\mathrm{s}}) + \frac{n s^{\mathrm{w}} \rho^{\mathrm{w}}}{\mathrm{K_w}} \dot{p}^{\mathrm{w}} + \frac{n s^{\mathrm{a}}}{\bar{\mathrm{R}}\Theta} \dot{p}^{\mathrm{a}} + n(\rho^{\mathrm{w}} - \rho^{\mathrm{a}}) \dot{s}^{\mathrm{w}} \right] (\dot{\boldsymbol{v}}_{\mathrm{s}} - \boldsymbol{b}) = \mathrm{div}\,\dot{\boldsymbol{S}}_t \right)$$

Rate-type (including jerk term)

Material time derivative viewed from the soil skeleton

Finite deformation analysis based on Updated Lagrangian

◆ Soil skeleton-water coupled eq.

◆ Soil skeleton-air coupled eq.

Numerical analysis method

Spatial discretization of the soil skeleton	Finite element method
Spatial discretization of the pore fluid	Finite volume method (from Christian and Tamura)
Temporal discretization	Linear jerk method (following Wilison's θ method) and trapezium rule

Outline of analysis method

◆ Skeleton stress eq.

$$-\boldsymbol{T}' = -\boldsymbol{T} - (s^{\mathrm{w}} p^{\mathrm{w}} + s^{\mathrm{a}} p^{\mathrm{a}})\boldsymbol{I} = -\boldsymbol{T} - p^{\mathrm{a}}\boldsymbol{I} + s^{\mathrm{w}}(p^{\mathrm{a}} - p^{\mathrm{w}})\boldsymbol{I}$$

◆ Constitutive eq.

Elastoplastic constitutive eq. SYS Cam-clay model considering unsaturated effect

Referring to Kyokawa et al. (2009) and Zhang & Ikariya (2011), larger intercept of NCL and CSL, lower the degree of saturation.

◆ State eq. of pore air

State eq. of an ideal gas

◆ Unsaturated hydraulic property

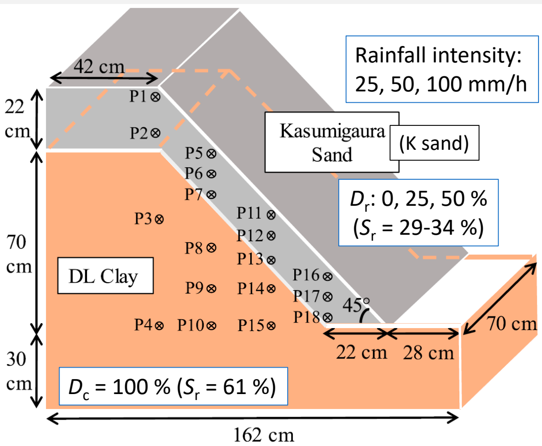
$$S_{\mathrm{e}} = \{1 + (\alpha p^{s})^{n}\}^{-m} \qquad k^{\mathrm{w}} = k_{\mathrm{s}}^{\mathrm{w}} \cdot S_{\mathrm{e}}^{\frac{1}{2}} \left\{ 1 - \left(1 - S_{\mathrm{e}}^{\frac{1}{\mathrm{m}}} \right)^{\mathrm{m}} \right\}^{2}, \quad k^{\mathrm{a}} = k_{\mathrm{d}}^{\mathrm{a}} \cdot (1 - S_{\mathrm{e}})^{\frac{1}{2}} \left(1 - S_{\mathrm{e}}^{\frac{1}{\mathrm{m}}} \right)^{2\mathrm{m}}$$

van Genuchten – Mualem model

Application to simulation of a rainfall model test

Overview of model tests and analysis conditions

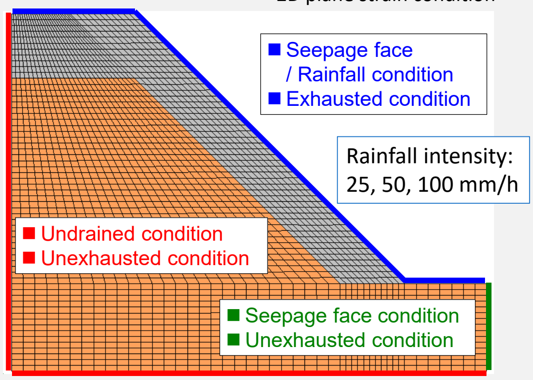
1g model tests by Chueasamat et al. (2018)



⊗ : Water pressure measurement point

Analysis conditions

2D plane strain condition

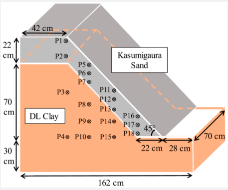


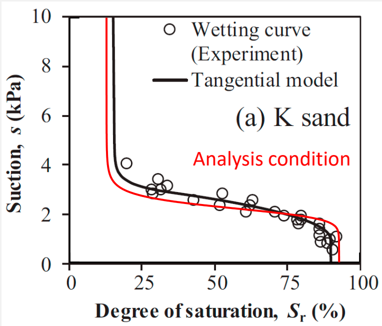
Parameters for SYS Cam-clay model

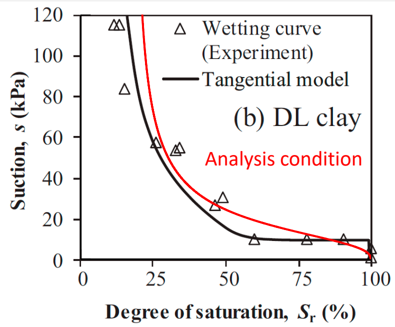
- DL clay: Values from Yoshikawa & Noda (2020)
- K sand: Values for DL clay when D_c = 80 %

Overview of model tests and analysis conditions

K sand (surface layer) | DL clay (foundation)







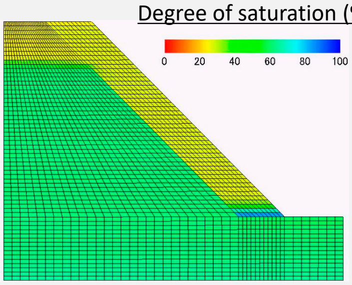
Saturated hydraulic conductivity	1.25×10^{-4} m/s	6.68×10^{-7} m/s

Deformation and failure simulations for three cases of rainfall intensities of 25, 50, and 100 mm/h

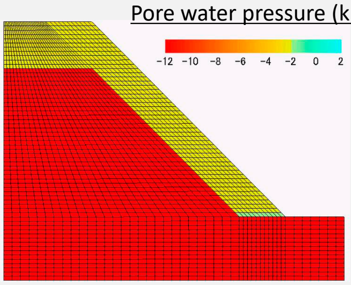
Analysis results (Rainfall intensity: 100 mm/hour)

Output at equal time intervals

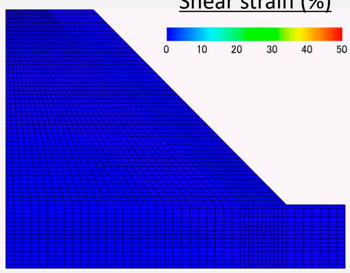
Degree of saturation (%)

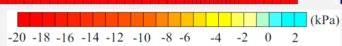


Pore water pressure (kPa)

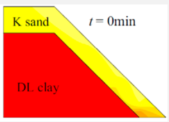


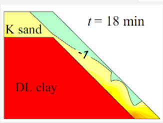
Shear strain (%)

