National Institute for Land and Infrastructure Management
Ministry of Land, Infrastructure, Transport and Tourism
Asahi1, Tsukuba-shi, Ibaraki, 305-0804, Japan

# 国総研・日越大学ジョイントセミナーを開催
# ～道路技術と施策の紹介～

November 25th, 2022

- 国総研は、11 月 25 日（金）にベトナム国家大学ハノイ校日越大学※（ハノイ市）とのジョイントセミナーをオンライン形式で開催しました。

- 今回のセミナーにおけるテーマは「道路技術と施策の紹介」です。国総研からは、道路維持管理や防災・災害復旧等に関する本邦技術や国土交通省の施策などを発表しました。日越大学からはハノイ市近郊に位置するホン川デルタ地帯における軟弱地盤特性に関する発表を行いました。

- 本セミナーは、国総研所長や日越大学のプログラムディレクターによる主催者挨拶に始まり、発表者による発表や聴講者からの質疑応答、最後には日越大学の専任講師による挨拶で大盛況のうちに締めくくられました。

- セミナーの概要および当日の様子についてお知らせします。詳細は次頁よりご覧下さい。

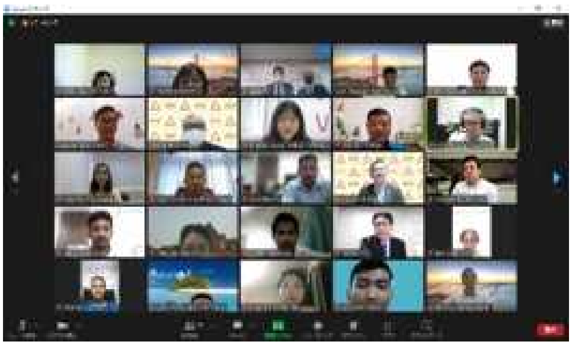
※日越大学：2014 年に JICA の技術協力によりハノイ市に設立。日本企業のインターンシップも取り込み、国際レベルで実践的な人材育成を図っている。必須科目として、日本語教育も実施。これまでは修士課程のみだったが、今年９月から学部コースも開設。

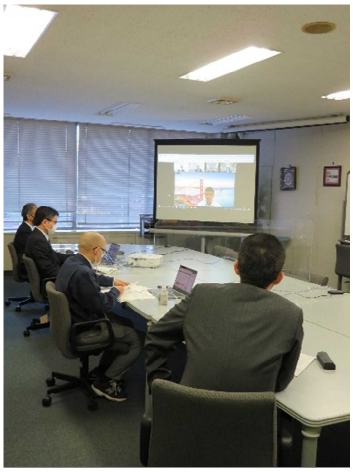
1. 開催日
   2022 年 11 月 25 日（金）
   13:00-15:20（ベトナム時間）
   15:00-17:20（日本時間）

2. 概要
   〇タイトル：道路技術と施策の紹介
   〇参加者：96 名（事前登録数）、うち本邦企業からは 14 名参加
   〇会場：オンライン形式（ZOOM）
   〇内容：
   冒頭では所長が主催者挨拶、本省道路局企画課国際室の福井室長が来賓挨拶を行いました。続いて、道路構造物研究部からは日本における道路構造物の維持管理について、道路交通研究部からはビッグデータを活用した災害後の交通可能な道路を特定する取組について、土砂災害研究部からは日本における土砂災害の防止と軽減についてそれぞれ発表を行いました。日越大学からはハノイ市近郊に位置するホン川デルタ地帯における軟弱地盤特性に関する発表を行いました。各発表では質疑応答も活発に行われ、最後には日越大学専任講師からの閉会の挨拶を以て、盛況のうちにジョイントセミナーを終了することができました。

3. 開催の状況


**所長挨拶の様子**


**参加者記念撮影**


**国総研参加者の様子**

# INTRODUCTION OF ROAD TECHNOLOGY AND POLICY MAKING

## ～道路技術と施策の紹介～

-International Joint Seminar of VJU and NILIM-

国総研・日越大学ジョイントセミナー

### ◎TIME

令和4年11月25日（金）

13:00-15:20 (Vietnam Time)

15:00-17:20（日本時間）

### ◎VENUE

Online(ZOOM)

### ◎REGISTRATION AND CONTACT INFO

Email:takeda.s@vju.ac.vn

Register:

https://forms.gle/oiMqYu7oQd6MHxCh6

### ◎PROGRAM

1.Opening address & Guest's address

主催者挨拶＆来賓挨拶

2.Session

(1) Maintenance and management of road structures in Japan: Decade of road maintenance revolution
日本における道路構造物の維持管理：
道路メンテナンス改革の10年

(2) Efforts to identify passable roads after disasters from road traffic big data
ビッグデータを活用した災害後の通行可能な道路を特定する取組

(3) Prevention and mitigation of sediment disasters in Japan
日本における土砂災害の防止と軽減

(4) Compressibility Characteristics of Soft Clays in the Red River Delta

3.Closing

## TIME TABLE

**■13:00-13:10 (Vietnam Time), 15:00-15:10（日本時間）**

**Opening Address**　主催者挨拶

- Mr. OKUMURA Yasuhiro, Director-General, National Institute for Land and Infrastructure Management (NILIM), Ministry of Land, Infrastructure, Transport and Tourism, Japan

- Prof.Dr. Sc. Nguyen Dinh Duc, Program Director, Master's Program in CIVIL Engineering(MCE), VNU Vietnam Japan University (VJU), (Affiliation: Vietnam National University (VNU), Hanoi)

**■13:10-13:15 (Vietnam Time), 15:10-15:15（日本時間）**

**Guest's Address**　来賓挨拶

- Mr. FUKUI Takanori, Director for International Affairs, Planning Division, Road Bureau, Ministry of Land, Infrastructure, Transport and Tourism, Japan
  国土交通省道路局企画課国際室　室長　福井　貴規

**■13:15-15:15 (Vietnam Time), 15:15-17:15（日本時間）**

**Session1: Maintenance and management of road structures in Japan: Decade of road maintenance revolution**

Dr. KATAOKA Shojiro (Research Coordinator for Road Structures Management, Road Structures Department, NILIM)

**Session2: Efforts to identify passable roads after disasters from road traffic big data**

Mr. ISHIHARA Masaaki (Researcher, Intelligent Transport Systems Division, Road Traffic Department, NILIM)

**Session3: Prevention and mitigation of sediment disasters in Japan**

Dr. AKIYAMA Kazuya (Research Coordinator for Sediment Disaster Prevention, Sabo Department, NILIM)

**Session4: Compressibility Characteristics of Soft Clays in the Red River Delta**

Ms. Khin Phyu Sin (Master's Program in CIVIL Engineering(MCE), VNU Vietnam Japan University (VJU))

**■15:15-15:20 (Vietnam Time), 17:15-17:20（日本時間）**

**Closing**

- Dr. Nguyen Ngoc Vinh, Lecturer, Master's Program in CIVIL Engineering(MCE), VNU Vietnam Japan University (VJU)
  日越大学 専任講師 グエン　ゴック　ヴィン

Chairman: Dr. Nguyen Tien Dung, Lecturer, Master's Program in CIVIL Engineering(MCE), VNU Vietnam Japan University (VJU)
日越大学　専任講師　グエン　ティエン　ズン

# Maintenance and Management of Road Structures in Japan:

## *Decade of Road Maintenance Revolution*

KATAOKA Shojiro

Research Coordinator for Road Structures Management

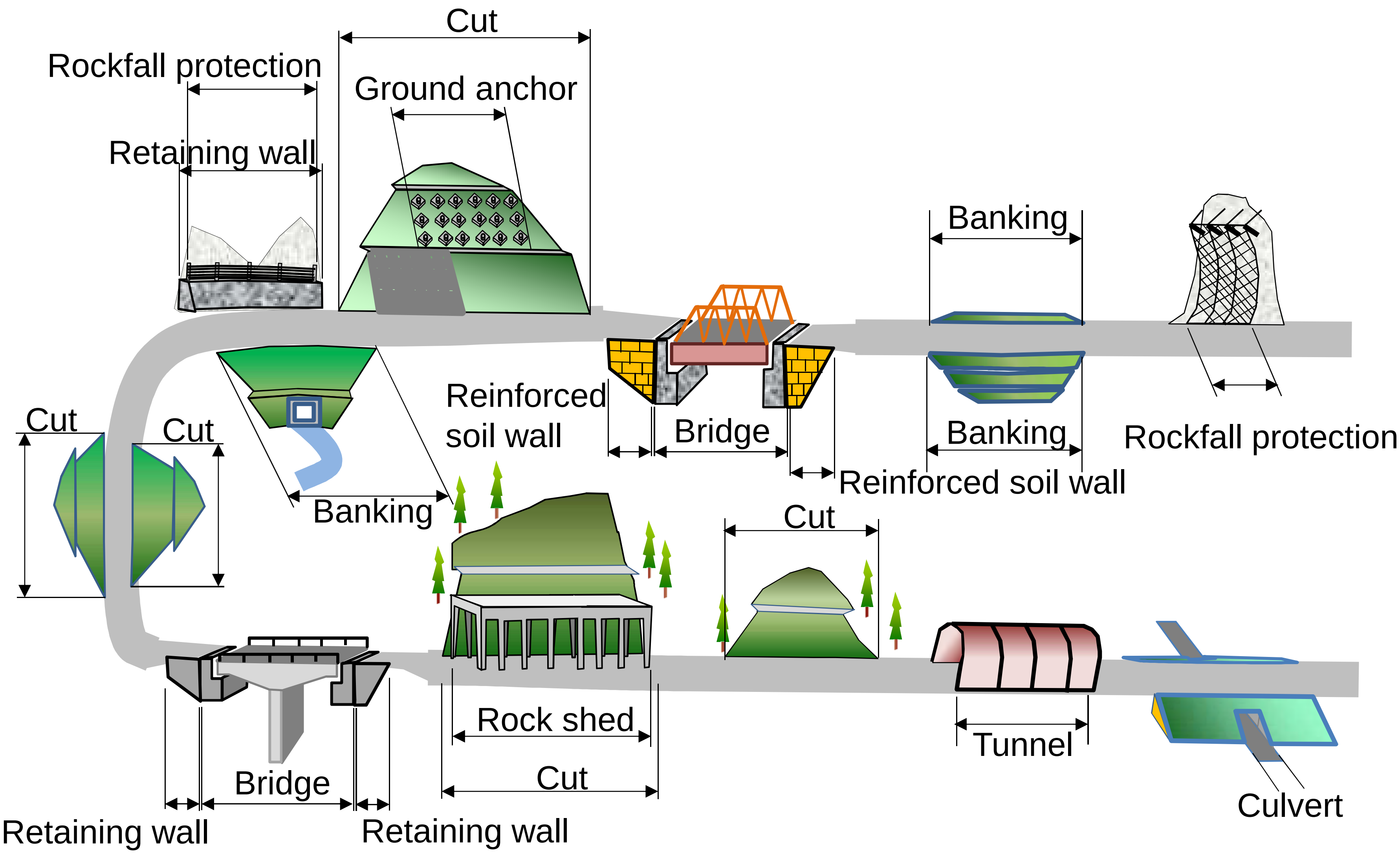
Road Structures Department, NILIM, MLIT, Japan

VJU-NILIM Joint Seminar online, November 25, 2022

# Contents

# Various structures support road traffic

Even small failure of one structure suspends it



# Road structures suffer deterioration

In Japan, we have…

700K+ Bridges

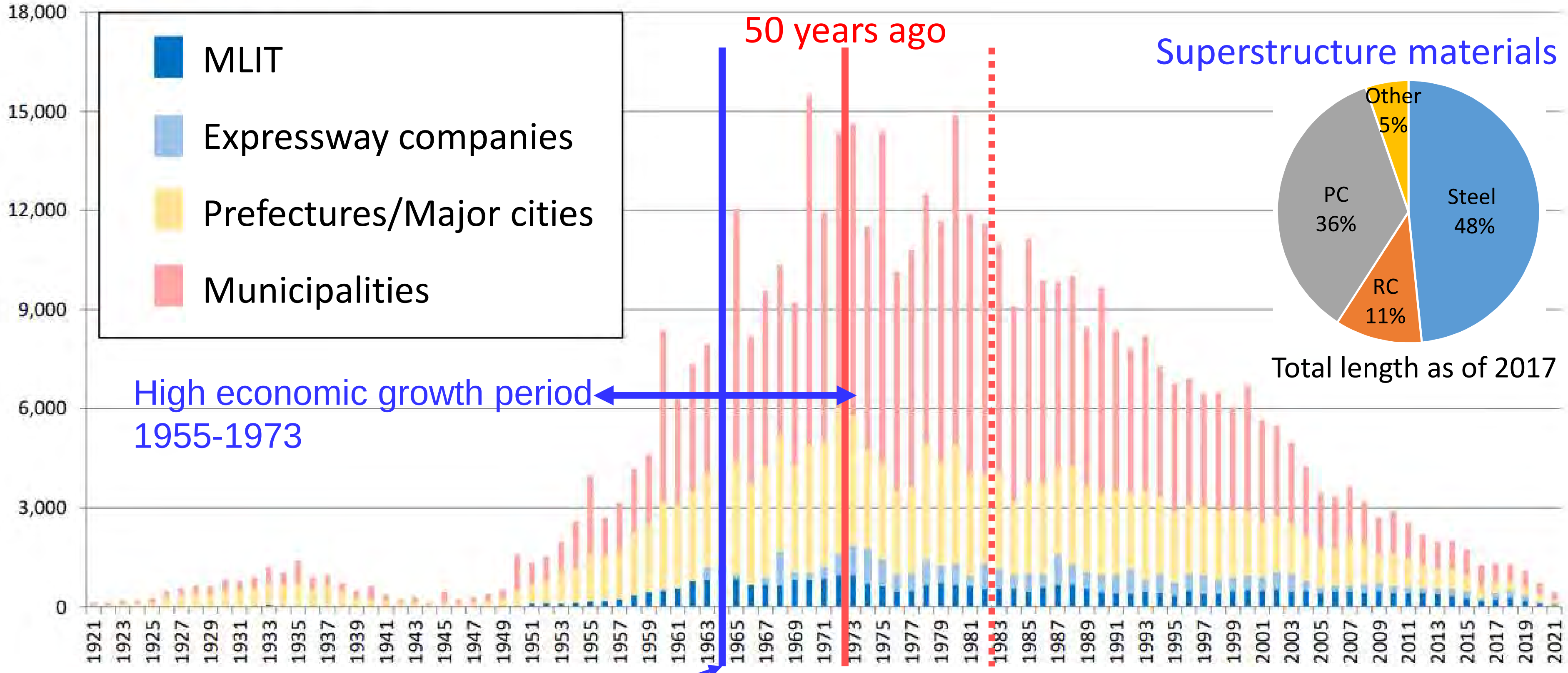
10K Tunnels



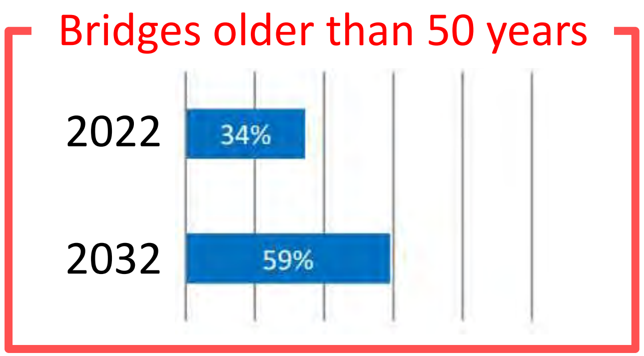

Various types of Earthworks

1G m Pavements

# ... because they are aging.




https://www.joc.or.jp/past_games/tokyo1964/



# History of national highway inspection (-2012)

Each Regional Bureau used its own guideline

→Uneven inspection methods and results

1988 First common Bridge Inspection Guideline

→Close visual inspection of each bridge every 10 years

Serious deterioration cases were found

Chloride (Salt)-induced deterioration

2001 NILIM was established and started supporting revision of the guideline

2004 Revised Bridge Inspection Guideline

→Close visual inspection every 5 years

→ "Evaluation" was introduced for taking action

| | |
|---|---|
| I | Good |
| II | Preventive maintenance |
| III | Repair work is required |
| IV | Emergency action is needed |

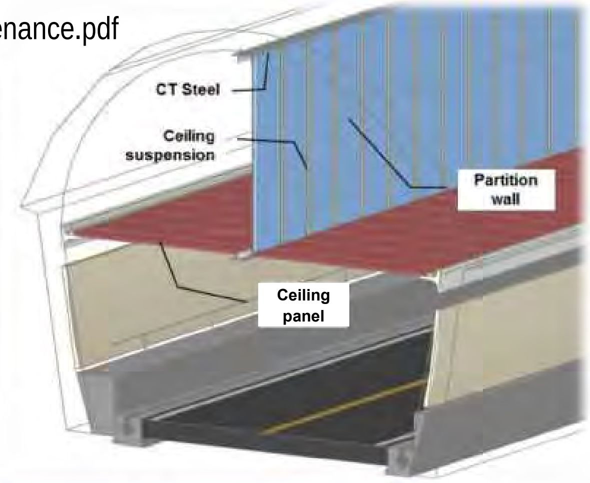
2012 Ceiling panel collapse in Sasago Tunnel


Dec 2, 2012

# Turning Point：Ceiling panel collapse in Sasago tunnel

https://www.mlit.go.jp/road/road_e/pdf/RoadMaintenance.pdf

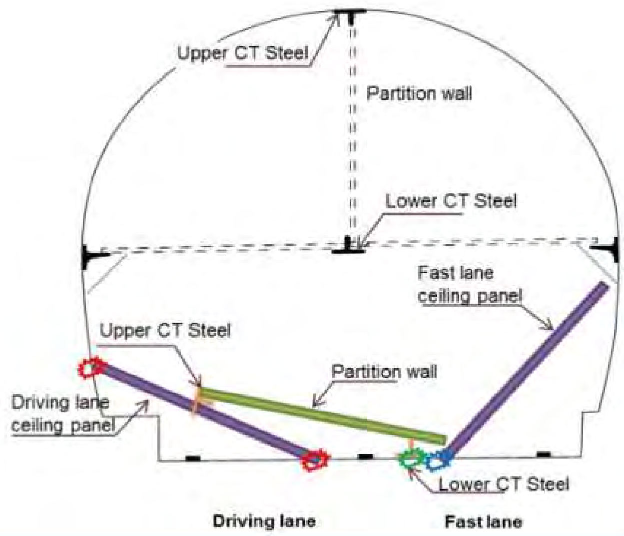
- December 2, 2012
- Tunnel opened: 1977 (35 years old)
- Daily Traffic Volume: 40,576 (both directions, as of 2010)
- 3 vehicles involved, 9 dead, 2 injured
- Dec. 29: Re-opened a single-lane in each direction
  Feb. 8, 2013: Fully re-opened




Sasago Tunnel (east bound) to Tokyo


**driving lane** **fast lane**

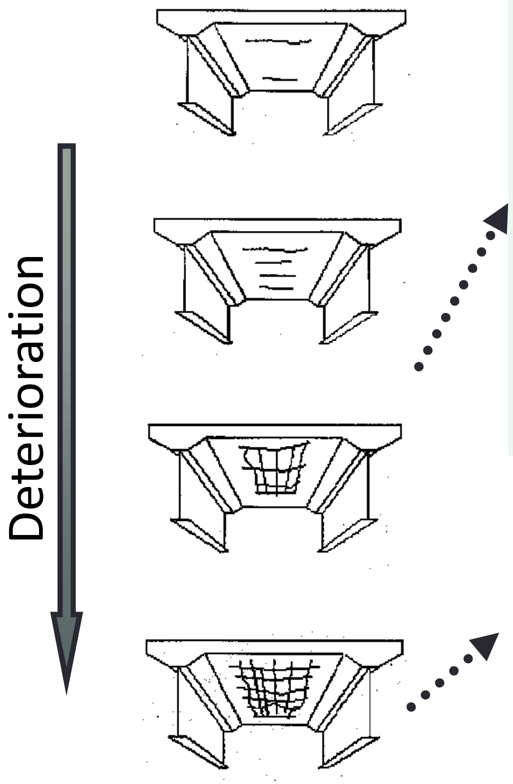
**(Dec. 5, 2012)**




NILIM supported verification of inspection method and the accident analysis.