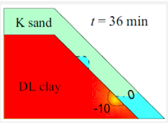




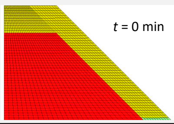
Experiment

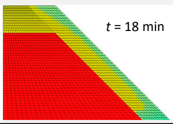


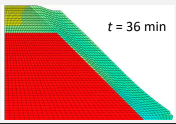




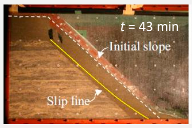
Analysis

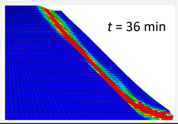






Reproduction of change in pore water pressure with time





Reproduction of slip failure behavior

Analysis results (Rainfall intensity: 100 mm/hour)

10

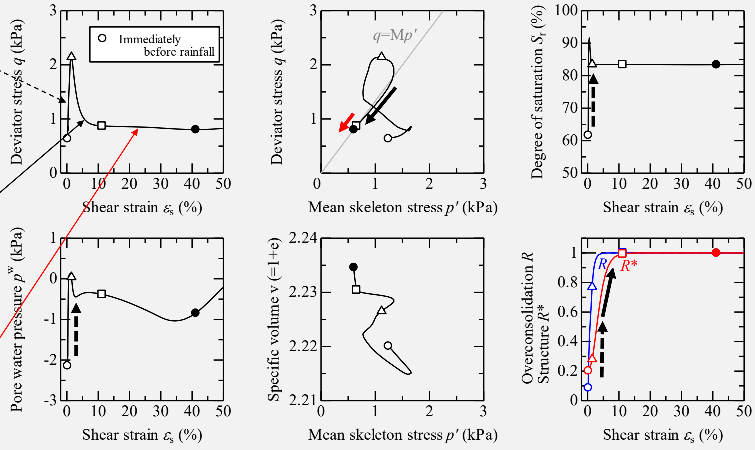
Mechanical behavior of the soil element at toe located on the slip line

Softening behavior with plastic volume expansion above critical state line *q*=M*p'*

○→△ The rise in the degree of saturation and pore pressure caused plastic deformation and it caused the loss of overconsolidation and structure (increase in R and R*).

△→□ Overconsolidation and structure were lost further, and softening behavior with plastic volume compression due to the loss of structure occurred.

□→● Softening behavior with plastic volume expansion above the critical state line *q*=M*p'*, which is a characteristic of Cam-clay model, occurred, leading to a large deformation.



Analysis results (difference among 3 rain intensities)

11

Rainfall intensity: 25 mm/h, 50 mm/h, 100 mm/h

Experiment

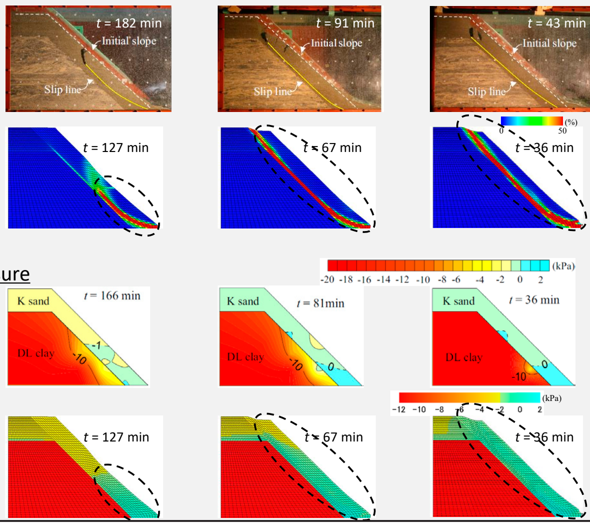
Analysis

Shear strain

Pore water pressure

Experiment

Analysis



The tendency for the slip area to increase with rainfall intensity has been reproduced.

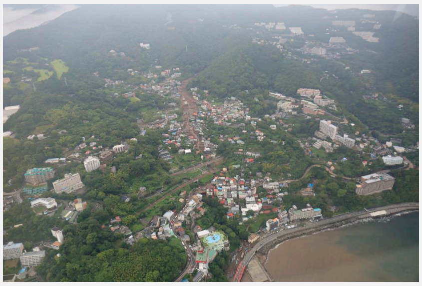
The higher the rainfall intensity, the higher the pore water pressure to the top of the slope.

Application to a real problem (Atami embankment collapse)

Overview of Atami landslide

Location: Aizome River basin, Izuyama District, Atami City, Shizuoka Prefecture
Date: July 3, 2021, around 10:30 a.m.

Embankment collapse at the head of Aizome River
Shizuoka Prefecture UAV photograph (July 3, 2021)

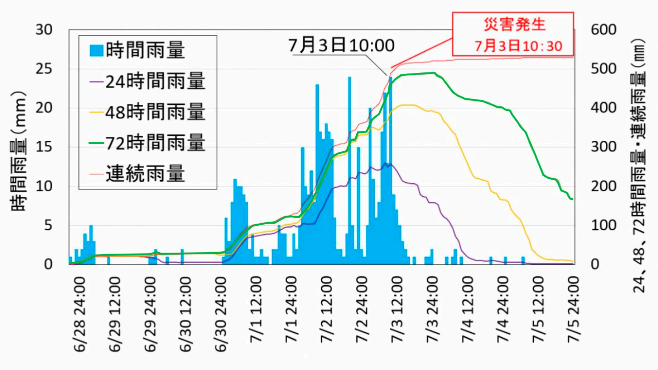


Situation in Izuyama District, Atami City
GSI aerial photograph (July 5, 2021)

Overview of Atami landslide

14

Rainfall conditions



Rainfall conditions up to the landslide
(Atami Rainfall Observatory, Shizuoka Pref.)

24-hour rainfall:
Largest since 2009

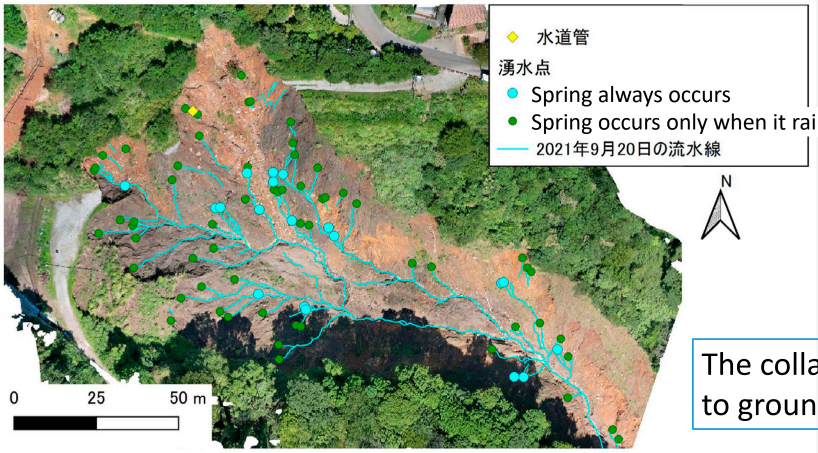
48-hour rainfall:
Largest in recorded history

72-hour rainfall:
Largest in recorded history

Overview of Atami landslide

15

Field survey of spring water points by drone

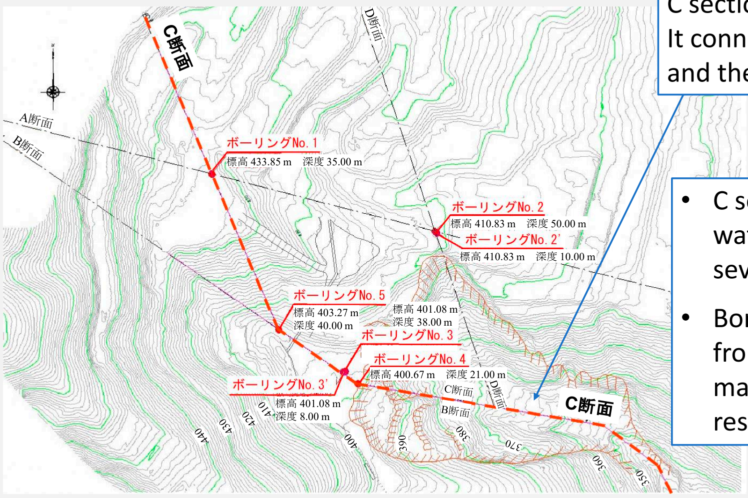


The collapse area is prone to groundwater inflow

Distribution of spring sites (using orthophoto taken on September 10, 2021)

Analytical Cross Section

◆ Plan view around the collapsed area



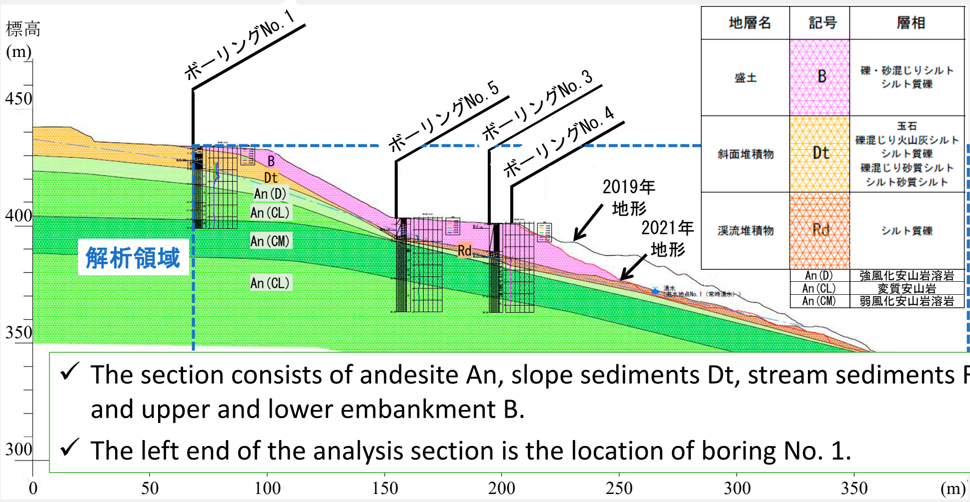
Assuming 2-D plane strain condition

C section was selected.
It connects boring Nos. 1, 5, 3, 4, and the Aizome River valley area.

- C section can easily collect water and become subject to severe external force conditions.
- Boring locations were selected from the same perspective, making it easier to use boring results.

Analytical Cross Section

◆ Geological map of C section



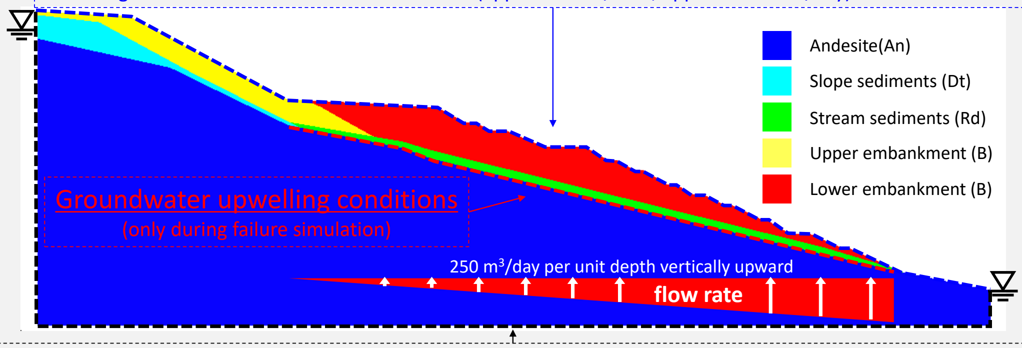
✓ The section consists of andesite An, slope sediments Dt, stream sediments Rd, and upper and lower embankment B.

✓ The left end of the analysis section is the location of boring No. 1.

Hydraulic boundary condition

Rainfall boundary condition

- From the time of embankment construction to subsequent steady state: 1,500 mm in 1 year (approx. 4 mm/day)
- During failure simulation: 459 mm in 58 hours (approx. 8 mm/hour, approx. 190 mm/day)



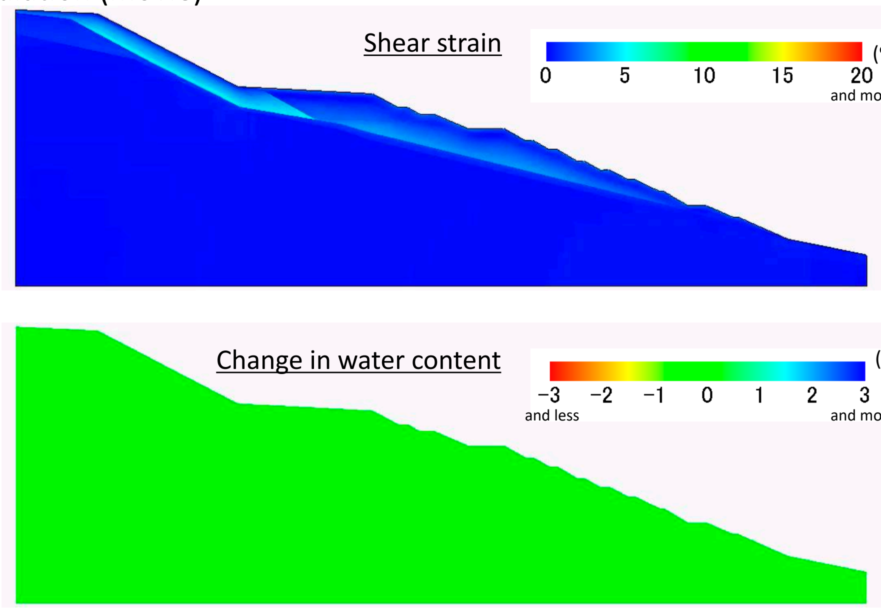
Constant head condition (head values distributed linearly corresponding to the water levels at left and right end)

In the July 1-3 failure simulation, conditions were set to supply a given flow rate from the bottom of the highly permeable stream sediments.

Soil parameters

- Mechanical properties (elasto-plastic constitutive equation SYS Cam-clay model)
  - Upper and lower embankment: set based on mechanical tests of soil taken from the site.
  - Other soil materials: set rigid conditions that are less prone to deformation
    In the failure simulation, the condition that soil other than embankment is not deformed is set.
- Hydraulic properties (hydraulic conductivity and soil water retention)
  - Determined based on in-situ permeability tests and soil water retention tests
  - For the lower embankment, two cases with different hydraulic properties were conducted to determine the difference in deformation behavior.

Failure simulation (movie)



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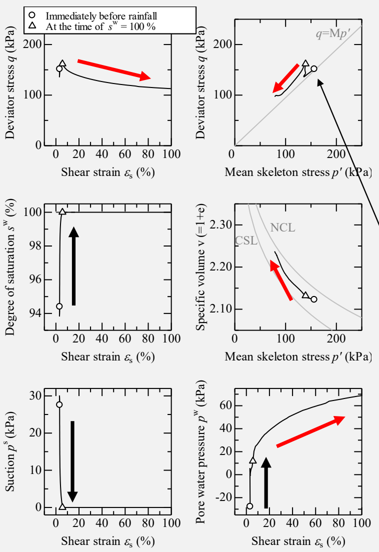
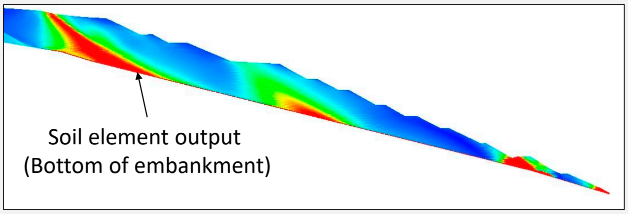
Failure simulation





High shear stress (stress ratio q/p')
during embankment construction process

Groundwater inflow increases pore water pressure, decreases suction, and increases the degree of saturation.