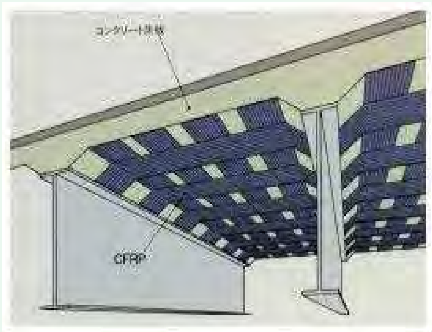
# Future Direction : Preventive Maintenance

Repeat minor maintenance work for saving life cycle cost compared to leaving the damage until replacement or major repair work.

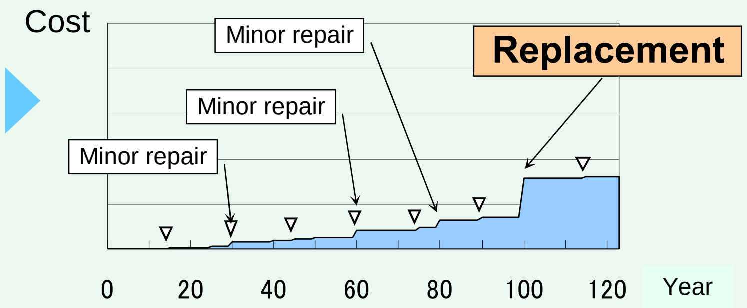



## [Preventive maintenance]

CF Sheet reinforcement etc.



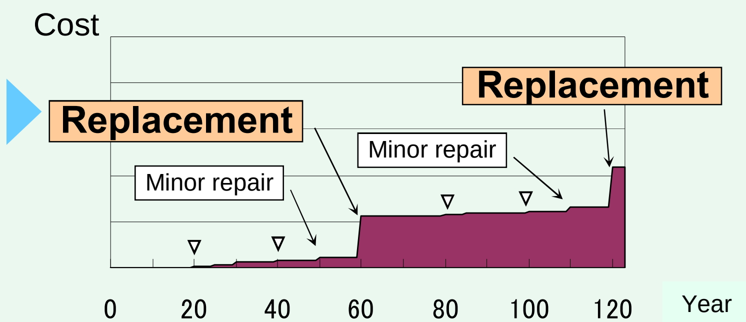

+ Lifetime extension
+ LCC minimization




## [Follow-up repair]

Replacement

- Replace more often
- Traffic has to be stopped
- Larger LCC



# Decade of revolution from 2012 (1/3)

2012 Ceiling panel collapse in Sasago Tunnel

2012 Urgent inspection for tunnel equipment

2013 Intensive inspection for road stocks

We must
- establish a maintenance cycle
  (obligation of administrators)
- establish a mechanism to facilitate the cycle
  (budget, system, skill, support)

Close visual inspection of tunnel equipment and bridge

2013.6 Amendment of Road Act

2014.3 Public notice of revision to Ordinances — 2014.7 into force

→Implement a close visual inspection of all tunnels, bridges, etc. every five years

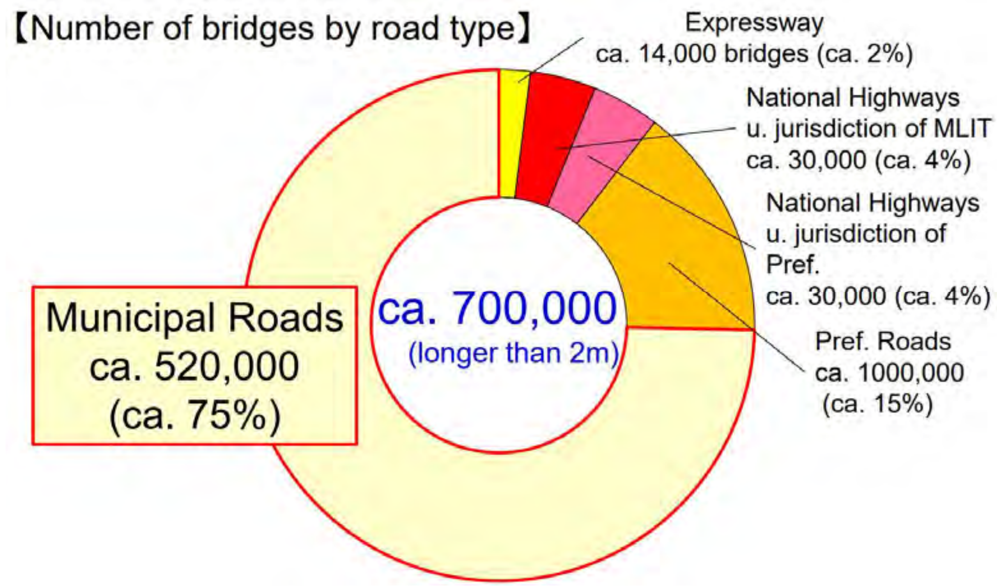
→Evaluate structure condition across Japan based on a uniform standard

2014.6 National guidelines for periodic inspection

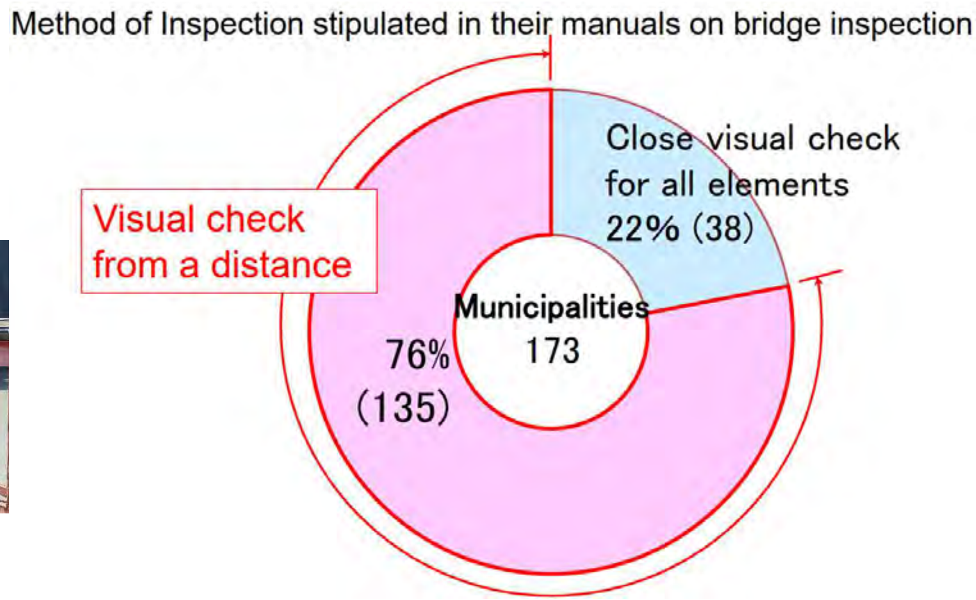
NILIM contributed to the revisions and draft-making of the guideline.

# Dramatic changes in inspection

Municipalities must conduct the inspection every 5 years as well.




Distant visual inspection became invalid.



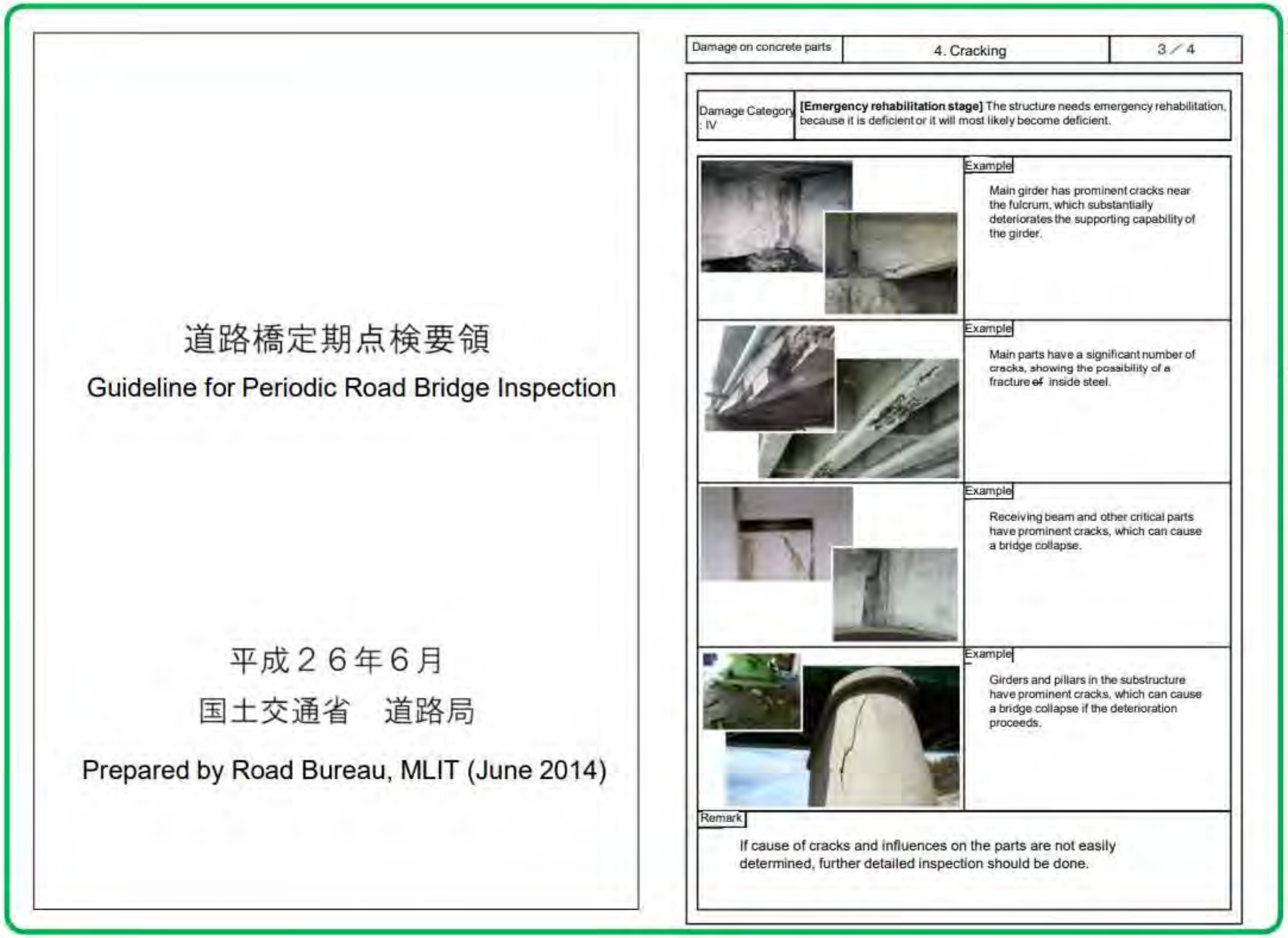

https://www.mlit.go.jp/road/road_e/pdf/RoadMaintenance.pdf

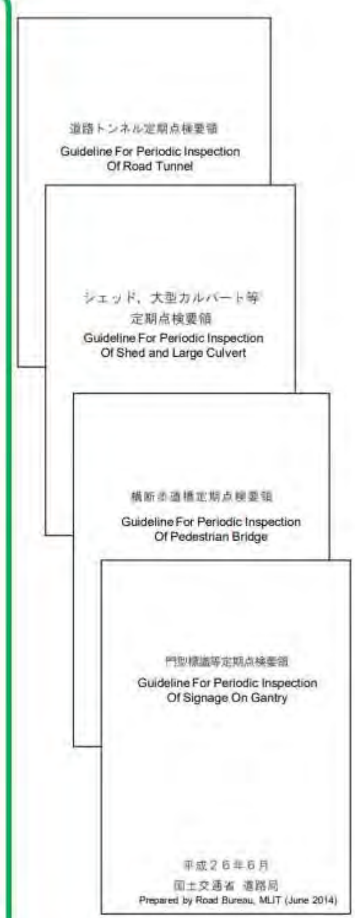
# 2014 National guidelines for periodic inspection

MLIT, with support from NILIM, developed a series of inspection guidelines describing

- Types of deformation need attention
- Case examples

in order to assist inspection by municipalities .



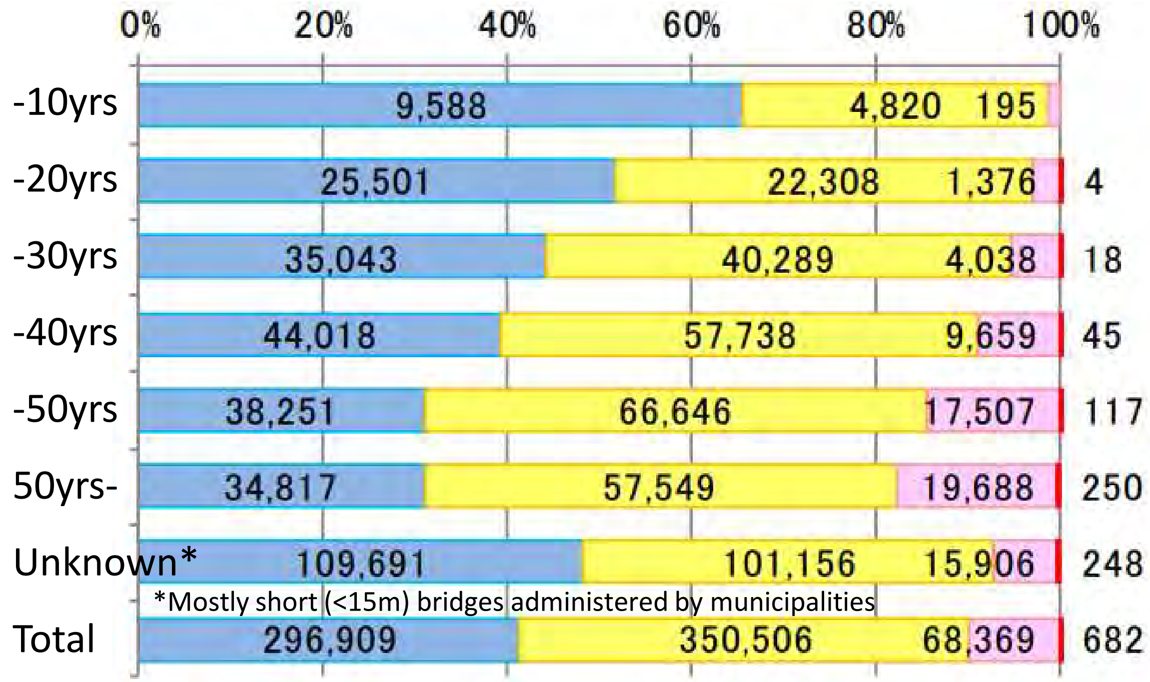



# Decade of revolution from 2012 (2/3)

2014.6 National guidelines for periodic inspection

2014.7 First round of the periodic inspection started (-FY2018)

Summary of the first round inspection(bridges)




| | | |
|---|---|---|
| ■ | Ⅰ | Good |
| ■ | Ⅱ | Preventive maintenance |
| ■ | Ⅲ | Repair work |
| ■ | Ⅳ | Emergency action |

-Older bridges are worse, as expected.
-Quantitative evidence was obtained for planning maintenance strategy.

2019.2 Revised national guidelines for periodic inspection

NILIM contributed to the revisions and draft-making.

# 2019 National guidelines for periodic inspection

Issues from the 1st-round inspection (FY2014-2018)

- Difficult :

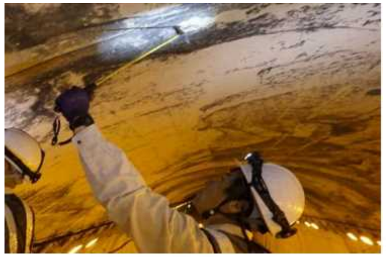
Inspections require technical considerations
→ Reference materials

✓Reference for checking underwater part

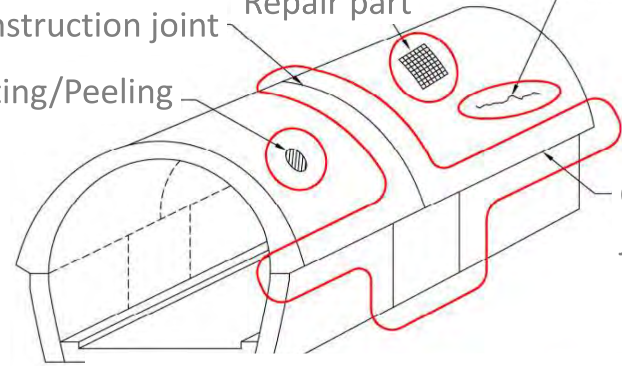
✓Reference for damage examples and inspection of bridges with tensile elements (Suspension, Cable-stayed, Arch, ….)

- Consuming:

Prevent over-checking
→ Illustrate necessary/unnecessary checking in the guidelines or references



Cost-cut by new technology
→ Alternative method to close visual inspection

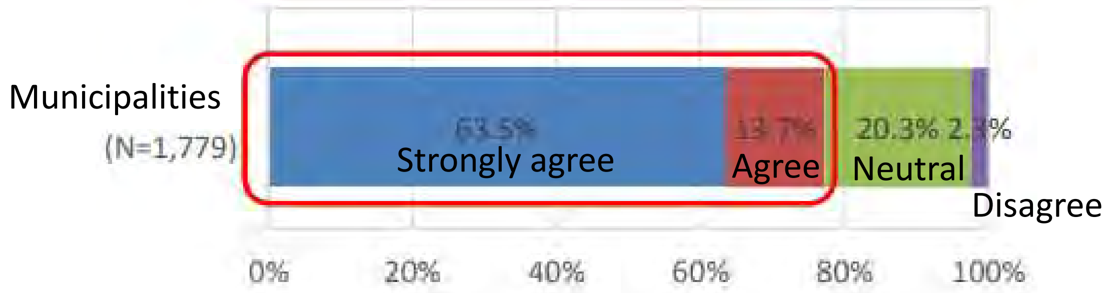



Hammering test area from 2nd-round

# Support for using new technologies

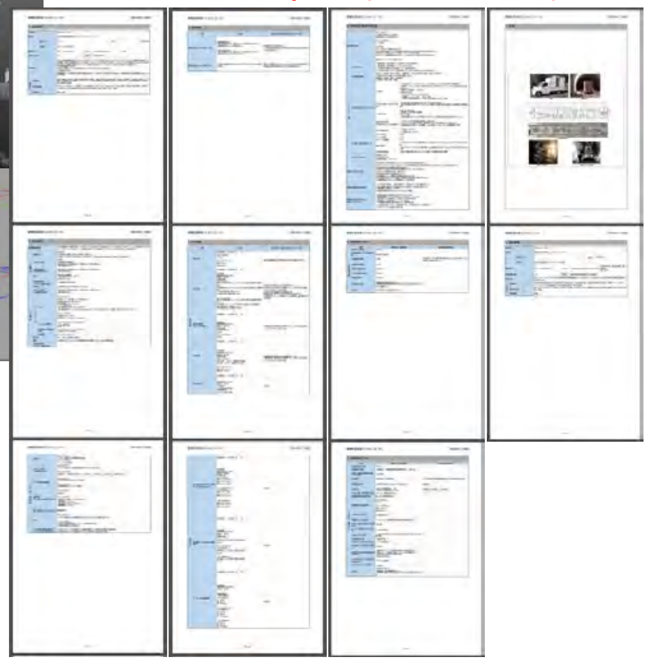
Questionnaire to municipalities:

The cost required for the inspection is a burden.




→ Strong needs for cost-cut by new technologies

An example (one item)



https://www.mlit.go.jp/road/sisaku/inspection-support/

→ What technologies are available?

→ Performance catalog of inspection support technologies

16 items (Feb. 2019) → 172 items (Sep. 2022)

→ Guideline & Examples

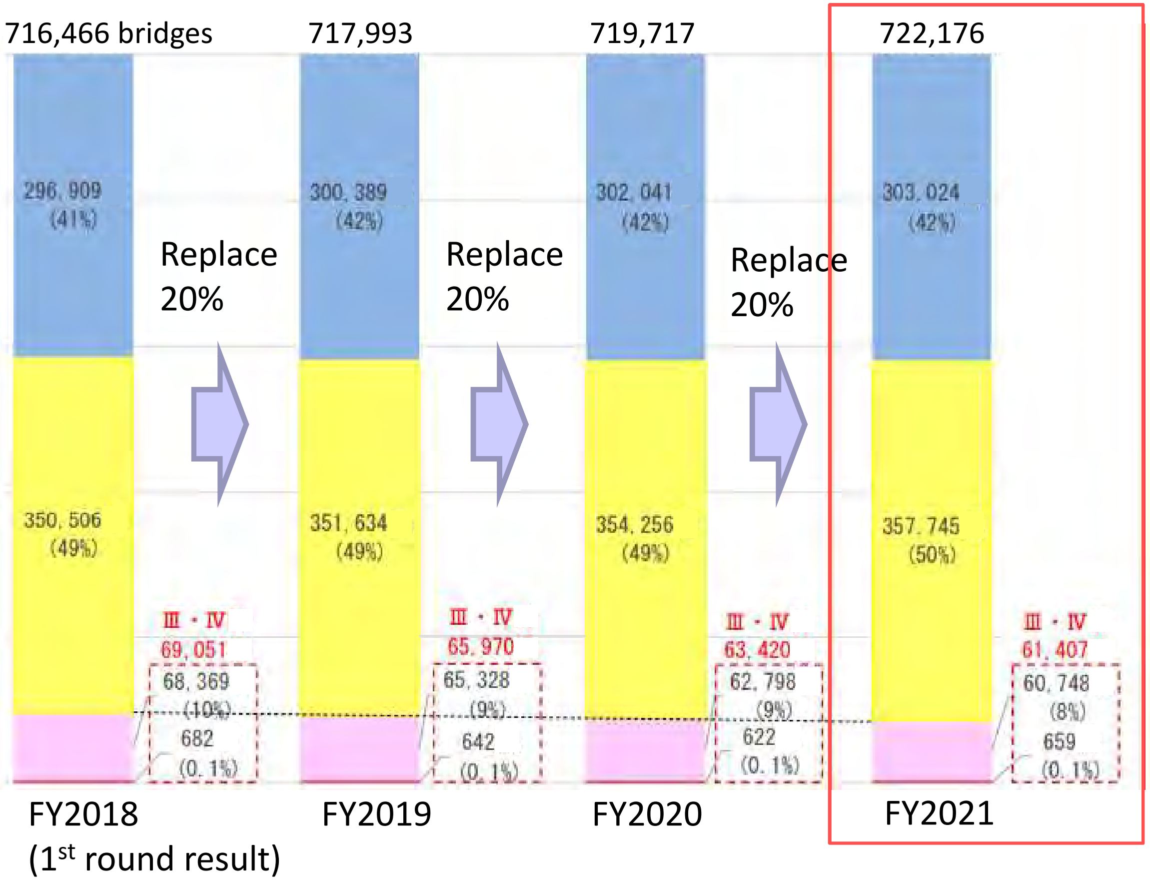
# Decade of revolution from 2012 (3/3)

2019.2 Revised national guidelines for periodic inspection

2019.4 Second round of the periodic inspection started (-FY2023)

Overall inspection result is improving from the first round.

Bridges




| | | |
|---|---|---|
| ■ | Ⅰ | Good |
| ■ | Ⅱ | Preventive maintenance |
| ■ | Ⅲ | Repair work |
| ■ | Ⅳ | Emergency action |

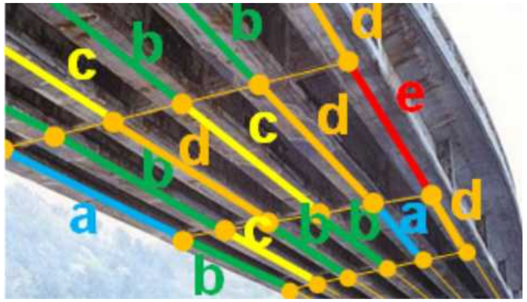
→ 20-30 years to erase Ⅲ・Ⅳ.

2024.2? Re-revised national guidelines for periodic inspection

NILIM conducts research for the revisions and draft-making.

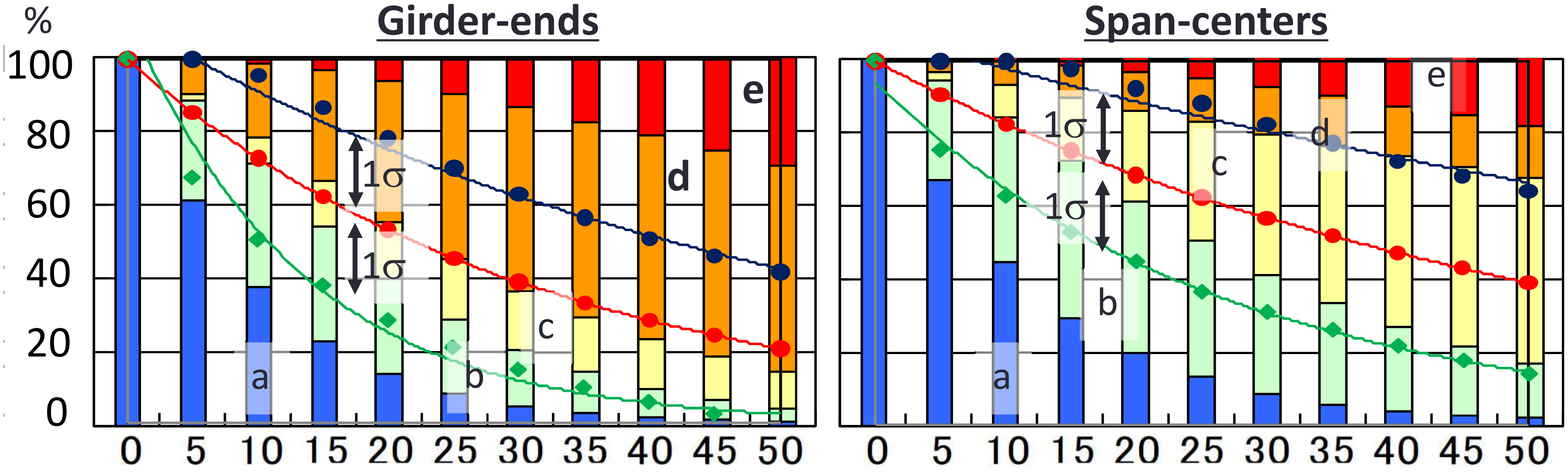
# Contribution & Challenge by NILIM (1/2)

NILIM carried out stochastic analysis using segment-level inspection data of 24,000 bridges.




a-e: Damage extent of segment

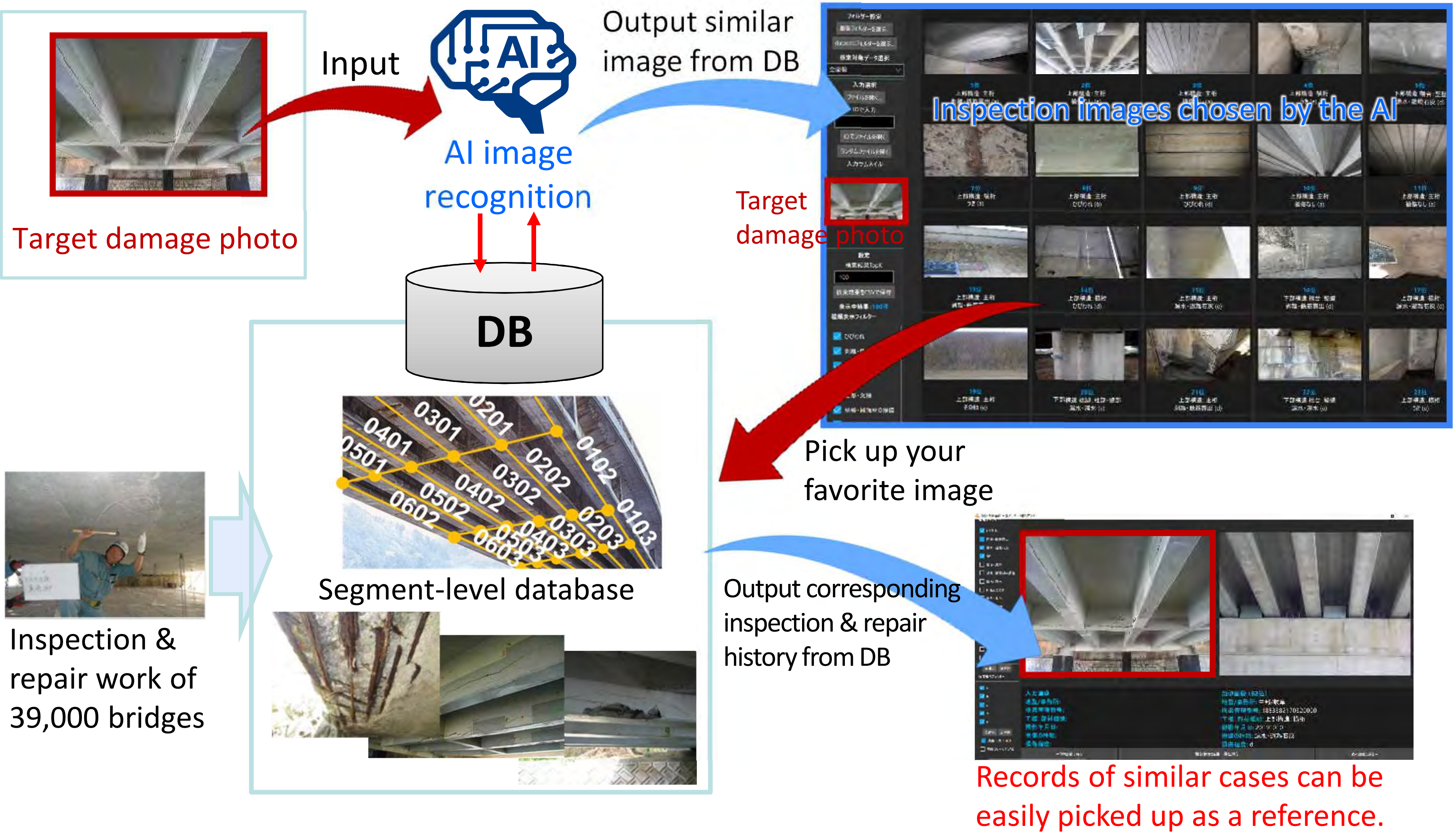
Example: Markov chain state transition probabilities for corrosion in steel I-girder beams




- ❑ Girder-ends and span-centers have different deterioration characteristics.
- ❑ Deterioration & LCC cost estimations have a large uncertainty.

# Contribution & Challenge by NILIM (2/2)

NILIM developed "AI image-searching application" for convenient use of inspection big data.



# Summary

- Learning precious lessons from the tunnel accident in 2012, periodic inspection was regulated to all road administrators and has been conducted since 2014.

- Overall inspection result seems improving but still takes a few decades to change our major work from “follow-up repair” to “preventive maintenance”.

- Administrators, especially those in municipalities, feel the inspection cost is heavy and cost-cut by new technologies becomes an urgent issue.

- MLIT continues support for using new technologies.

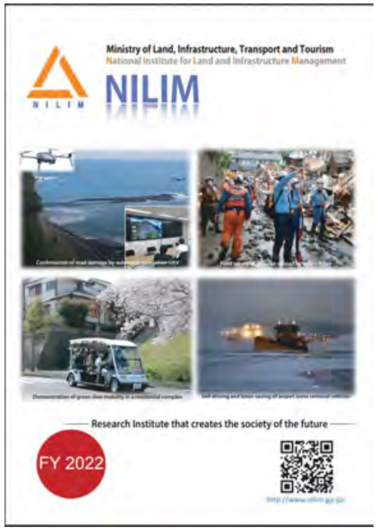
# Thank you for your kind attention！

## For more about NILIM…


NILIM Website (English)
http://www.nilim.go.jp/english/eindex.htm

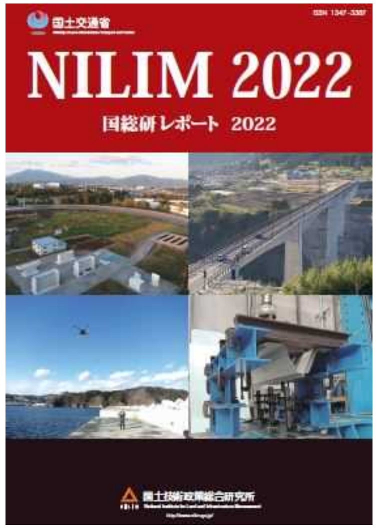
You Tube Channel
https://www.youtube.com/channel/UC5l193hxIF1CrZ85DTBnm8Q

Brochure




http://www.nilim.go.jp/english/about/nilim2022e.pdf

Annual Report




http://www.nilim.go.jp/english/annual/annual2022/ar2022e.html

2022 International Joint Seminar of VJU and NILIM

# Efforts to Identify Passable Roads after Disasters from Road Traffic Big Data

Researcher, Intelligent Transport Systems Division,
Road Traffic Department, NILIM, Japan

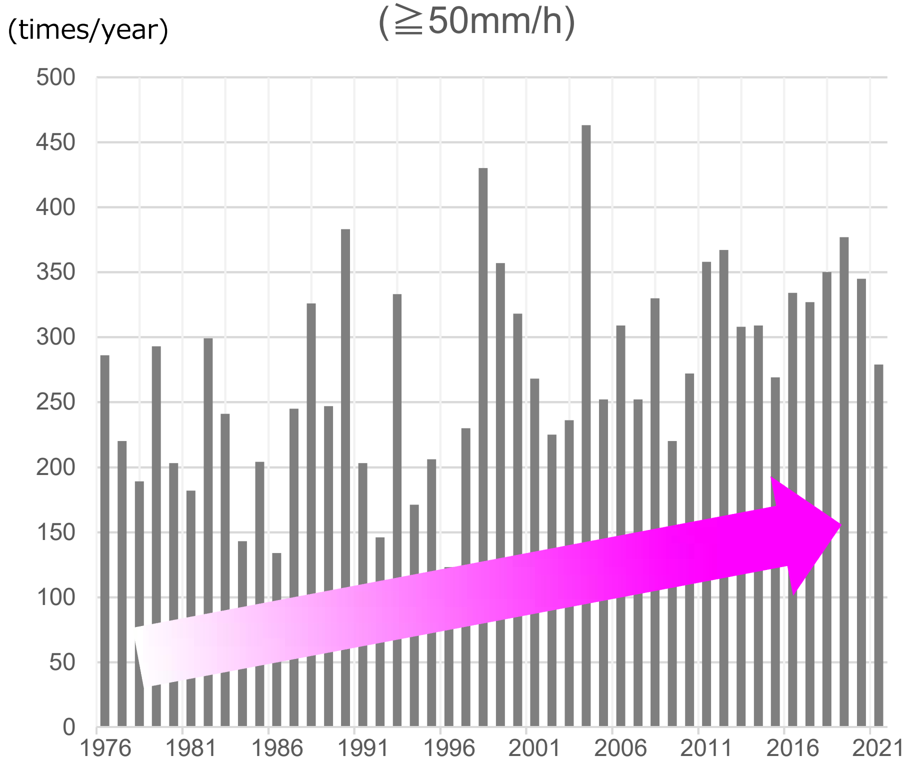
ISHIHARA Masaaki

# Contents

# 1. Introduction

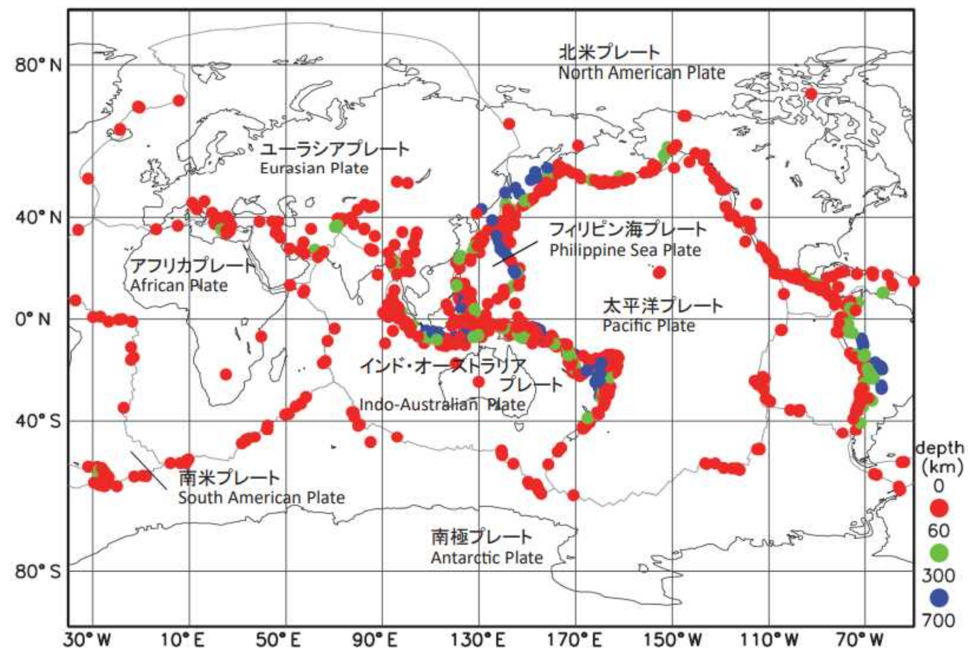
- In Japan, flood damage has become more severe, and the danger of large-scale earthquakes is increasing.
- In the event of a disaster, it is necessary to provide drivers with road closure information as quickly as possible.

Number of annual occurrences of rainfall (≧50mm/h)




https://www.data.jma.go.jp/cpdinfo/extreme/extreme_p.html

Hypocenter distribution of magnitude (≧6) 2012-2021




https://www.bousai.go.jp/kaigirep/hakusho/pdf/r4_all.pdf

# 1. Introduction

- Field studies are necessary to grasp the locations of road closures
- Lack of immediacy due to the time it takes to collect the initial information
- Demand for a system that provides road administrators with real-time information on non-passable roads and traffic

https://www.mlit.go.jp/river/sabo/jirei/r2dosha/r2_07gouu_201222.pdf

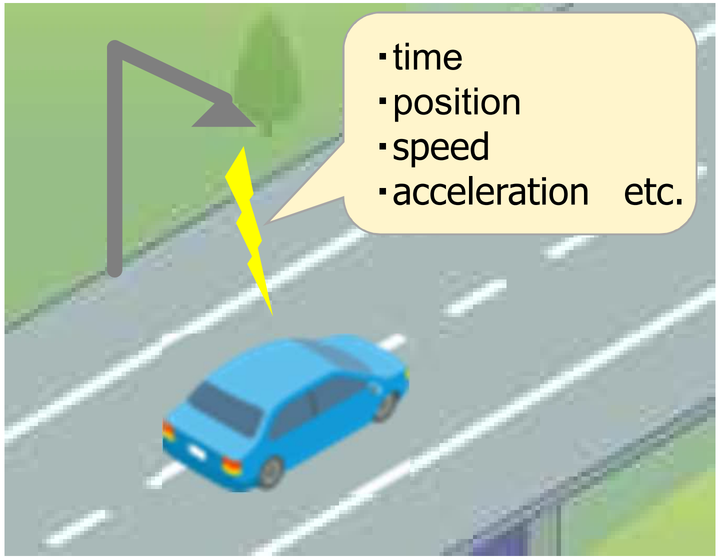
https://www.hido.or.jp/itsapq/jsp/auth/trab/no97/tokusyu5-10.pdf

# 2. Traffic Record Display System

## 2.1 Outline

- Information overlaid on a map: traffic records derived from vehicle probe data.
- Grasp the traffic status of all roads in Japan.
- Identify passable routes that can be used to access disaster areas.