Once the degree of saturation reaches 100 %, further water absorption caused the increase in pore pressure and it causes a decrease in mean effective stress and shear stress:
Softening behavior with plastic volume expansion above q=Mp'

22

Summary of application to Atami embankment collapse

State subjected to large shear forces (high stress ratio) due to construction of high embankment

Groundwater inflow

Saturation and decrease in effective stress (increase in stress ratio) due to water pressure rise

Water absorption (plastic volume expansion) and shear stress reduction (softening)

Softening with plastic volume expansion shown above the critical state line, a characteristic of the Cam-clay model

In this analysis, water absorption softening occurs upward from near the toe of the embankment, where water easily collects, sliding occurs where the embankment could no longer resist the embankment load, eventually, the entire embankment collapsed.

Geotechnical approaches for preservation of openly exhibited Geo-relics damaged by rainfall infiltration

Mai Sawada
School of Environment and Society, Tokyo Institute of Technology, Japan

Excavated geo-relics are vulnerable to damage by natural processes. The aim of this study is to contribute to the establishment of a technical framework for the preservation of openly exhibited geo-relics. This study also examines the preservation of an openly exhibited geo-relic in Japan, which has experienced surface deformation in the soft soil layer due to water infiltration. The surface deformation is numerically investigated by performing seepage-deformation analyses based on unsaturated soil mechanics in order to understand its mechanism and to obtain effective countermeasures. The results show that deformation develops in the surface layer of the slope as the bonding between soil particles, represented by skeleton stress, and decreases when water infiltrates the slope. Although the calculation considers the influence of groundwater, as well as precipitation, the results show that the deformation of the slope is primarily controlled by precipitation, not by groundwater. Furthermore, the elevation of the groundwater does not contribute to the development of surface deformation. Based on the mechanism of the surface deformation, replacing the surface layer with a well-compacted, highly permeable soil is proposed to improve slope stability. It is predicted that this proposed method will be effective because the replaced zone retains sufficient strength and stiffness when it is wet, despite a decrease in the skeleton stress due to rainfall infiltration. This countermeasure has been adopted for the actual restoration of a damaged slope.

References

[1] Sawada, M. and Mimura, M. (2022). Geotechnical approaches for preservation of openly exhibited Geo-relics damaged by rainfall infiltration. Soils and Foundations, 62(1), 101097.

[2] Agency for Cultural Affairs, Nara National Research Institute for Cultural Properties, Archeological Institute of Kashihara Nara prefecture and Asuka Village Board of Education, 2017. Excavations report in the Takamatsuzuka tumulus, 139-148. (in Japanese)

WS-3 Towards the Thought Process of Slope Disaster Prevention in the Digital Era

Geotechnical approaches for preservation of openly exhibited Geo-relics damaged by rainfall infiltration

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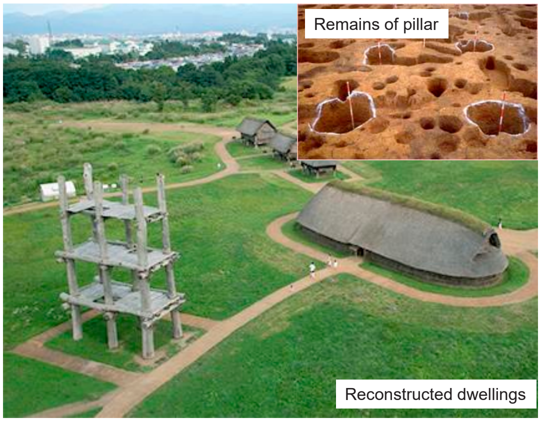
1

Introduction

Conservation and exhibition of geo-relics are becoming important

Mozu-Furuichi Kofun Group: Mounded Tombs of Ancient Japan (2019)



Jomon Prehistoric Sites in Northern Japan (2021)

https://bunka.nii.ac.jp/ https://sannaimaruyama.pref.aomori.jp/about/iseki/ 2

Open exhibition

Open exhibitions are attractive, but they are easy to be damaged.

Excavation → Re-burying

↓

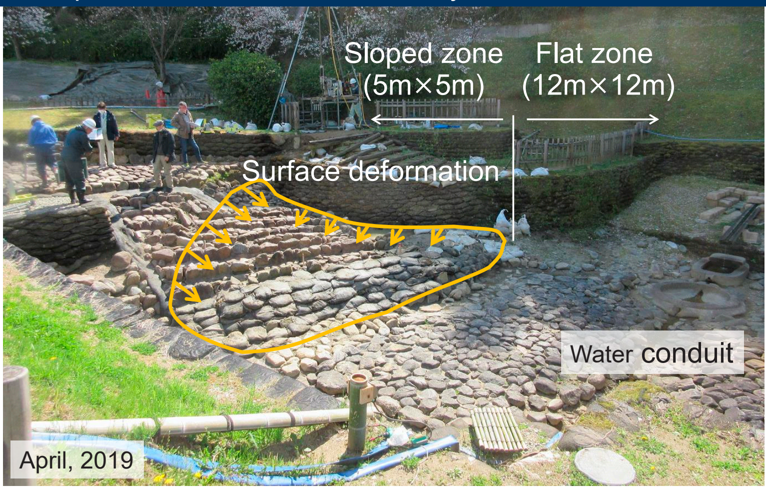
Open exhibition

Outdoors	Indoors
	
Rainfall, wet-dry cycles, freeze-thaw cycles, etc.	Desiccation cracking, salt crystallization, fungi, etc.

3

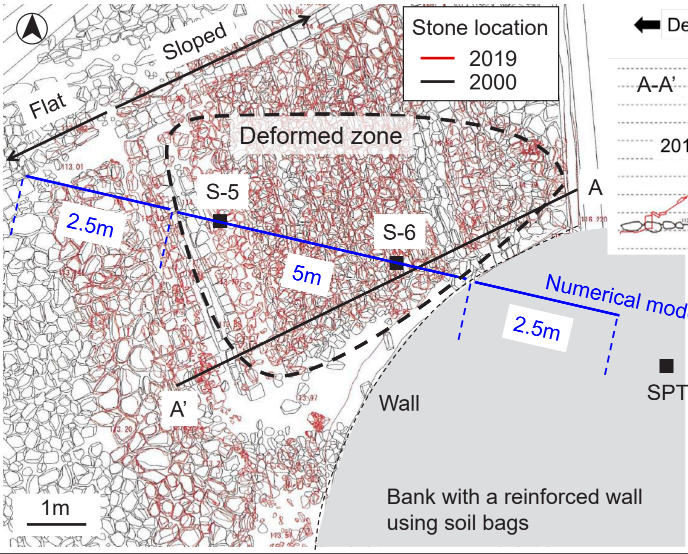
Sakafuneishi Site (Asuka Village, Nara, Japan)

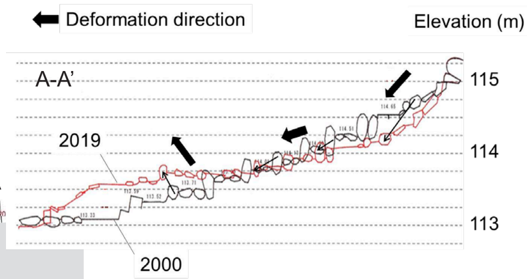
The slope deformation was caused by rainfall infiltration.