*E*lectronic *T*oll *C*ollection system

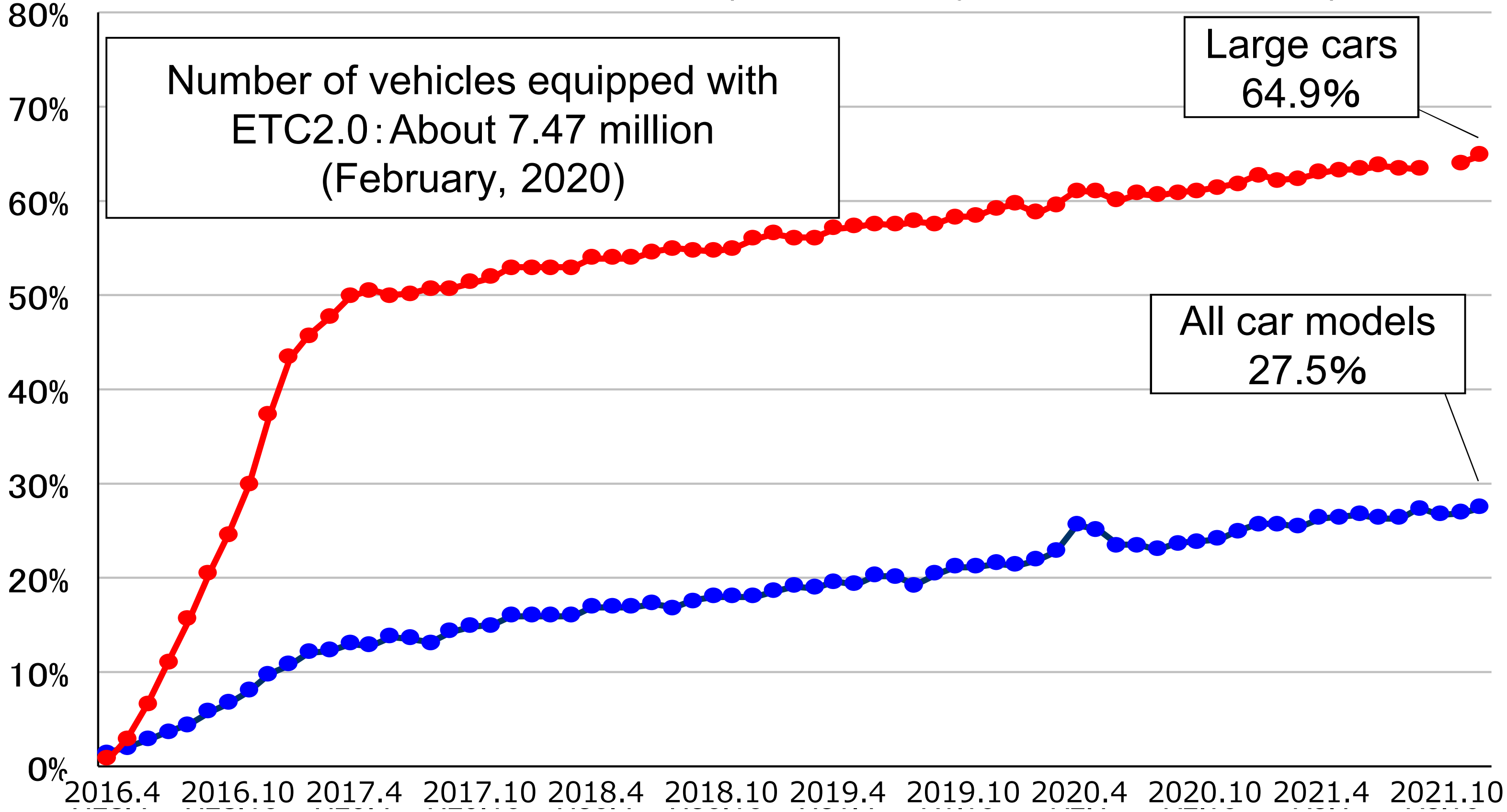


# 2. Traffic Record Display System

## 2.1 Outline

- Information overlaid on a map: traffic records derived from vehicle probe data.
- Grasp the traffic status of all roads in Japan.
- Identify passable routes that can be used to access disaster areas.

ETC2.0 penetration rate (expressway, December 2021)



# 2. Traffic Record Display System

## 2.2 Issues & Improvements

# Issues

- Lacking in terms of immediacy of data
- Adapting to big data
- Difficulty comparing with past data
- Deterioration and obsolescence

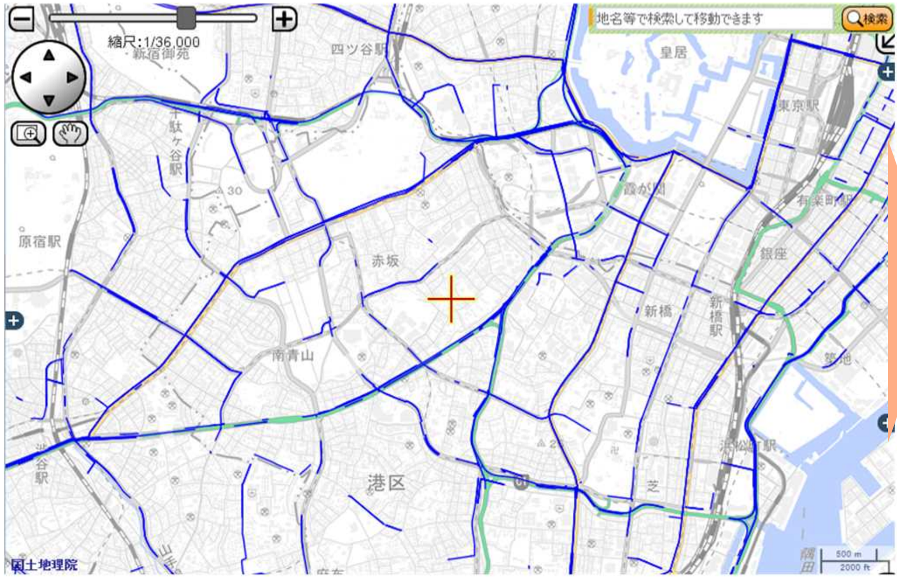
# Improvement

I. Display the traffic record
II. Segmented display by road type
III. Immediacy of data
IV. Displayable time frame

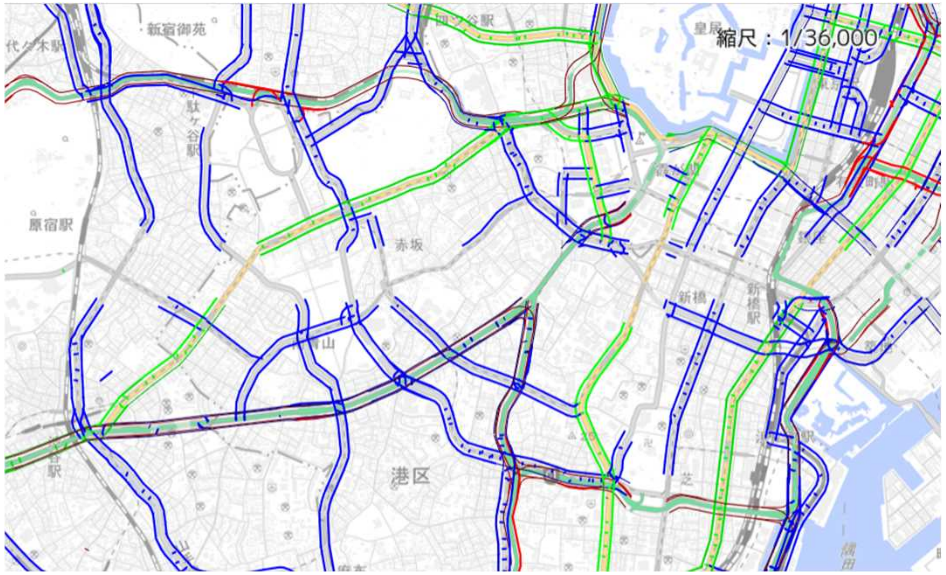
# 2. Traffic Record Display System

## Ⅰ. Display the traffic record

Before upgrade




After upgrade




- ➢ Display roads traveled by one or more vehicles on a map
- ➢ Display content cannot be adjusted according to conditions

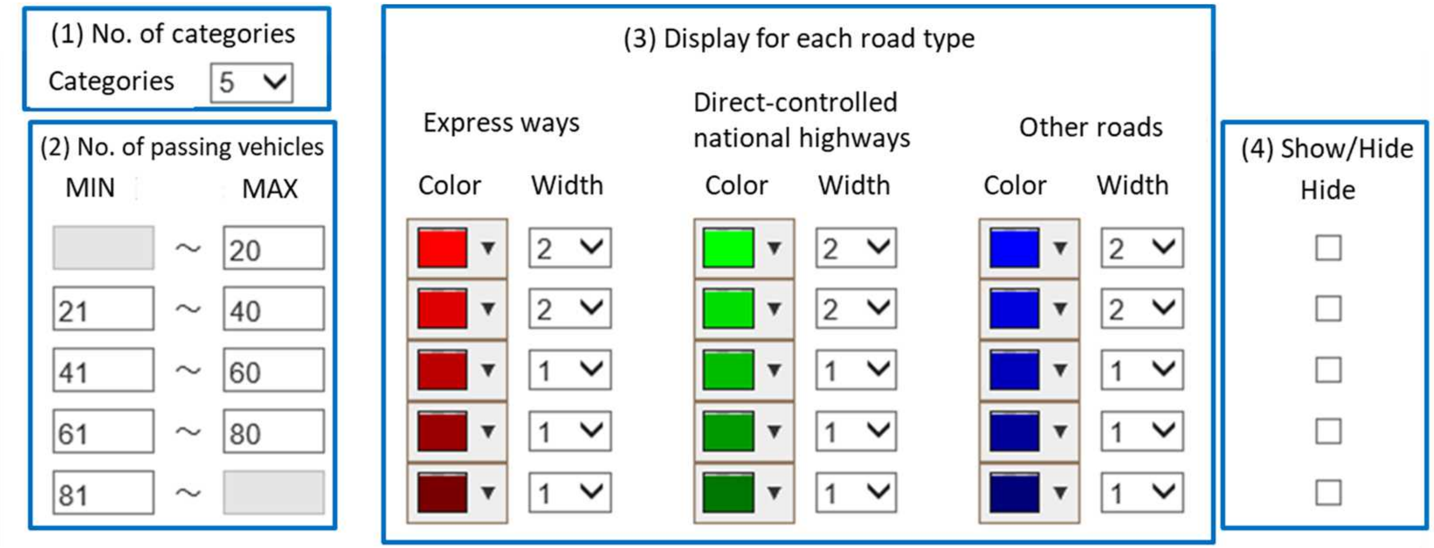
- ➢ Free settings can be made according to traffic conditions and regions

Example of display

## Ⅰ. Display the traffic record

Improved to display the number of passing vehicles classified by category

(1) Number of categories displayed
(2) Classification by number of passing vehicles
(3) Display for each road type
(color and width of displayed lines)
(4) Lines can be shown or hidden



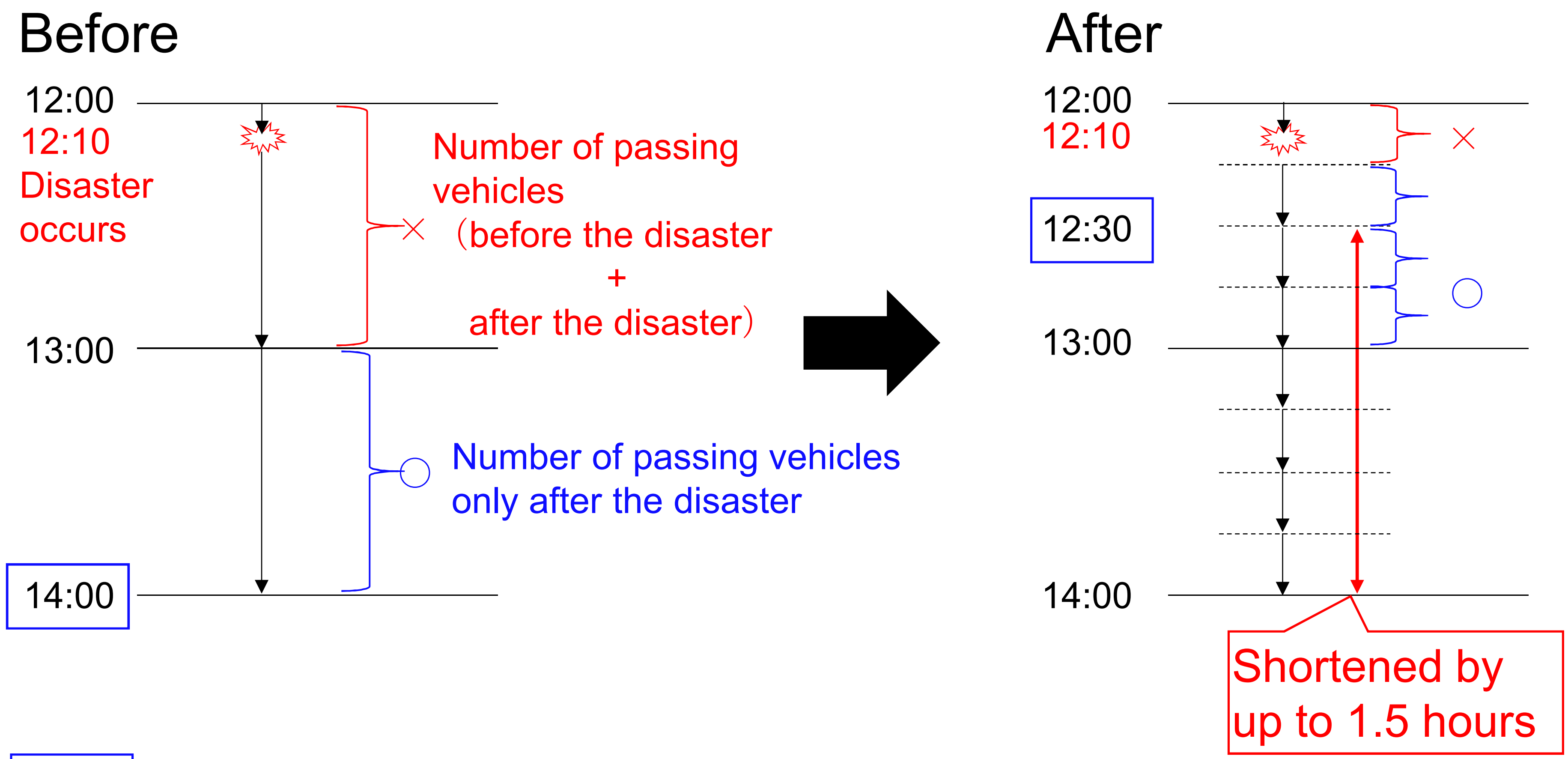

Example display settings for number of passing vehicles

## Ⅱ. Segmented display by road type

- Before the upgrade, the system would display traffic records on the map by road type in two categories.
- Because road type is not segmented, jurisdiction of the road administrator cannot be determined on the map.
- Improved the system to allow for segmented display by road type.

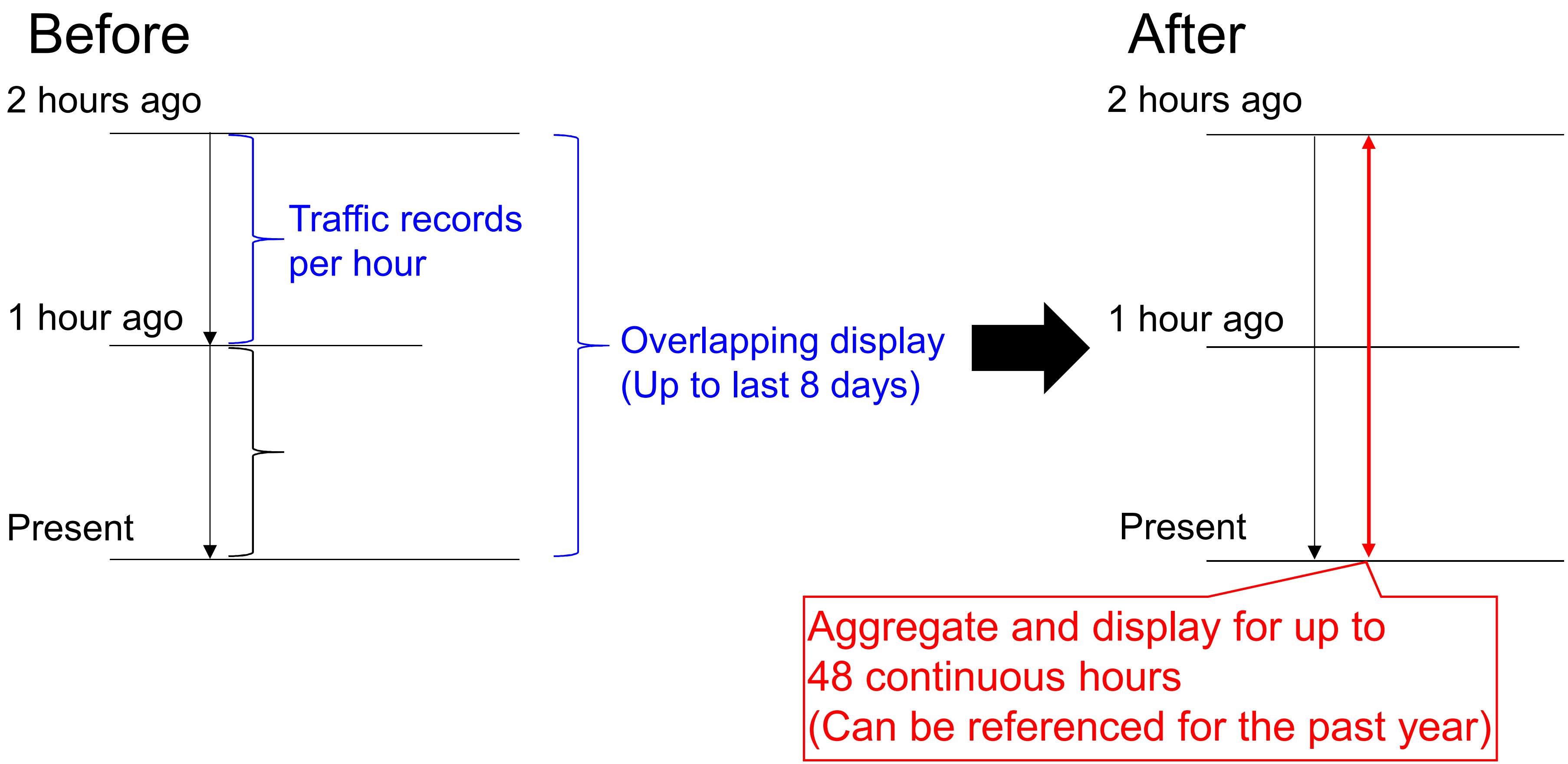

Example of display by road type

## Ⅲ. Immediacy of data




: the time when the system can output the number of passing vehicles after the disaster

## Ⅳ. Displayable time frame




Upgrade of displayable time frame

# 3. Application Examples

## About the 2020 Kyushu Floods

Number of victims

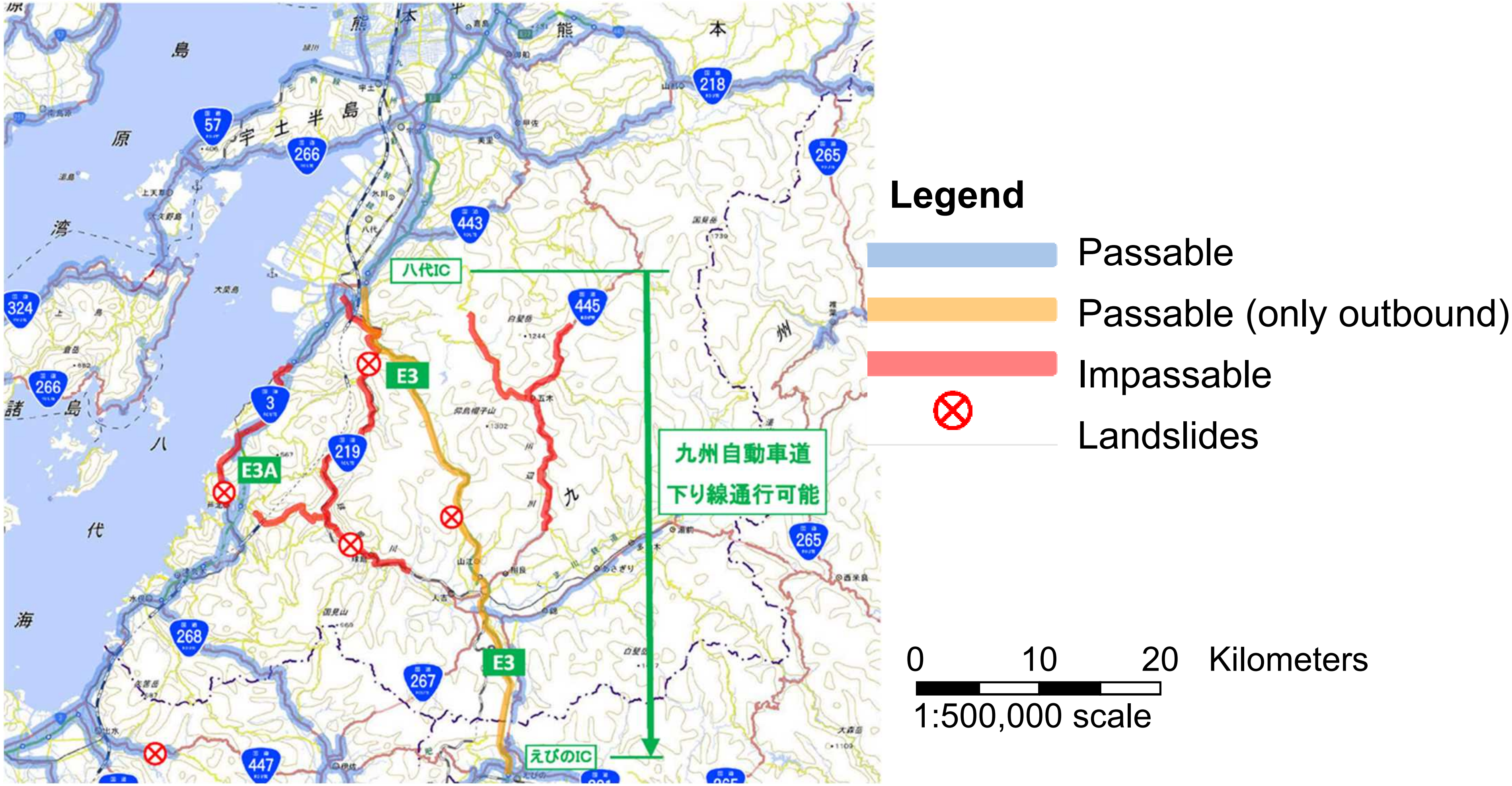
| Missing and dead | Injured |
|---|---|
| 86 | 77 |

Number of damaged houses

| Completely or partially destroyed | Flooded |
|---|---|
| 6,129 | 6,825 |


| | |
|---|---|
| July 4 at 3:50 a.m. | Put on high alert |
| July 4 at 4:50 a.m. | Heavy Rain Emergency Warning |
| July 4 at 5:00 p.m. | Published Passable Map on the Internet |

# 3. Application Examples




The publicly available Passable Map (first version)

# 4. Conclusion

- System utilizes vehicle probe data collected by MLIT
- System aggregates and visualizes traffic records
- Road administrators can promptly grasp traffic restrictions
- Possible to promptly provide road users with information

### In the future

- Gain an understanding of the needs and opinions of users
- Evaluate the system
- Implement function improvements

# Prevention and mitigation of sediment disasters in Japan

Kazuya AKIYAMA

Research Coordinator for Sediment Disaster Prevention,
Sabo Department, NILIM

# Contents

1. Sediment disasters in Japan
2. Non structural measures
   (Land-use regulation and control)

# 1. Sediment disasters in Japan

# What is sediment disasters?

Sediment disasters can be generally classified in a debris flow, a landslide, and a slope failure

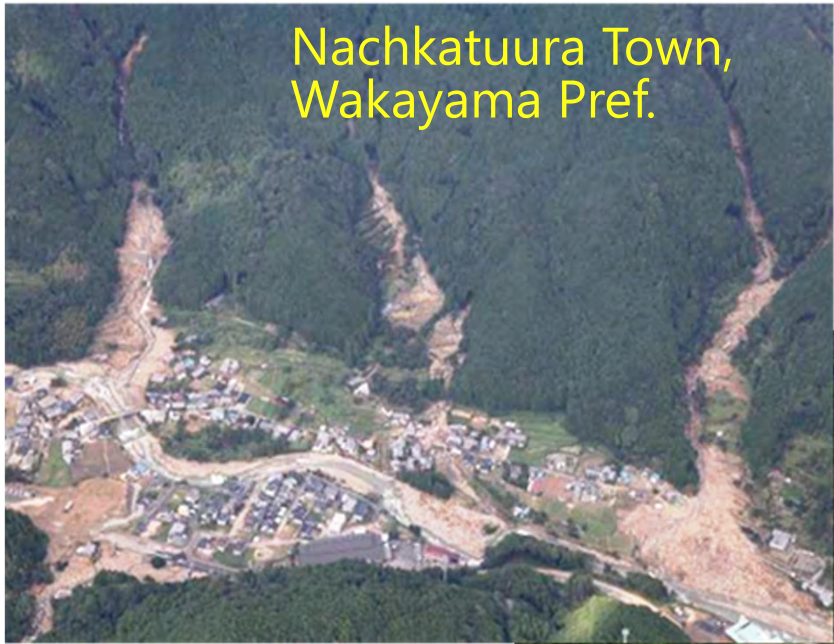
Sediment disaster

- Debris flow: flowing earth and sand from upstream
- Landslide: moving earth and sand on a gentle slope
- Slope failure : moving earth and sand on a steep slope

Others：Disasters or phenomena supported by Sabo (Sediment disaster prevention) Works

- Drainage sediment control: prevent sediment from flowing downstream and rising river bed
- Driftwood disaster: prevent fallen trees from flowing downstream
- Snow avalanche: avalanches damage to community
- Volcanic eruption: volcanic mud flow, debris flow, etc.

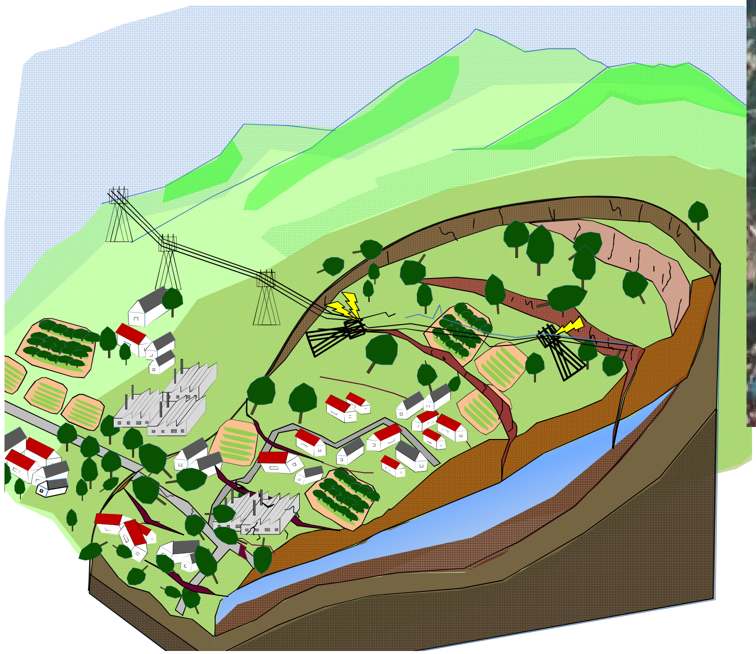
# Debris flow





Part of soil, stone and gravel making up a hillside and river bed is intermingled with water from long-continuing or localized rainfall, etc. and is carried instantly downstream. The flow is called a “debris flow”. The velocity being 20-40 km/hour depending on the magnitude, the debris flow easily destroy houses and other structures all at once.

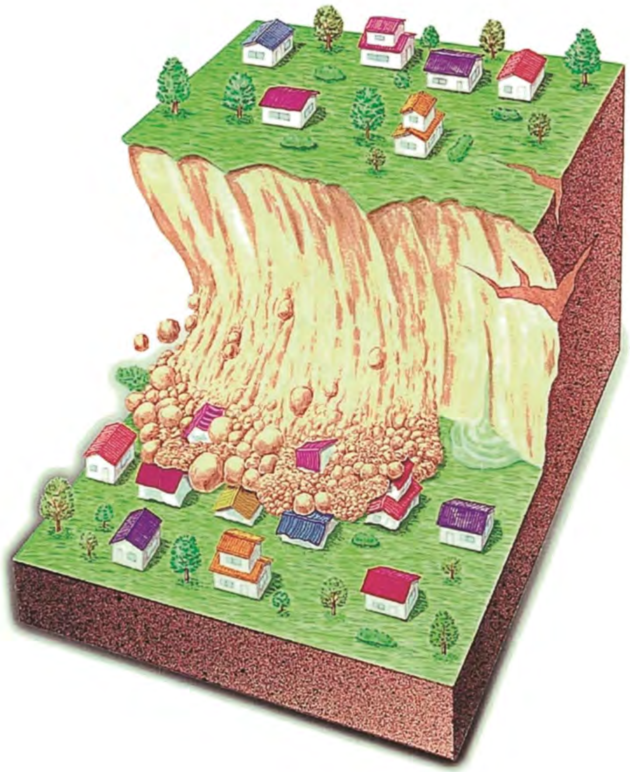
# Landslide





A landslide is a phenomenon in which soil mass on a slope moves slowly along the slip surface downward the slope under the influence of ground water and other causes. Since landslides occur over an extensive area and a large amount of soil mass is moved in general, it can cause serious damages.

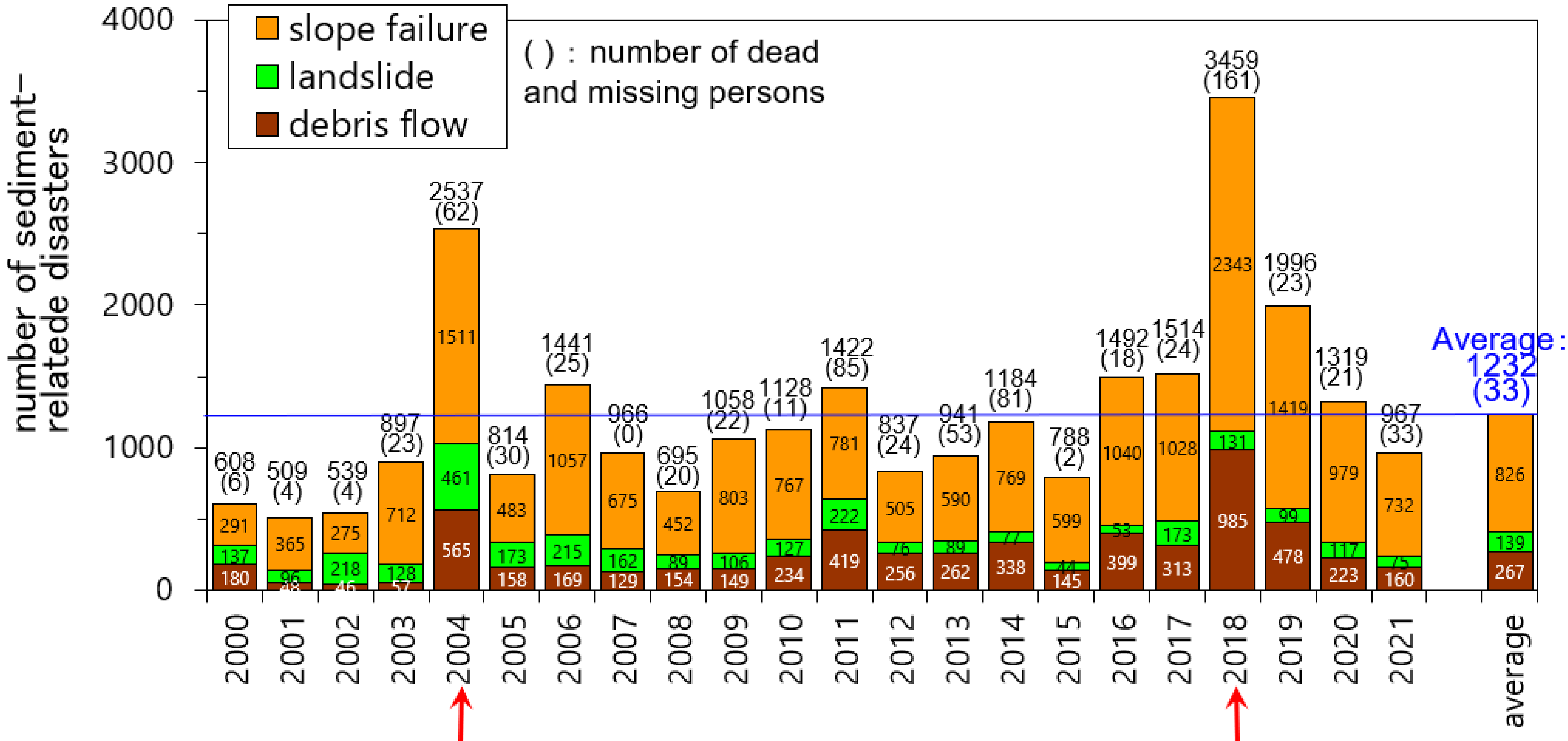
# Slope failure





A slope failure is a phenomenon that a slope collapses abruptly due to weakened self-retainability of the earth under the influence of a rainfall or an earthquake. Because of sudden collapse of slope, many people fail to escape from it if it occurs near a residential area, thus resulting in a higher rate of fatalities.

# Outline of sediment disasters from 2000 to 2021 (for 22 years) in Japan

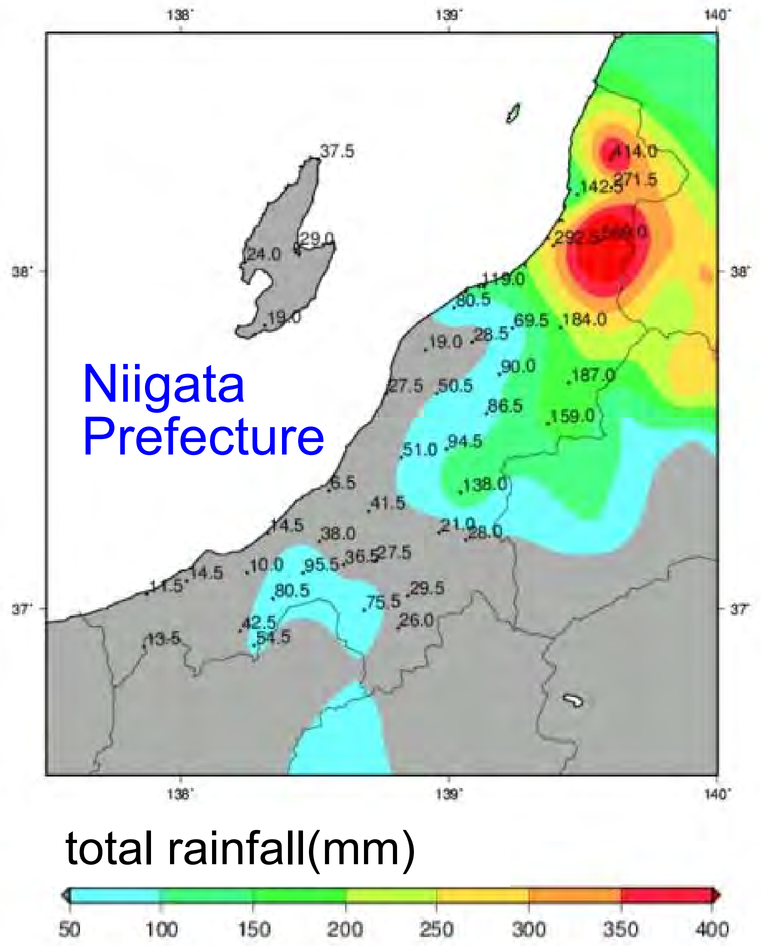



Heavy Rain in Niigata and Fukushima Prefectures in July, 10 typhoons, Mid Niigata Prefecture Earthquake in October

Heavy Rain in Western Japan in July, Hokkaido Iburi Eastern Earthquake in September

Data: Sabo (Erosion and Sediment Control) Department, Ministry of Land, Infrastructure, Transport and Tourism (MLIT)

# Sediment disasters caused by the heavy rain from August 3 to 5, 2022



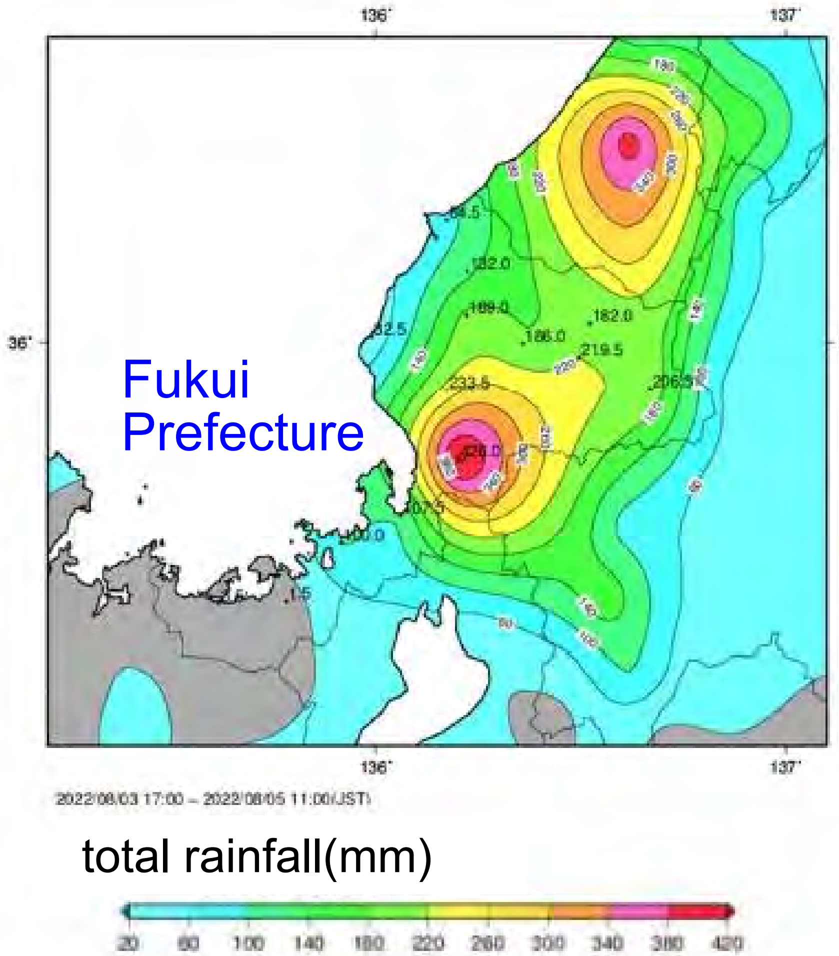

Figure：Japan Meteorological Agency(JMA)


Koiwauchi, Murakami City, Niigata Prefecture

Photos：Sabo (Erosion and Sediment Control) Department MLIT

Debris flow and driftwood disasters in the eastern part of Murakami City, Niigata Prefecture

# Sediment disasters caused by the heavy rain from August 3 to 5, 2022






National Road No.8



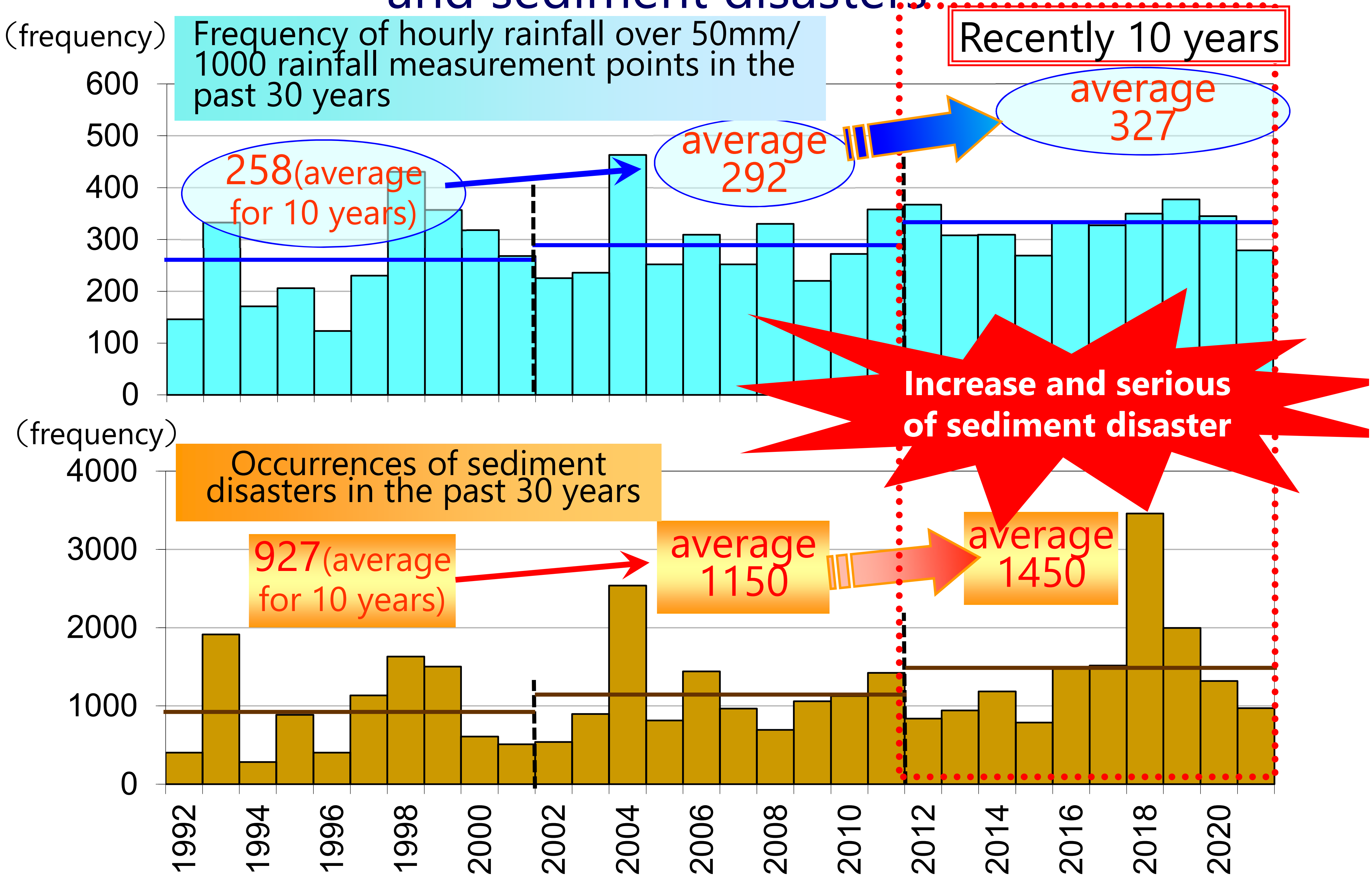
Hokuriku Expressway

Figure: Japan Meteorological Agency(JMA)