4

Survey



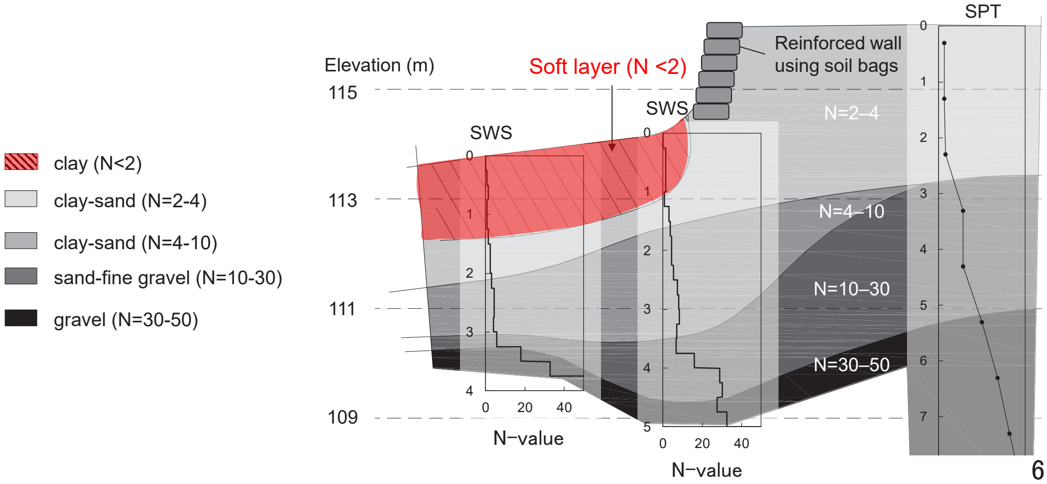


- Stone location survey
- Flat zone was stable
- Sounding tests

5

Soil profiles

The slope had a soft surface layer with N < 2



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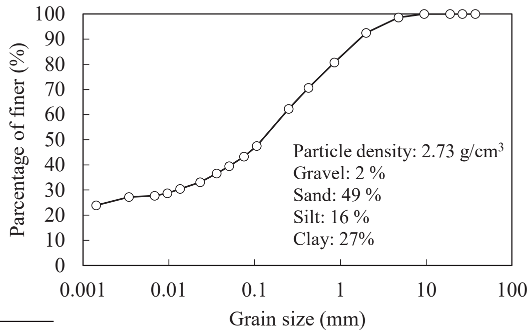
Materials



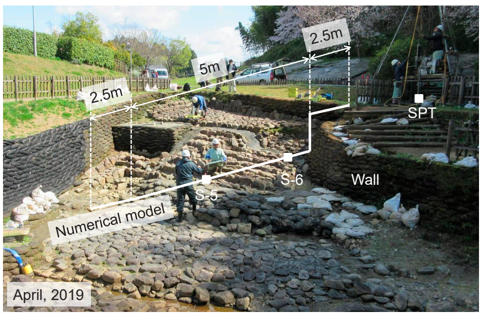
F_c (%)	43
Dry density (g/cm^3)	1.4
Permeability (m/s)	3.4×10^{-6}
Failure stress ratio	1.31
Normalized shear modulus	67

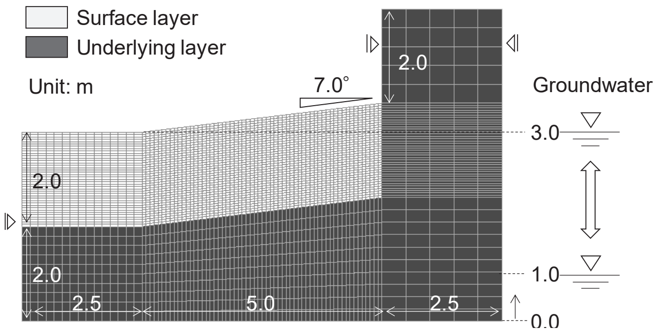
- Oedometer test
- Water retention test
- Permeability test
- Constant suction triaxial test

7

Numerical simulation

- 1 Oct – 31 Oct, 2017 (maximum rainfall intensity: 24 mm/h)
- Seepage-deformation FE analysis
- Elasto-plastic model based on skeleton stress (LIQCA2018)





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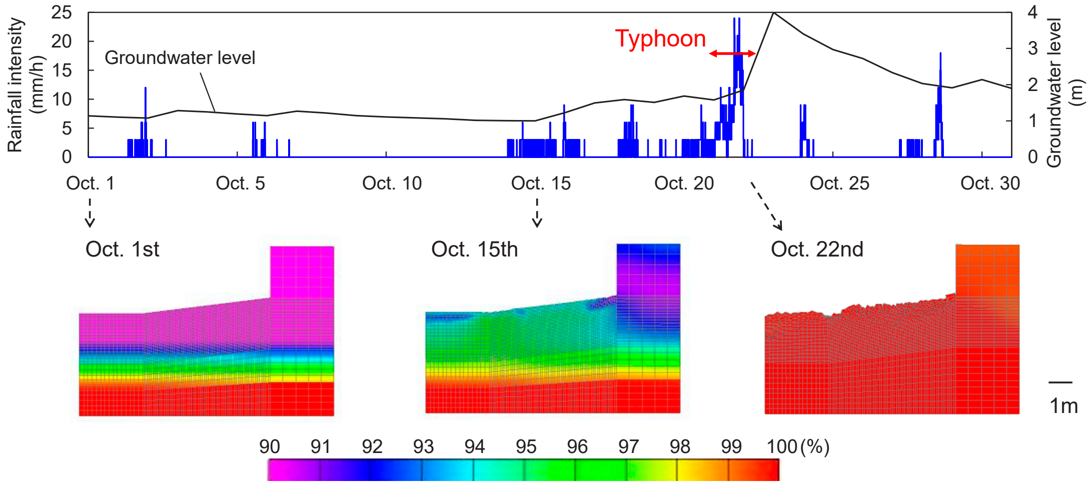
Degree of saturation

Degree of saturation began to increase before the typhoon.



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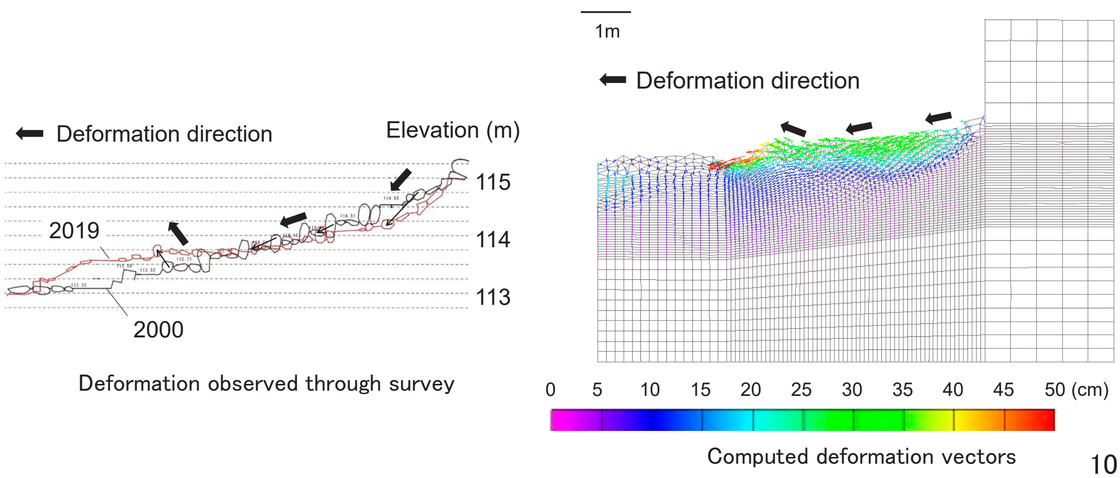
Deformation