Photos: Explanatory materials for the 3rd meeting, Fukui Prefectural Disaster Traffic Management Study Group, Kinki Regional Development Bureau, MLIT

Debris flow disasters in Minamiechizen Town, Fukui Prefecture

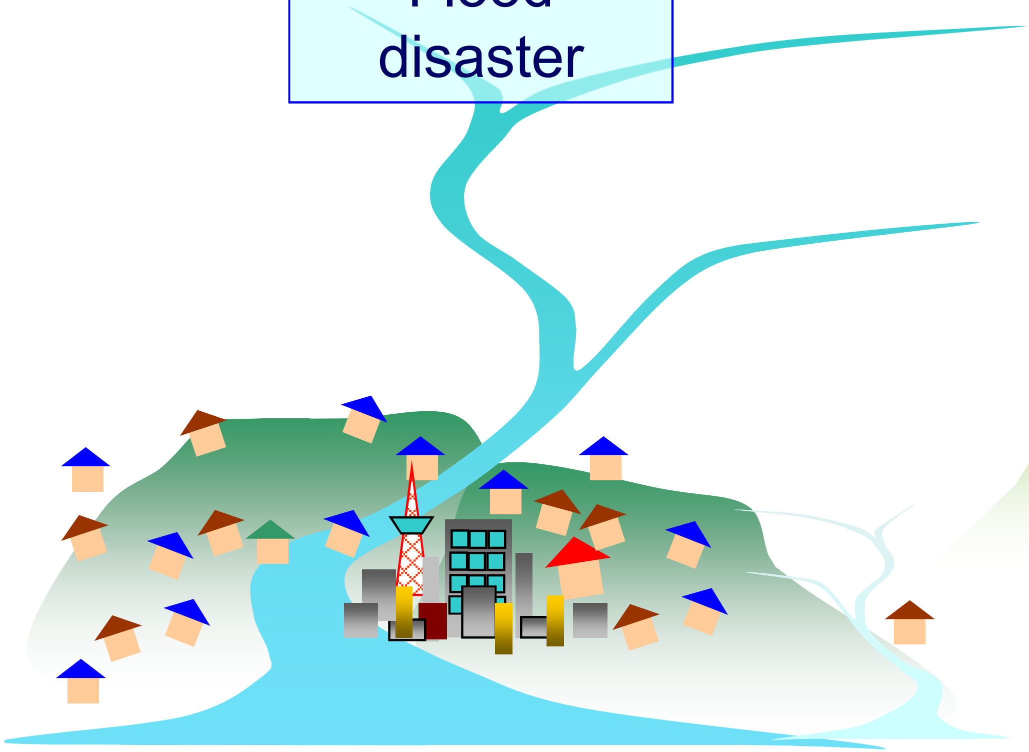
# Changes with the patterns of hourly rainfall and sediment disasters



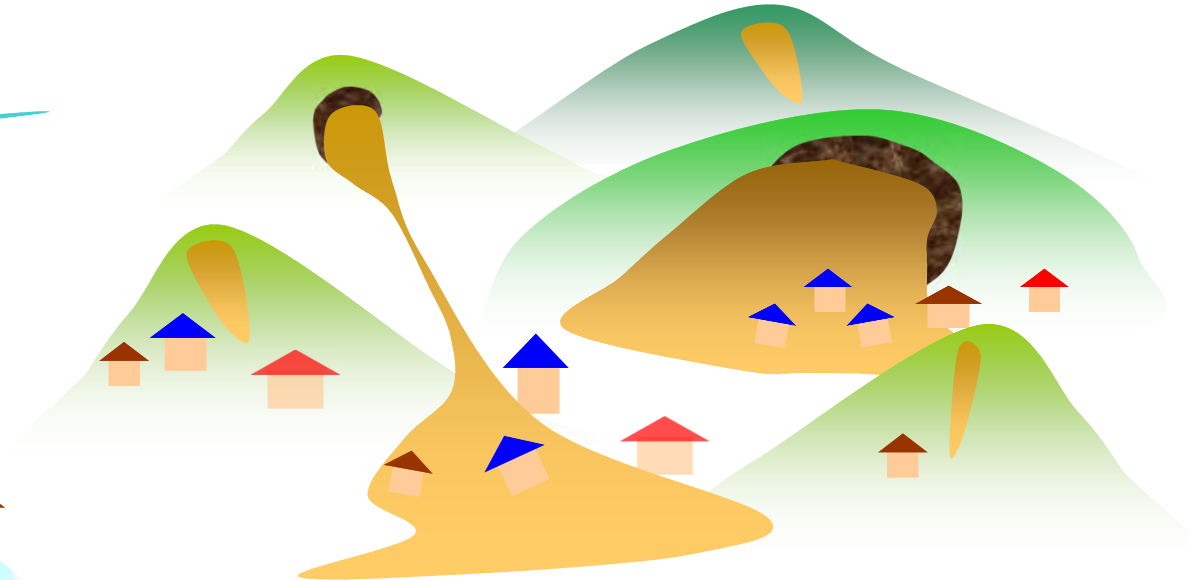

Data: Japan Meteorological Agency(JMA) and Sabo (Erosion and Sediment Control) Department, MLIT

# Comparison of flood disaster and sediment disaster

Flood disaster



Sediment disaster



## Keywords of flood disaster

1. Flood points exist inside river (flood area can be fixed)
2. Basic and trigger factors are limited (rain)
3. Sufficient period of time to evacuate (ex. rain→rising river water→disaster)
4. Water of rising river can be recognized and danger degree can be judged

## Keywords of sediment disasters

1. Sediment disaster points exist everywhere on slope
2. Basic and trigger factors are various (rain, rising groundwater level, earthquake, geomorphology, geology, etc.)
3. Unpredictable (sudden) phenomena (ex. earthquake→slope failure, rain→debris flow)
4. Phenomena can not be recognized because of under ground and danger degree can not be judged

# 2. Non structural measures
# (Land-use regulation and control)

- Sediment Disaster Prevention Law

# Three strategies for preventing sediment disasters (sabo works)

Protect people

Control development and protect people

**Land conservation**

Disaster mitigation/ Land monitoring

## Non-structural measures
Warning and evacuation

In areas designated as "sediment disaster hazard areas" based on the Sediment Disaster Prevention Laws
- Preparation of hazard maps for sediment disasters
- Strengthening of warning and evacuation system through preparation of sediment disaster warning information and their dissemination, improvement of information system, etc.

- Sediment Disaster Prevention Law

## Structural measures
Facilities against disasters

- Sabo works
- Landslide prevention works
- Slope failure prevention works

- Sabo Law
- Landslide Prevention Law
- Law on Prevention of Disasters Caused by Steep Slope Failure

Protect people & properties

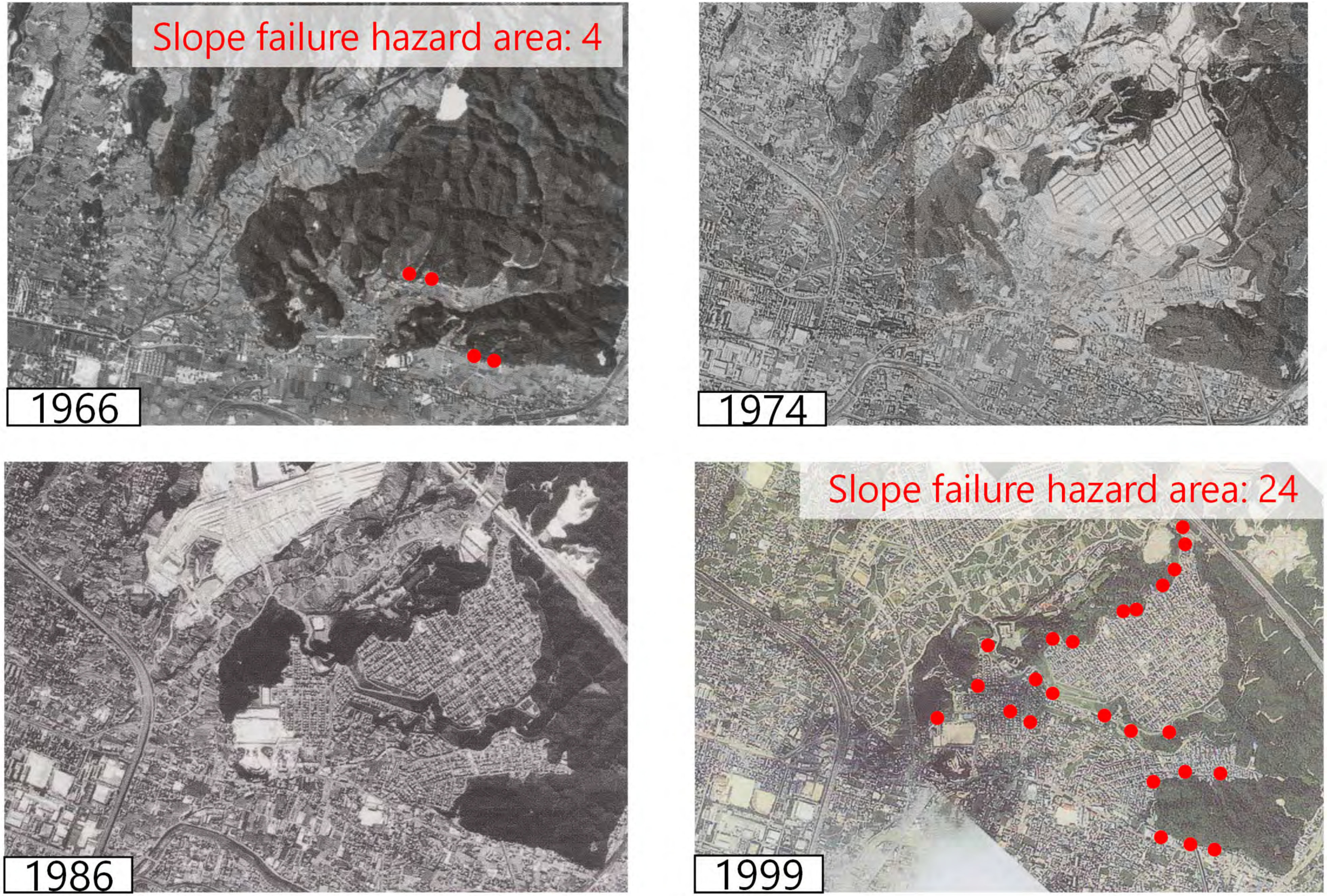
## Non-structural measures
Restriction on acts, land development and building structure

Sabo designated area, landslide and slope failure prevention areas
- Restriction on cutting tree, banking and other acts considered harmful for the conservation of land.

Special sediment disaster hazard area (Red-zone)
- Restriction on building structure
- Restriction on specific development works

- Sabo Law
- Landslide Prevention Law
- Law on Prevention of Disasters Caused by Steep Slope Failure
- Sediment Disaster Prevention Law

# Urbanization and sediment disasters




Situation of residential land development in Saeki Word, Hiroshima City

# Sediment disasters in the southwestern part of Hiroshima Prefecture on June 29, 1999

- sediment disasters in the southwestern part of Hiroshima Prefecture：325
- human damages：31 people died and 59 injured
- house damages：101 houses totally destroyed

集中豪雨 11人死亡

広島・山口・岡山・島根 23人が行方不明

広島・呉 土砂崩れ相次ぐ

1999年6月30日 中国新聞報道

# Outline of Sediment Disaster Prevention Law

The "Sediment Disaster Prevention Law*" was established with the intention of instituting comprehensive non-structural measures to protect people from sediment disasters. These non-structural measures include public of risk information of areas prone to sediment disaster, development of warning and evacuation system, restriction on new land development for housing and other specific purposes, and promotion of relocation of existing houses (legislated on May 2000).

* Law concerning the Promotion of Sediment Disaster Prevention in Sediment Disaster Hazard Area

Sediment Disaster under the Scope of the Law: Debris flow, landslide and slope failure

**Preparation of basic guidelines for preventing sediment disasters [Minister of the Land, Infrastructure, Transport and Tourism]**

・Basic policies for preventing sediment disasters
・Guidelines for basic survey
・Policy in the designation of special sediment disaster hazard areas
・Policy for relocation of buildings in special sediment disaster hazard areas

**Implementation of basic survey [Prefectural government]**

・Survey for designation of sediment disaster hazard areas and special sediment disaster hazard areas

**Implement basic survey**

Survey geomorphology, geology and land use of areas such as stream or slope where suffering sediment disasters

**Designation of sediment disaster hazard area (area prone to sediment disaster)[Governor of prefectural government]**

・Establishment of a system for the communication of information, and warning and evacuation
・Publicity of information on warning and evacuation to local people

**Designation of special sediment disaster hazard area (area where damages to building and serious hazards may be posed to residents) [Governor of prefectural government]**

・License system for specific land development
License is required for land development for housing and social welfare facilities
・Restriction on building structure (Building certification is required even for buildings outside the city planning area)
・Recommendation of relocation of buildings that are vulnerable to serious damages in case of a sediment disaster
・Financing and funding for those who move their residence to a safe area under recommendation

**Designate hazard area**

Designate areas based on the basic survey

**Sediment disaster hazard area (Yellow zone)**
**(area prone to sediment disaster)**

**Special sediment disaster hazard area (Red-zone)**
**(area where damages to building and serious hazards may be posed to residents)**

# Determination of sediment disaster hazard area (Yellow Zone)

## Debris flow

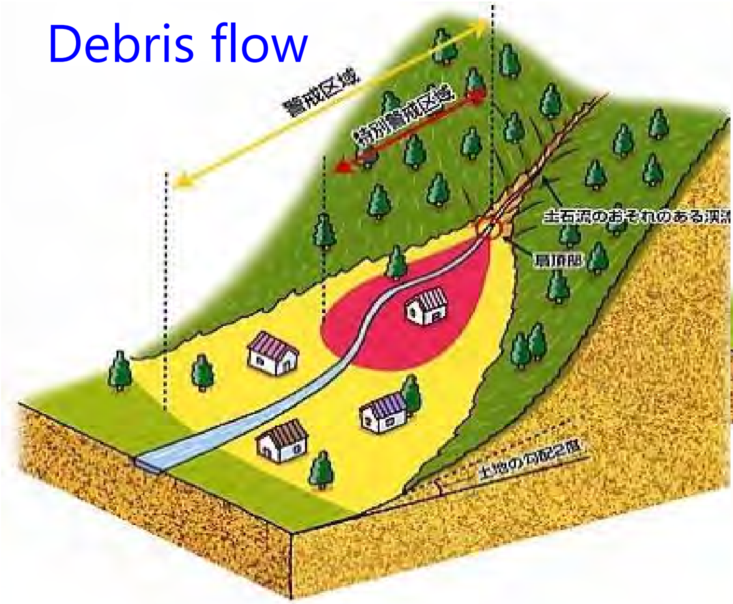
Area located under a torrent prone to debris flows and having a slope gradient 2 degrees or more below the crest of the alluvial fan.

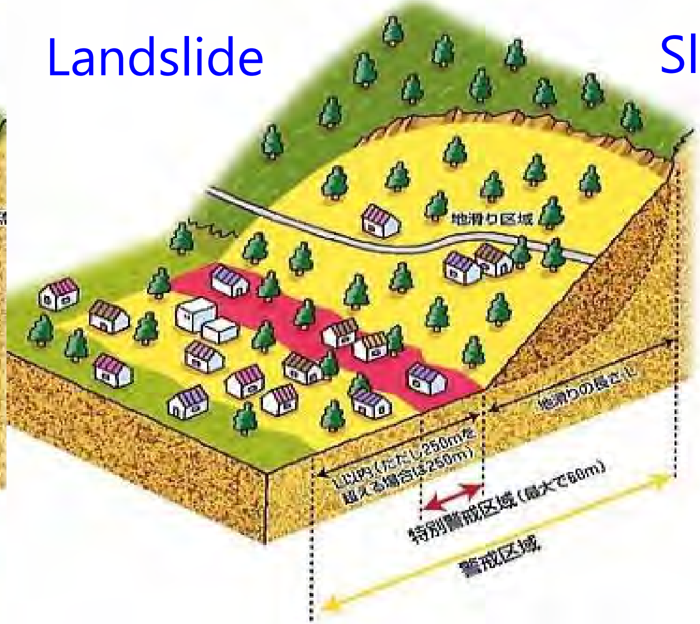
## Landslide

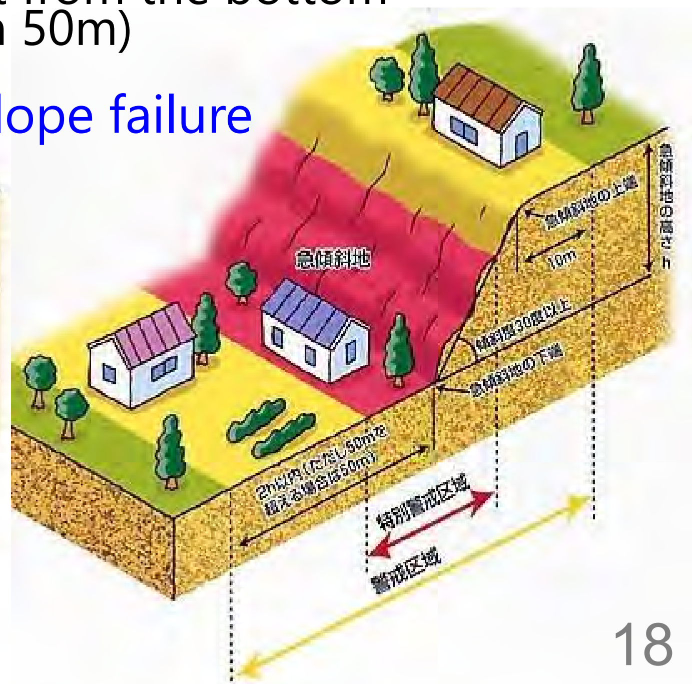
- Landslide area (Area which is currently prone to landslides or possibly vulnerable to landslide in future)
- Area included within a distance equivalent to the length of the landslide mass from the bottom end of the landslide area (250m if the length of the landslide mass is longer than 250m)

## Slope failure

- Area having a slope gradient of 30 degrees or more and slope height of 5m or more
- Area included within a 10m horizontal distance from the top end of the slope
- Area included within a distance twice the slope height from the bottom end of the slope (50m if the slope height is more than 50m)

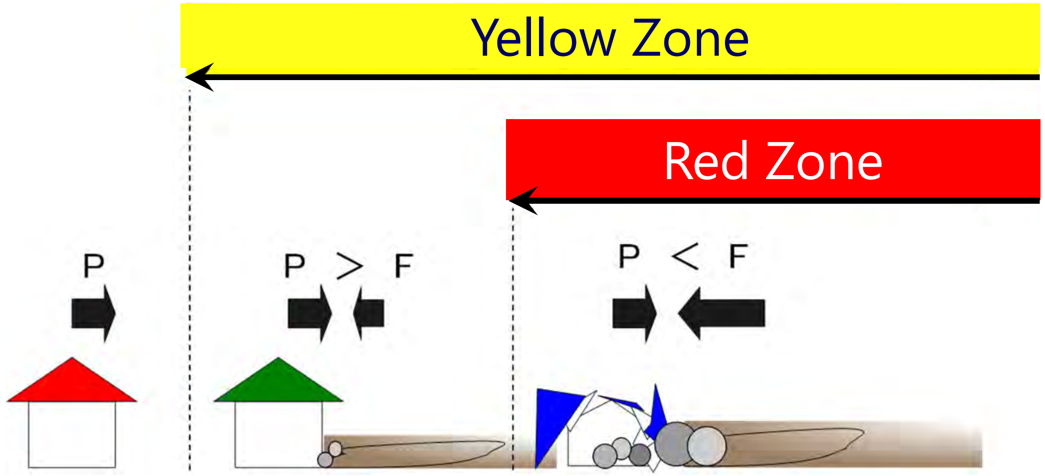


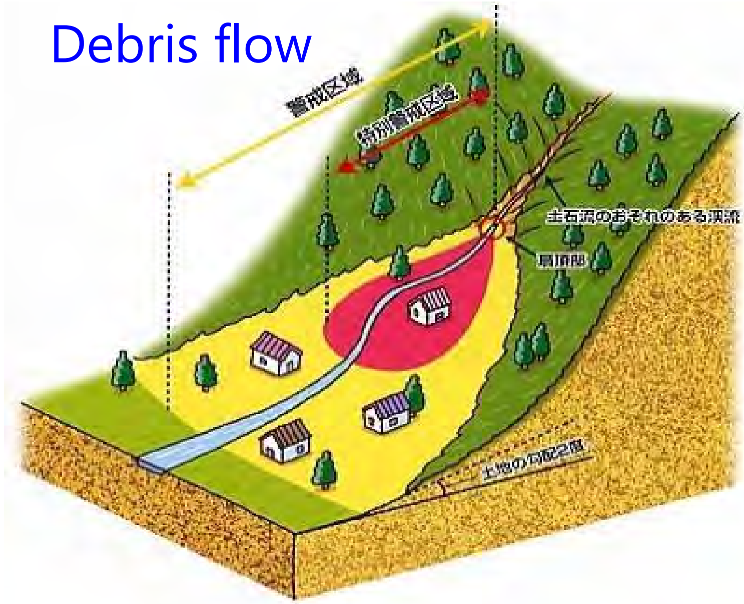
# Determination of special sediment disaster hazard area (Red Zone)

Area in which the magnitude of force exerted on a building by the movement of earth and rocks caused by slope failure exceeds the structural strength that an ordinary building can withstand without causing injury or death.

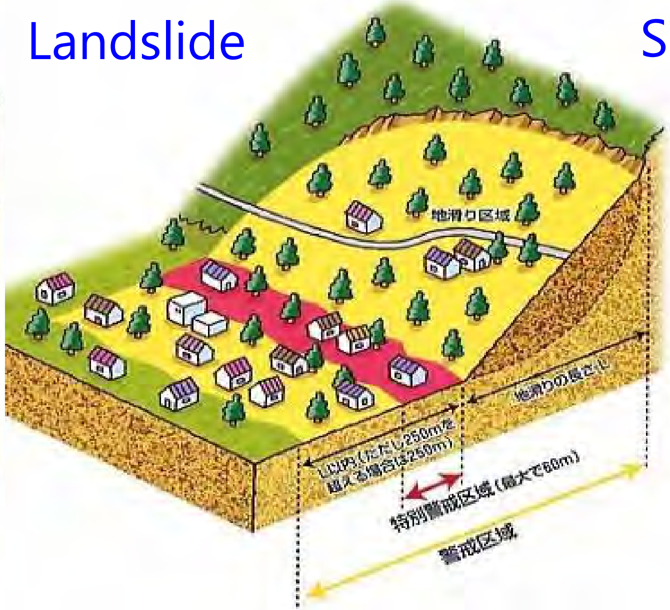



*In case of a landslide, the above-stated force is the magnitude of force that acts on a building in 30 minutes after debris and rocks starts to act on the building by the sliding land block. The landslide hazard area is an area included within a 60m-distance from the bottom end of the landslide area.

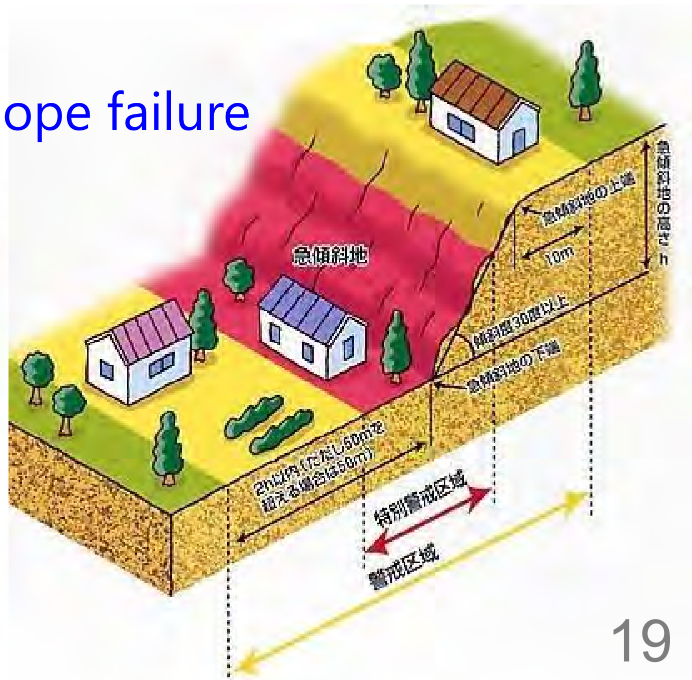
Debris flow




Landslide




Slope failure

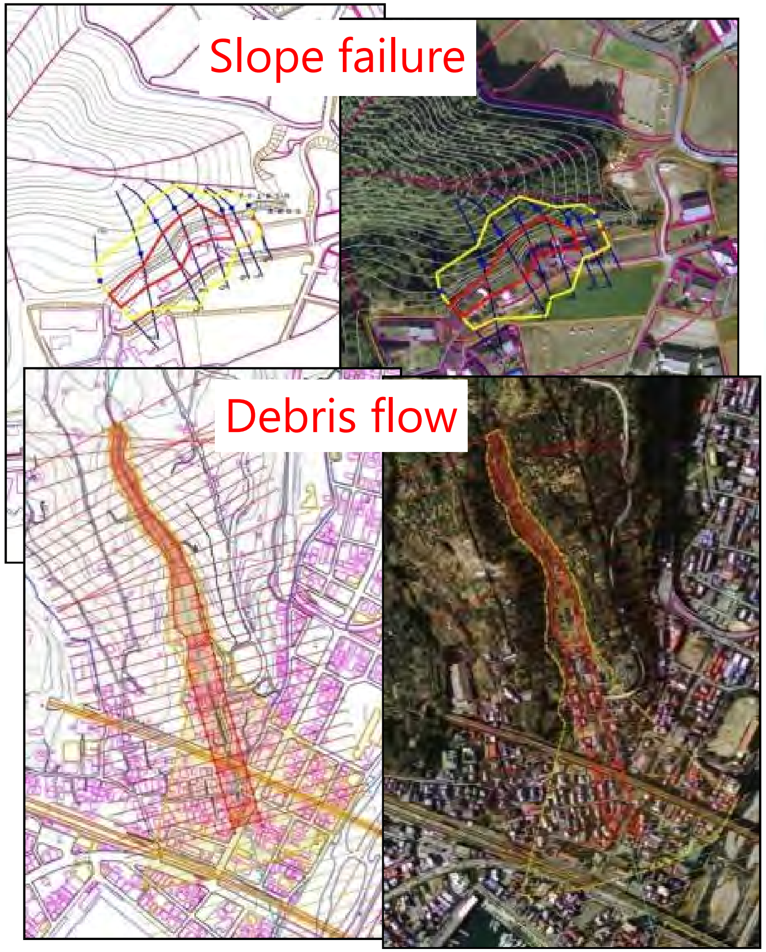


# Sign board of sediment disaster hazard area (Yellow zone) and special sediment disaster hazard area (Red zone)


# Example of sediment disaster hazard area (Yellow & Red Zone)

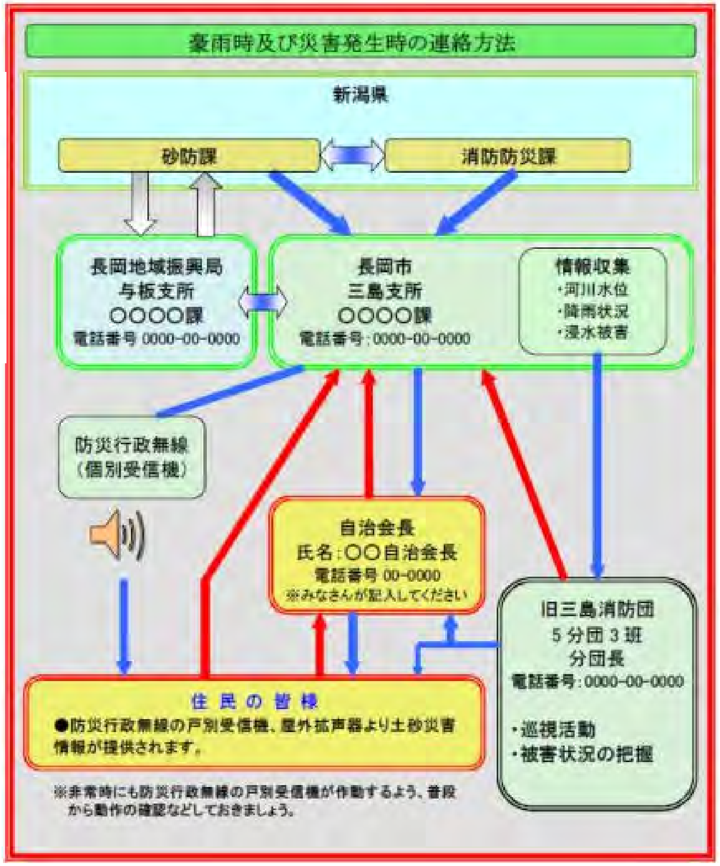
# Sediment disaster hazard map

A hazard map against sediment disaster shows the relation between debris flow, landslide, and slope-failure hazard areas and evacuation places, evacuation routes, method of transmitting information at the event of sediment disaster, and necessary matters in order to ensure smooth warning and evacuation.




Sediment disaster hazard area

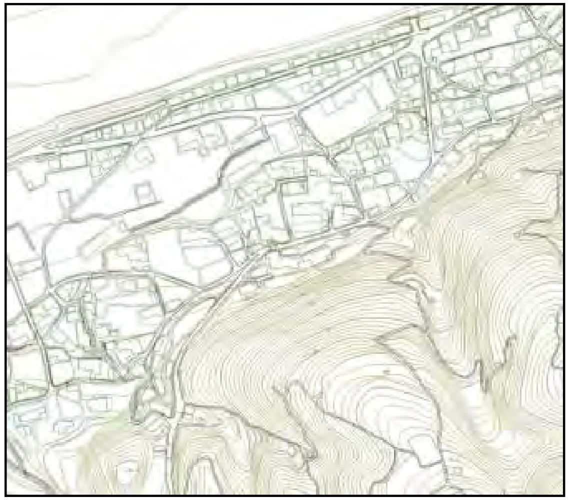

Evacuation places and disaster classification




Method of transmitting information

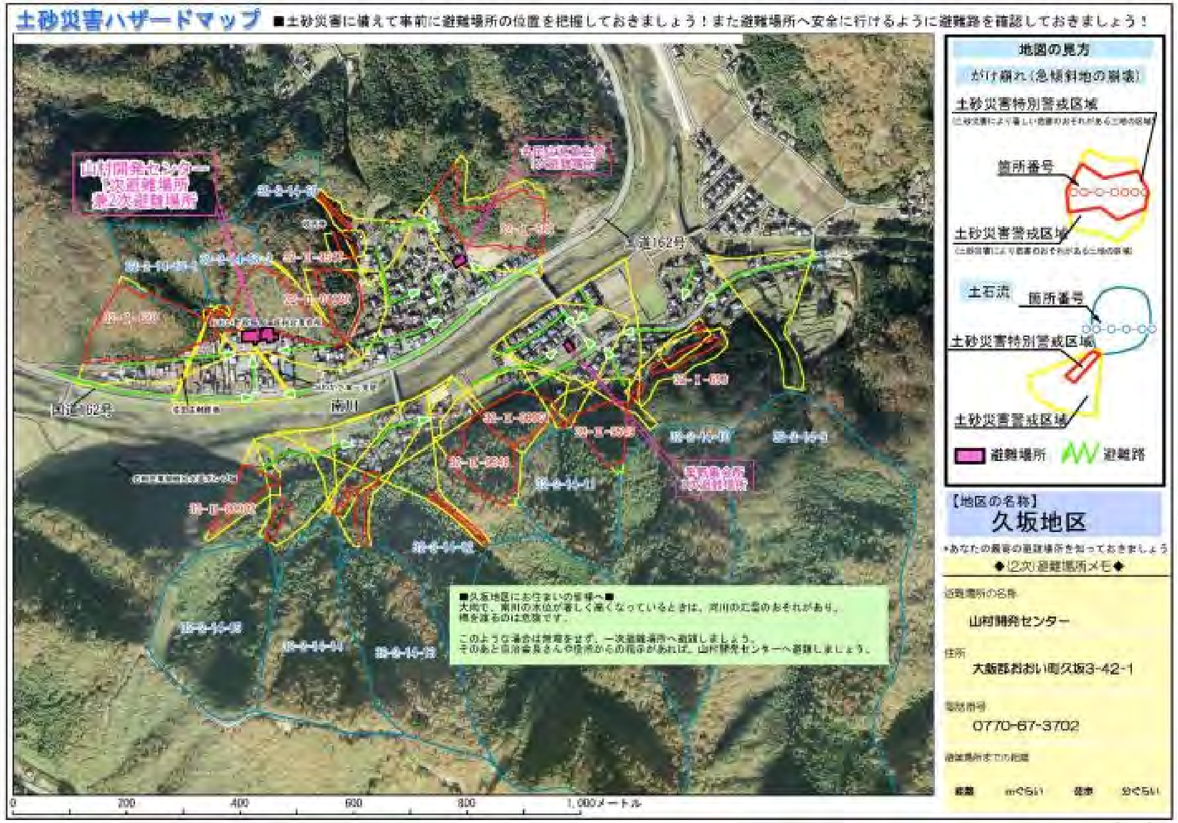
# Examples of sediment disaster hazard map


Kouchi district, Saeki Word, Hiroshima City



Digital Mapping data

Aerial photo (orthophoto)




Kusaka district, Ohi Town, Fukui Prefecture

# Summary

## Three strategies for preventing sediment disasters

- Structural measures (Facilities against disasters)
  - ➢Hard measures are important to protect people life and properties
- Non structural measures (Warning and evacuation)
  - ➢Protect people even if properties are damaged
- Non structural measures (Restriction on acts, land development building structure)
  - ➢Do not increase hazard area

Thank you for your attention

Kazuya AKIYAMA
Sabo Department, National Institute for Land and Infrastructure Management, MLIT
Asahi 1, Tsukuba, Ibaraki, 305-0804, JAPAN
e-mail：akiyama-k92ta@milt.go.jp

# Compressibility Characteristics of Soft Clays in the Red River Delta

*Presented by*

*Khin Phyu Sin*

# Content

# 1. Introduction

## Geological condition of the RRD

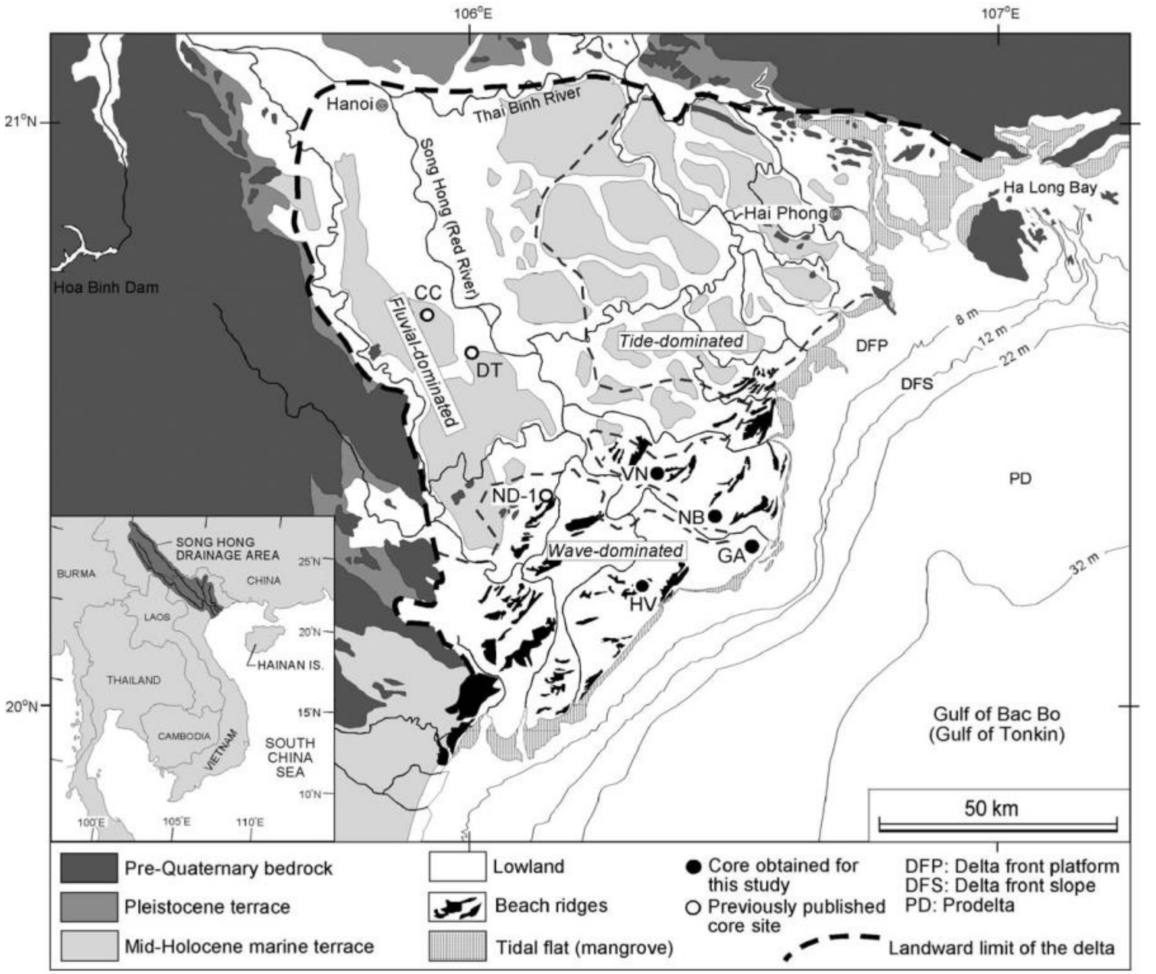
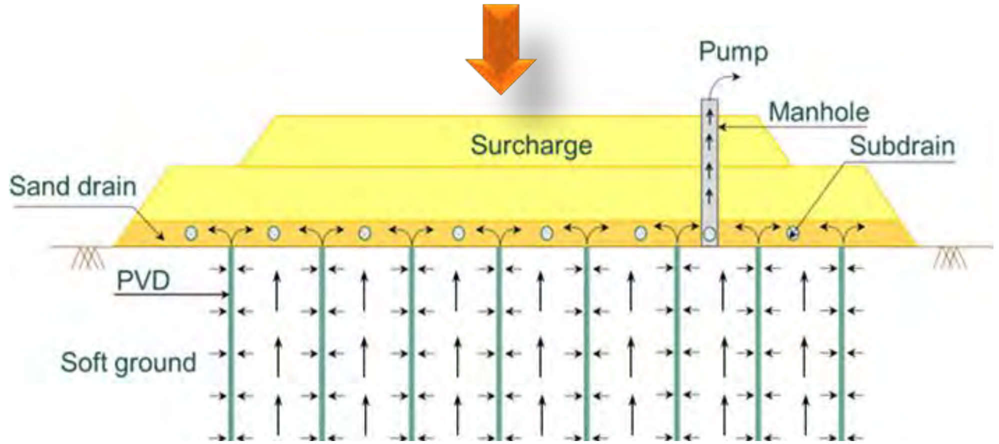