Computed deformation was qualitatively consistent with the measured values



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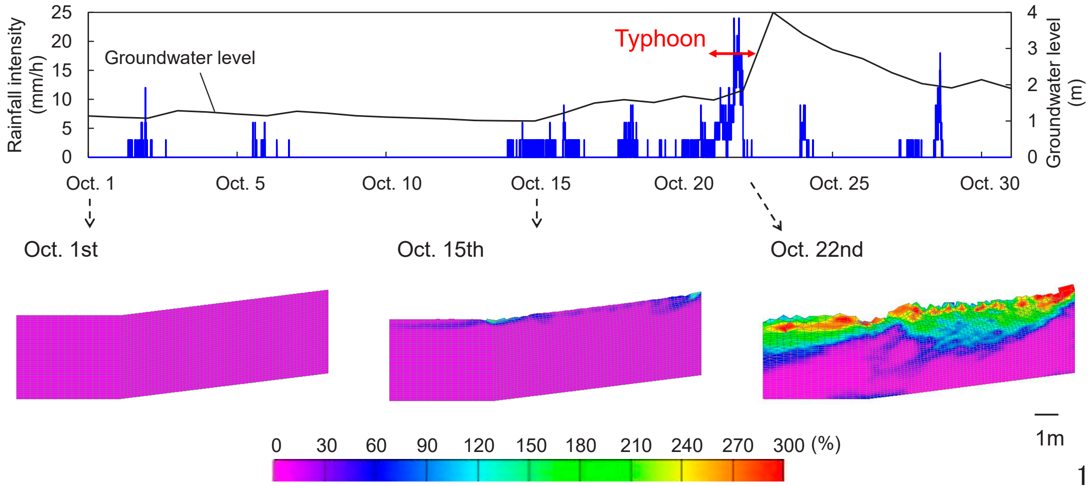
Deviatoric plastic strain

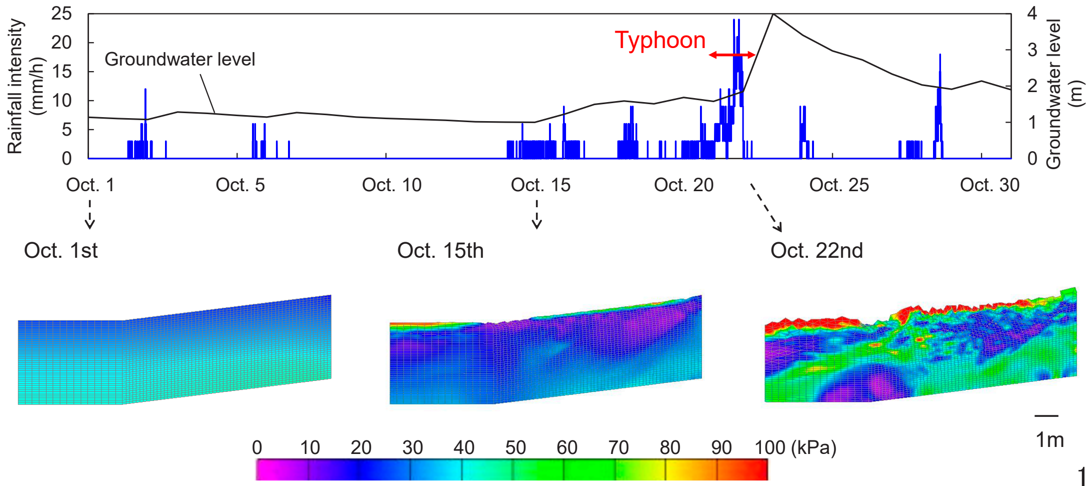
Degree of saturation began to increase before the typhoon.



11

Mean skeleton stress

Suction-induced strength decreased as the degree of saturation increased.



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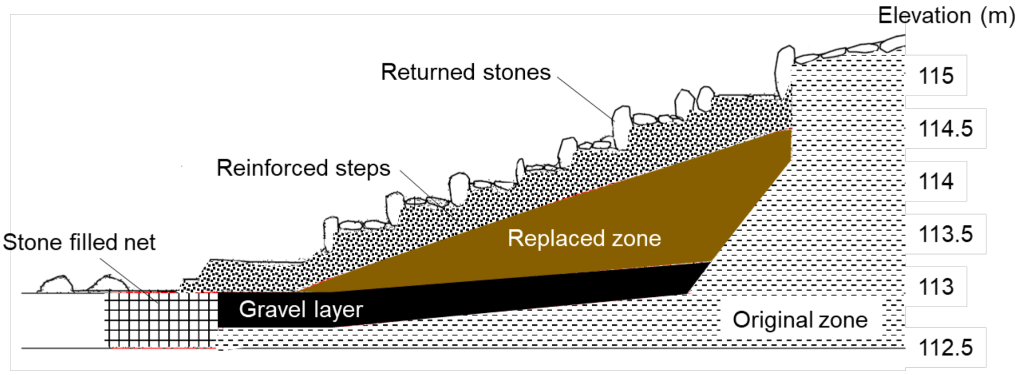
Restoration proposal

- Lowering groundwater level was not effective
- Replacement of the soft surface soil
- Densely compacted permeable sandy soil improves slope stability



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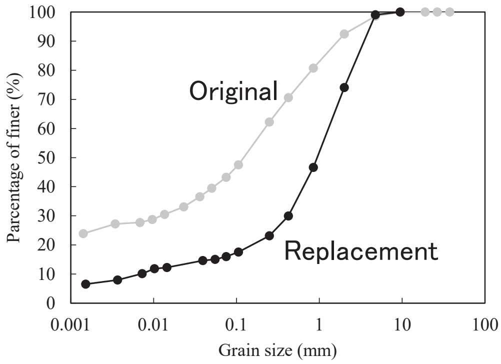
Replacement soil



	Original	Replacement
F_c (%)	43	16
Dry density (g/cm^3)	1.4	1.7
Permeability (m/s)	3.4×10^{-6}	1.5×10^{-4}
Failure stress ratio	1.31	1.55
Normalized shear modulus	67	236

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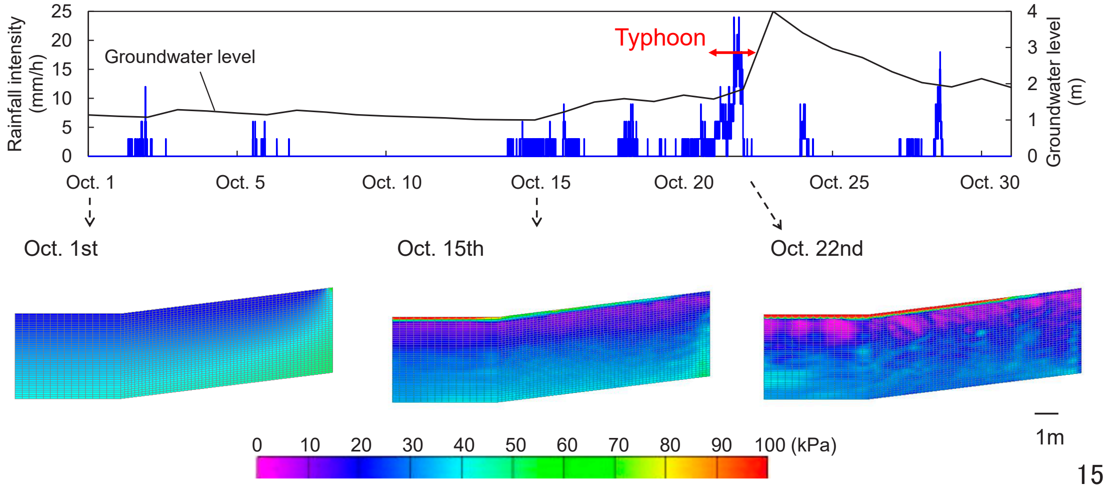
Restored slope –Mean skeleton stress–

Tokyo Tech

Suction-induced strength decreased in the restored slope.



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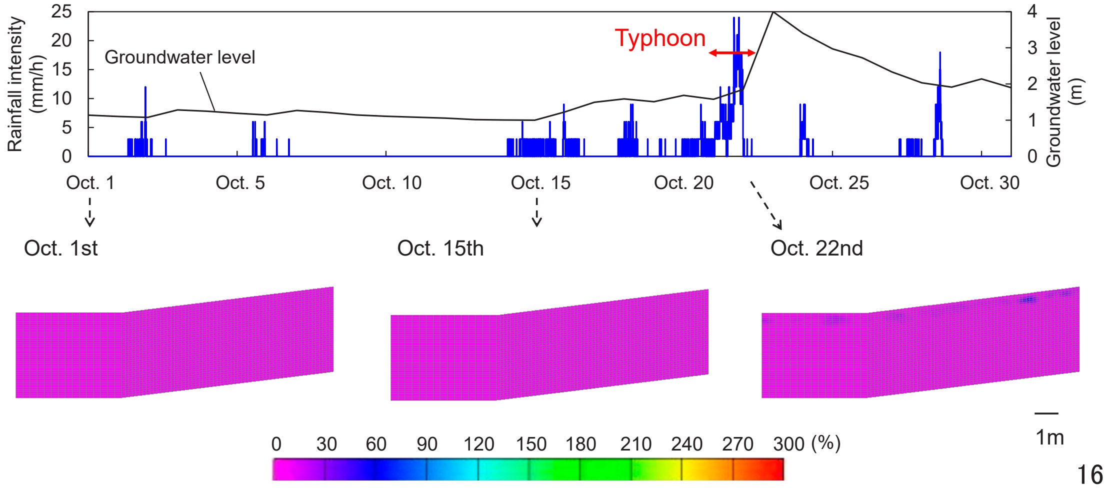
Restored slope –Deviatoric plastic strain–

Tokyo Tech

The restored slope was stable when it was wet and mean skeleton stress decreased.



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Conclusions

- The slope deformation developed in the soft surface layer with $N<2$. We need to ensure an understanding of field investigations in geo-relics by demonstrating their importance through case studies.

- The damage mechanism investigation and restoration proposal were conducted based on simulation results. The deformation was caused by a reduction in the suction-induced stiffness and strength. The slope was restored by replacing the surface soil with densely compacted permeable soil.

- The quantitative evaluation enables the discussion of the restoration of open exhibits of geo-relics from the perspectives of both archeological authenticity and geotechnical validity.

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MI レクチャーノートシリーズ刊行にあたり

本レクチャーノートシリーズは、文部科学省 21 世紀 COE プログラム「機能数理学の構築と展開」（H15-19 年度）において作成した COE Lecture Notes の続刊であり、文部科学省大学院教育改革支援プログラム「産業界が求める数学博士と新修士養成」（H19-21 年度）および、同グローバル COE プログラム「マス・フォア・インダストリ教育研究拠点」（H20-24 年度）において行われた講義の講義録として出版されてきた。平成 23 年 4 月のマス・フォア・インダストリ研究所（IMI）設立と平成 25 年 4 月の IMI の文部科学省共同利用・共同研究拠点として「産業数学の先進的･基礎的共同研究拠点」の認定を受け、今後、レクチャーノートは、マス・フォア・インダストリに関わる国内外の研究者による講義の講義録、会議録等として出版し、マス・フォア・インダストリの本格的な展開に資するものとする。

2022 年 10 月
マス・フォア・インダストリ研究所
所長　梶原 健司

2023年度採択分　九州大学マス・フォア・インダストリ研究所 共同利用研究集会

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MI Lecture Note Vol.52	佐伯　　修 岡田　勘三 髙木　　剛 若山　正人 山本　昌宏	Study Group Workshop 2013 Abstract, Lecture & Report 142pages	November 15, 2013
MI Lecture Note Vol.53	四方　義啓 櫻井　幸一 安田　貴徳 Xavier Dahan	平成25年度　九州大学マス・フォア・インダストリ研究所 共同利用研究集会　安全・安心社会基盤構築のための代数構造 ～サイバー社会の信頼性確保のための数理学～　158pages	December 26, 2013
MI Lecture Note Vol.54	Takashi Takiguchi Hiroshi Fujiwara	Inverse problems for practice, the present and the future　93pages	January 30, 2014
MI Lecture Note Vol.55	栄　伸一郎 溝口　佳寛 脇　　隼人 渋田　敬史	Study Group Workshop 2013 数学協働プログラム Lecture & Report 98pages	February 10, 2014
MI Lecture Note Vol.56	Yoshihiro Mizoguchi Hayato Waki Takafumi Shibuta Tetsuji Taniguchi Osamu Shimabukuro Makoto Tagami Hirotake Kurihara Shuya Chiba	Hakata Workshop 2014 ~ Discrete Mathematics and its Applications ~　141pages	March 28, 2014
MI Lecture Note Vol.57	Institute of Mathematics for Industry, Kyushu University	Forum “Math-for-Industry” 2014: “Applications + Practical Conceptualization + Mathematics = fruitful Innovation”　93pages	October 23, 2014
MI Lecture Note Vol.58	安生健一 落合啓之	Symposium MEIS2014: Mathematical Progress in Expressive Image Synthesis　135pages	November 12, 2014

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MI Lecture Note Vol.59	西井　龍映 岡田　勘三 梶原　健司 髙木　　剛 若山　正人 脇　　隼人 山本　昌宏	Study Group Workshop 2014 数学協働プログラム Abstract, Lecture & Report　196pages	November 14, 2014
MI Lecture Note Vol.60	西浦　　博	平成26年度九州大学 IMI 共同利用研究・研究集会（I） 感染症数理モデルの実用化と産業及び政策での活用のための新たな展開　120pages	November 28, 2014
MI Lecture Note Vol.61	溝口　佳寛 Jacques Garrigue 萩原　　学 Reynald Affeldt	研究集会 高信頼な理論と実装のための定理証明および定理証明器 Theorem proving and provers for reliable theory and implementations (TPP2014)　138pages	February 26, 2015
MI Lecture Note Vol.62	白井　朋之	Workshop on “β-transformation and related topics”　59pages	March 10, 2015
MI Lecture Note Vol.63	白井　朋之	Workshop on “Probabilistic models with determinantal structure” 107pages	August 20, 2015
MI Lecture Note Vol.64	落合　啓之 土橋　宜典	Symposium MEIS2015: Mathematical Progress in Expressive Image Synthesis　124pages	September 18, 2015
MI Lecture Note Vol.65	Institute of Mathematics for Industry, Kyushu University	Forum “Math-for-Industry” 2015 “The Role and Importance of Mathematics in Innovation”　74pages	October 23, 2015
MI Lecture Note Vol.66	岡田　勘三 藤澤　克己 白井　朋之 若山　正人 脇　　隼人 Philip Broadbridge 山本　昌宏	Study Group Workshop 2015 Abstract, Lecture & Report 156pages	November 5, 2015
MI Lecture Note Vol.67	Institute of Mathematics for Industry, Kyushu University	IMI-La Trobe Joint Conference “Mathematics for Materials Science and Processing” 66pages	February 5, 2016
MI Lecture Note Vol.68	古庄　英和 小谷　久寿 新甫　洋史	結び目と Grothendieck-Teichmüller 群 116pages	February 22, 2016
MI Lecture Note Vol.69	土橋　宜典 鍛治　静雄	Symposium MEIS2016: Mathematical Progress in Expressive Image Synthesis　82pages	October 24, 2016
MI Lecture Note Vol.70	Institute of Mathematics for Industry, Kyushu University	Forum “Math-for-Industry” 2016 “Agriculture as a metaphor for creativity in all human endeavors” 98pages	November 2, 2016
MI Lecture Note Vol.71	小磯　深幸 二宮　嘉行 山本　昌宏	Study Group Workshop 2016 Abstract, Lecture & Report　143pages	November 21, 2016

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MI Lecture Note Vol.72	新井　朝雄 小嶋　　泉 廣島　文生	Mathematical quantum field theory and related topics　133pages	January 27, 2017
MI Lecture Note Vol.73	穴田　啓晃 Kirill Morozov 須賀　祐治 奥村　伸也 櫻井　幸一	Secret Sharing for Dependability, Usability and Security of Network Storage and Its Mathematical Modeling　211pages	March 15, 2017
MI Lecture Note Vol.74	QUISPEL, G. Reinout W. BADER, Philipp MCLAREN, David I. TAGAMI, Daisuke	IMI-La Trobe Joint Conference Geometric Numerical Integration and its Applications　71pages	March 31, 2017
MI Lecture Note Vol.75	手塚　　集 田上　大助 山本　昌宏	Study Group Workshop 2017 Abstract, Lecture & Report　118pages	October 20, 2017
MI Lecture Note Vol.76	宇田川誠一	Tzitzéica 方程式の有限間隙解に付随した極小曲面の構成理論 ―Tzitzéica 方程式の楕円関数解を出発点として―　68pages	August 4, 2017
MI Lecture Note Vol.77	松谷　茂樹 佐伯　　修 中川　淳一 田上　大助 上坂　正晃 Pierluigi Cesana 濵田　裕康	平成29年度　九州大学マス・フォア・インダストリ研究所 共同利用研究集会（I） 結晶の界面，転位，構造の数理　148pages	December 20, 2017
MI Lecture Note Vol.78	瀧澤　重志 小林　和博 佐藤憲一郎 斉藤　　努 清水　正明 間瀬　正啓 藤澤　克樹 神山　直之	平成29年度　九州大学マス・フォア・インダストリ研究所 プロジェクト研究　研究集会（I） 防災・避難計画の数理モデルの高度化と社会実装へ向けて 136pages	February 26, 2018
MI Lecture Note Vol.79	神山　直之 畔上　秀幸	平成29年度　AIMaP チュートリアル 最適化理論の基礎と応用　96pages	February 28, 2018
MI Lecture Note Vol.80	Kirill Morozov Hiroaki Anada Yuji Suga	IMI Workshop of the Joint Research Projects Cryptographic Technologies for Securing Network Storage and Their Mathematical Modeling　116pages	March 30, 2018
MI Lecture Note Vol.81	Tsuyoshi Takagi Masato Wakayama Keisuke Tanaka Noboru Kunihiro Kazufumi Kimoto Yasuhiko Ikematsu	IMI Workshop of the Joint Research Projects International Symposium on Mathematics, Quantum Theory, and Cryptography　246pages	September 25, 2019
MI Lecture Note Vol.82	池森　俊文	令和２年度　AIMaP チュートリアル 新型コロナウイルス感染症にかかわる諸問題の数理 145pages	March 22, 2021

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MI Lecture Note Vol.83	早川健太郎 軸丸　芳揮 横須賀洋平 可香谷　隆 林　　和希 堺　　雄亮	シェル理論・膜理論への微分幾何学からのアプローチと その建築曲面設計への応用　49pages	July 28, 2021
MI Lecture Note Vol.84	Taketoshi Kawabe Yoshihiro Mizoguchi Junichi Kako Masakazu Mukai Yuji Yasui	SICE-JSAE-AIMaP Tutorial Advanced Automotive Control and Mathematics　110pages	December 27, 2021
MI Lecture Note Vol.85	Hiroaki Anada Yasuhiko Ikematsu Koji Nuida Satsuya Ohata Yuntao Wang	IMI Workshop of the Joint Usage Research Projects Exploring Mathematical and Practical Principles of Secure Computation and Secret Sharing　114pages	February 9, 2022
MI Lecture Note Vol.86	濱田　直希 穴井　宏和 梅田　裕平 千葉　一永 佐藤　寛之 能島　裕介 加葉田雄太朗 一木　俊助 早野　健太 佐伯　　修	2020年度採択分　九州大学マス・フォア・インダストリ研究所 共同利用研究集会 進化計算の数理　135pages	February 22, 2022
MI Lecture Note Vol.87	Osamu Saeki, Ho Tu Bao, Shizuo Kaji, Kenji Kajiwara, Nguyen Ha Nam, Ta Hai Tung, Melanie Roberts, Masato Wakayama, Le Minh Ha, Philip Broadbridge	Proceedings of Forum “Math-for-Industry” 2021 -Mathematics for Digital Economy-　122pages	March 28, 2022
MI Lecture Note Vol.88	Daniel PACKWOOD Pierluigi CESANA, Shigenori FUJIKAWA, Yasuhide FUKUMOTO, Petros SOFRONIS, Alex STAYKOV	Perspectives on Artificial Intelligence and Machine Learning in Materials Science, February 4-6, 2022　74pages	November 8, 2022

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MI Lecture Note Vol.89	松谷　茂樹 落合　啓之 井上　和俊 小磯　深幸 佐伯　　修 白井　朋之 垂水　竜一 内藤　久資 中川　淳一 濵田　裕康 松江　　要 加葉田雄太朗	2022年度採択分 九州大学マス・フォア・インダストリ研究所 共同利用研究集会 材料科学における幾何と代数 III　356pages	December 7, 2022
MI Lecture Note Vol.90	中山　尚子 谷川　拓司 品野　勇治 近藤　正章 石原　　亨 鍛治　静雄 藤澤　克樹	2022年度採択分 九州大学マス・フォア・インダストリ研究所 共同利用研究集会 データ格付けサービス実現のための数理基盤の構築　58pages	December 12, 2022
MI Lecture Note Vol.91	Katsuki Fujisawa Shizuo Kaji Toru Ishihara Masaaki Kondo Yuji Shinano Takuji Tanigawa Naoko Nakayama	IMI Workshop of the Joint Usage Research Projects Construction of Mathematical Basis for Realizing Data Rating Service 610pages	December 27, 2022
MI Lecture Note Vol.92	丹田　　聡 三宮　　俊 廣島　文生	2022年度採択分　九州大学マス・フォア・インダストリ研究所 共同利用研究集会 時間・量子測定・準古典近似の理論と実験 ～古典論と量子論の境界～　150pages	Janualy 6, 2023
MI Lecture Note Vol.93	Philip Broadbridge Luke Bennetts Melanie Roberts Kenji Kajiwara	Proceedings of Forum “Math-for-Industry” 2022 -Mathematics of Public Health and Sustainability-　170pages	June 19, 2023
MI Lecture Note Vol.94	國廣　　昇 池松　泰彦 伊豆　哲也 穴田　啓晃 縫田　光司	2023年度採択分　九州大学マス・フォア・インダストリ研究所 共同利用研究集会 現代暗号に対する安全性解析・攻撃の数理　260pages	Janualy 11, 2024
MI Lecture Note Vol.95	Osamu Saeki Wojciech Domitrz Stanisław Janeczko Marcin Zubilewicz Michał Zwierzyński	International Project Research-Workshop (I) WORKSHOP on Mathematics for Industry　364pages	March 14, 2024

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