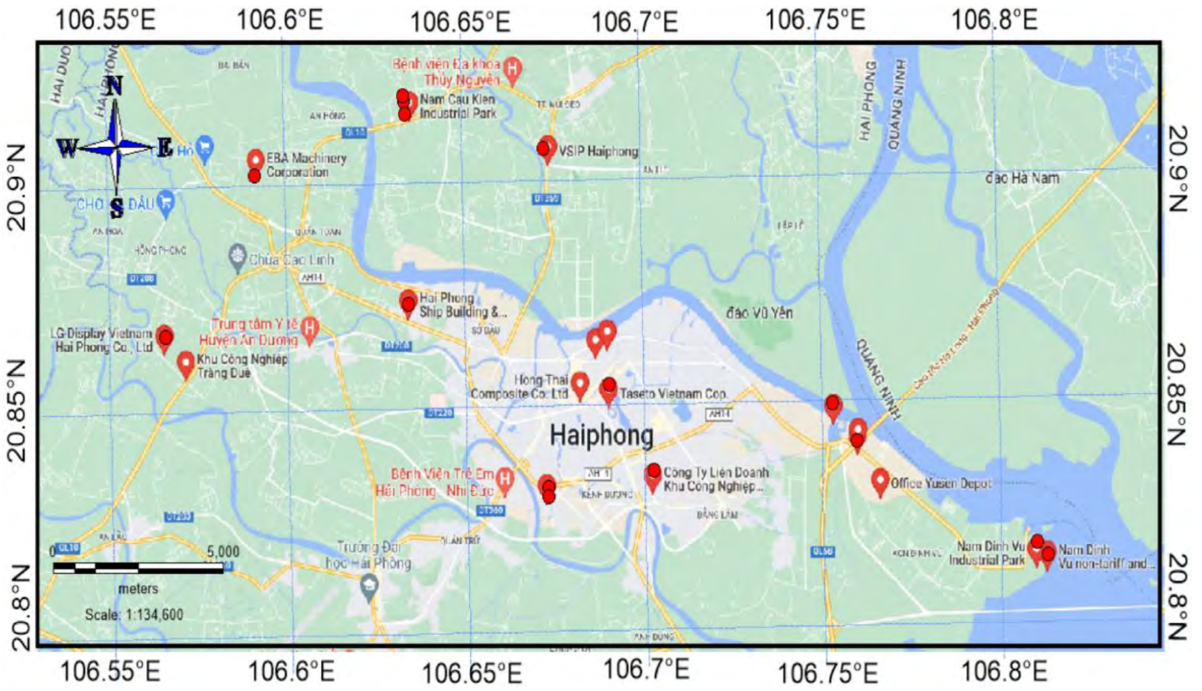

Figure 1. Quaternary geological and topographical map of RRD and adjacent areas (Tanabe et al., 2006)

- Second largest delta in Vietnam and fourth-largest delta in Southeast Asia, after the Mekong, Irrawaddy, and Chao Phraya deltas, in terms of delta plain area
- It was formed due to the sedimentation process throughout the Holocene period (9 kyr BP to date).
- Quaternary and Holocene sediments in the delta were strongly influenced by both fluvial and marine environments. Stratigraphic cross sections in the delta show the presence of fluvial sediments, estuarine sediments and deltaic sediments (Funabiki et al. 2007)
- The sediment accumulation curves (attitude vs age) from Tanabe et al., 2006 and Funabiki et al., 2007 indicate that up to the depth of about 40 m (from the present MSL), all deposits found from the cores are Holocene sediments with the age of less than 10 kyr;

# 1. Introduction

- The Red River Delta (RRD) includes many industrial zones (parks) and expressways where soft ground in large scale must be improved before the construction of facilities.
- Consolidation parameters, especially $c_r$ and $c_v$, are important parameters in estimating ultimate and time-dependence settlement values of the ground.




Many industrial Zones in Hai Phong City (similar to other provinces in the delta)

Excess Pore water pressure ($u$) at any time $t$ after loading

$$c_r\left(\frac{\partial^2 u}{\partial r^2}+\frac{1}{r}\frac{\partial u}{\partial r}\right)+c_v\frac{\partial^2 u}{\partial z^2}=\frac{\partial u}{\partial t} \quad \text{Eq. 1.}$$

where $c_r$ and $c_v$ = horizontal and vertical coefficients of consolidation of soil

Settlement of the improved ground at any time t

$$S_t=U_tS_c=\left(1-\frac{u}{u_0}\right)S_c=f\left(c_r,c_v,t,S_c\right) \quad \text{Eq. 2.}$$

where $S_c$ = ultimate consolidation settlement

# 2. Objectives of the Research

To evaluate horizontal coefficient of consolidation from consolidation test with central drain (e.g., $c_{r,CD}$) and with a peripheral drain (e.g., $c_{r,PD}$) of clays at some test sites in the delta using existing methods and to rank the reliability of the methods.

To examine the $c_{r,PD}/c_{r,CD}$ ratios from analytical solution on ideal soil and from experimental data on actual soil and the influence of some parameters to the ratios.

To evaluate compression index ($C_c$), recompression index ($C_r$) and preconsolidation stress ($\sigma'_p$) of the clays from the test sites and develop possible correlations for the parameters.

# 3. Methods used in this study for the determination of $c_r$, $c_v$, $C_c$, $C_r$, and $\sigma'_p$

**Methods to determine radial coefficient of consolidation, $c_r$, vertical coefficient of consolidation, $c_v$, compression index ($C_c$), recompression index ($C_r$) and preconsolidation stress ($\sigma'_p$) from Oedometer test**

| Table 1. Existing methods for the determination of $c_r$ from radial consolidation test with a CD using incremental loading | |
|---|---|
| 1 | Root t method (Berry & Wilkinson, 1969; Sridharan et al., 1996) |
| 2. | Matching $\log(d_e^2/t)$ vs. $U_r$ method (Sridharan et al. 1996) |
| 3. | Inflection point method (Robinson, 1997) |
| 4. | Non-graphical matching method (Robinson & Allam, 1998) |
| 5. | Log-log method (Robinson, 2009) |
| 6. | Steepest tangent fitting method (Vinod et al., 2010) |
| 7. | Log t method Sridhar & (Sridhar and Robinson, 2011) |
| 8. | Full-match method (Chung et al., 2017) |

| Table 2. Existing methods for determination of $c_r$ from radial consolidation test with a PD using incremental loading | |
|---|---|
| 1. | Root t method (Head and Epps, 1986) |
| 2. | Inflection point method (Ganesalingam et al., 2013) |
| 3. | Full-match method (Chung et al., 2019) |

| Table 3. Standardized methods used to determine the vertical coefficient of consolidation, $c_v$ | |
|---|---|
| 1. | Log t method (Casagrande and Fadum, 1940) |
| 2. | Root t method (Taylor, 1942) |

| Table 4. Methods to determine compression index ($C_c$), recompression index ($C_r$) and preconsolidation stress ($\sigma'_p$) from Oedometer test | |
|---|---|
| 1. | Casagrande (1936)'s method |
| 2. | Silva (1970)'s method |

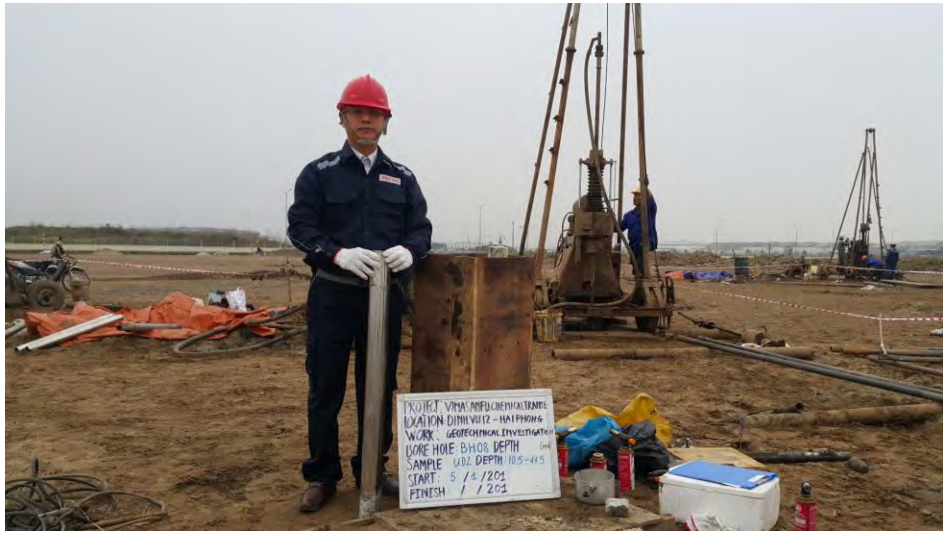
# 4. Location of the Study sites


Study sites for this research were taken from supervisor's research projects. They are:

1. Kim Chung Residential Complex (KC)
2. Dinh Vu industrial Zone (DVIZ)
3. Vietnam Singapore Industrial Park (VSIP)
4. Nam Dinh Thermal Power Project (TPP)

# 5. Sample Collections

## 5.2. Field tests



Example of soil boring and sampling at DVIZ site


Example of performance of CPTu test at DVIZ site

At each test site, soil boring and sampling were performed to collect soil samples for laboratory test. In addition, a CPTu sounding was also performed adjacent to the borehole (*carried out by the supervisor*).

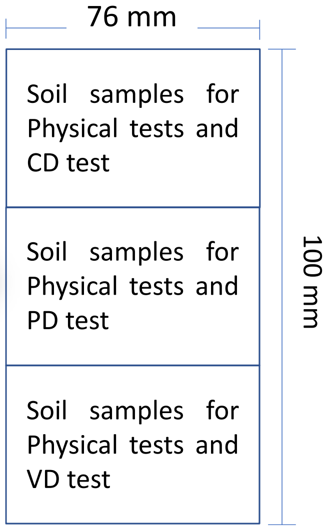
- ✓ For soil boring and sampling, the borehole was advanced by using the rotary wash method with the use of bentonite slurry to stabilize the borehole walls.
- ✓ At a sampling depth, a thin-walled fixed-piston tube sampler of 1.0 m long and 76 mm in inner diameter was hydraulically pushed down to collect undisturbed clay samples.
- ✓ Right after the sample tube was retrieved at the ground surface, the tube ends were cleaned and filled with paraffin and then carefully sealed by tape to preserve water content as well as integrity of the soil sample. All the boring and sampling procedures were carried out in accordance with ASTM D1452–09 and ASTM D1587–09, respectively.
- ✓ When the sampling at the borehole was finished, the sample tubes were then carefully transported to the laboratory for lab tests

# 5. Sample Collections

## 5.3. Laboratory tests

Sample tubes stored in the lab

Sample cutting in the lab



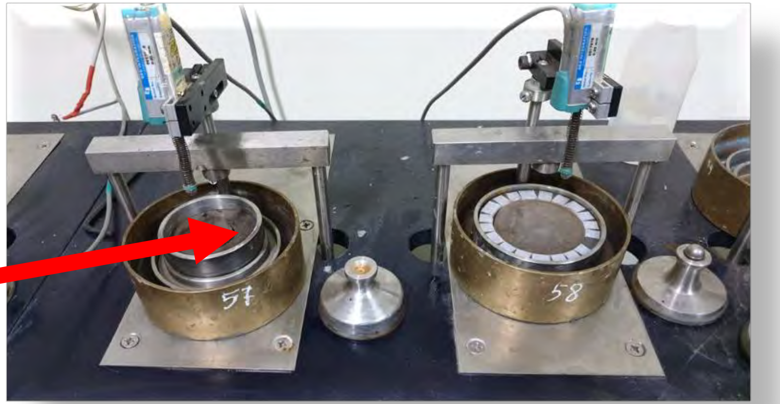

Parts of the sample taken for the tests

Physical tests, i.e., water content, specific gravity…

Consolidation tests with radial drainage (CD, PD, VD)

This central drain was manufactured so that the theoretical consolidation curves from a CD test and PD test are the same (***$n = D_e/D_c = 2.05$***).

Actual manufactured ratio: ***$n = 62/28 = 2.214$*** (some difference due to water jet cutting error)

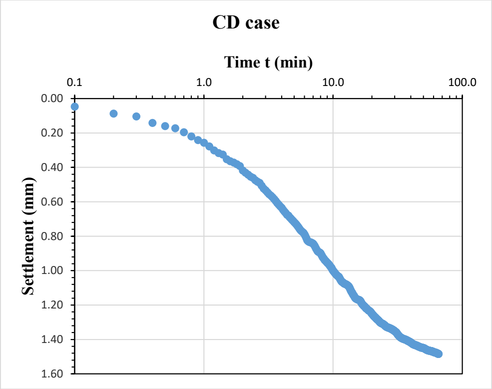


Performing the radial consolidation test in the lab

# 6. Analysis results and procedure

## 6.1. From implementation of the 1st objective

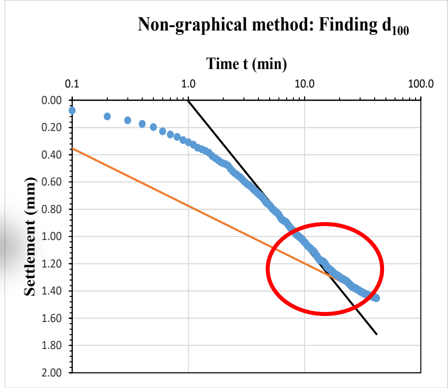
### Procedure for getting $c_r$ values

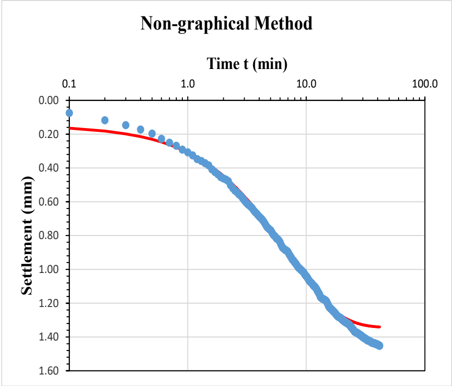



Consolidation curves obtained from the radial consolidation tests in lab (CD)

| Table 1. Existing methods for the determination of $c_r$ from radial consolidation test with a CD using incremental loading | |
|---|---|
| 1 | Root t method (Berry & Wilkinson, 1969; Sridharan et al., 1996) |
| 2. | Matching log($d_c^2$/t) vs. $U_r$ method (Sridharan et al. 1996) |
| 3. | Inflection point method (Robinson, 1997) |
| 4. | Non-graphical matching method (Robinson & Allam, 1998) |
| 5. | Log-log method (Robinson, 2009) |
| 6. | Steepest tangent fitting method (Vinod et al., 2010) |
| 7. | Log t method Sridhar & (Sridhar and Robinson, 2011) |
| 8. | Full-match method (Chung et al., 2017) |

Methods mentioned in slide *No. 5*




Exampl from Non-grphical method for analaying in Excel to get $c_r$

| | Sample name | Method name | Pressure (kPa) | $d_0$ (mm) | $d_{100}$ (mm) | $C_r$ (mm²/min) | SSD | MAPE |
|---|---|---|---|---|---|---|---|---|
| **KC-18 (M 31) Depth (23.9-24.0) m CD** | KC-18 (M 31)-CD800 | Root t | 800 | 0.095 | 0.812 | 36.829 | 0.010 | 1.504 |
| | KC-18 (M 31)-CD800 | Log (de2/t) | 800 | 0.074 | 0.837 | 37.000 | 0.003 | 0.759 |
| | KC-18 (M 31)-CD800 | Inflection Point | 800 | 0.074 | 0.791 | 33.019 | 0.052 | 1.939 |
| | KC-18 (M 31)-CD800 | Non-graphical | 800 | 0.074 | 0.837 | 35.788 | 0.003 | 0.750 |
| | KC-18 (M 31)-CD800 | Log-Log | 800 | 0.067 | 1.122 | 27.645 | 0.683 | 4.531 |
| | KC-18 (M 31)-CD800 | Steepest tangent | 800 | 0.031 | 0.837 | 49.832 | 0.045 | 1.946 |
| | KC-18 (M 31)-CD800 | Log t | 800 | 0.067 | 0.854 | 36.209 | 0.007 | 0.754 |
| | KC-18 (M 31)-CD800 | Full-match | 800 | 0.079 | 0.771 | 33.945 | 0.004 | 0.917 |

# 6. Analysis results and procedure

## 6.1. From implementation of the 1st objective

### Ranking the methods

Procedures for ranking the methods

(*or procedures for choosing method which yield the predicted settlement results closest to the reality*)

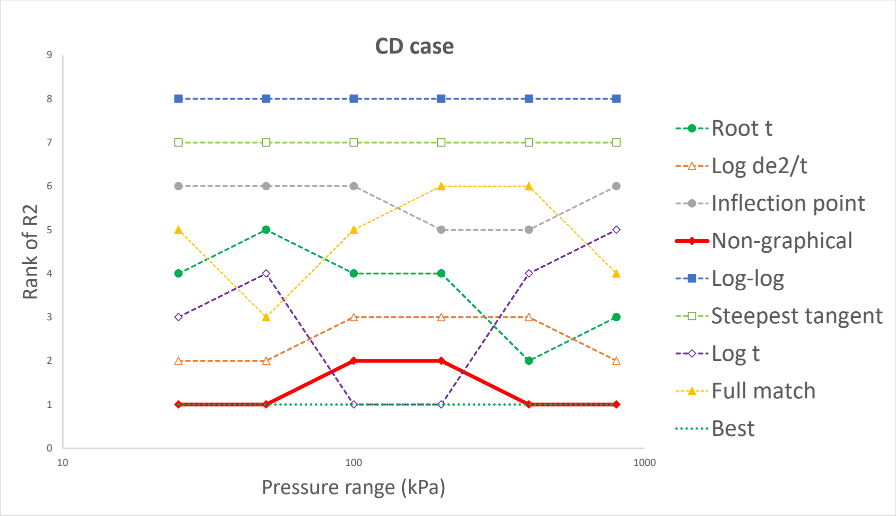
1. For each method, determine $c_{r,CD}$ (or $c_{r,PD}$) from the time ($t$) and **measured settlement ($\delta_m$) data** curve (*as mentioned in slide No.19 and 20*).
2. For each method, calculate the **estimated settlement of the sample ($\delta_e$)** by using the theoretical consolidation equation with the inputs of $c_r$, $d_0$, $d_{100}$ .
3. For each method, plot a graph of $\delta_m$ *vs* $\delta_e$ for all data points (of one pressure level) from the 4 test sites (VSIP site, DVIZ site, KC site, TPP) and determine $R^2$ and Root Mean Squared Error (***RMSE***) from the correlation.
4. Rank the methods using $R^2$ and ***RMSE*** indicators. The ranking principles are as follows:
   - ***The higher the $R^2$ value, the better the method.*** *Thus, the method producing the highest $R^2$ value is the best method ( Rank = 1) and vice versa*
   - ***The lower the RMSE value, the better the method.*** *Thus, the method producing the smallest RMSE value is the best method (Rank = 1) and vice versa*

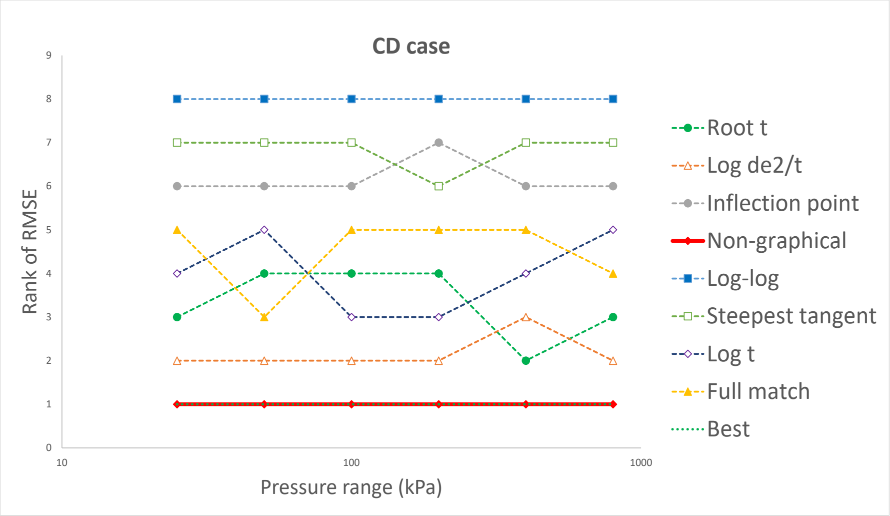
# 6. Analysis results and procedure

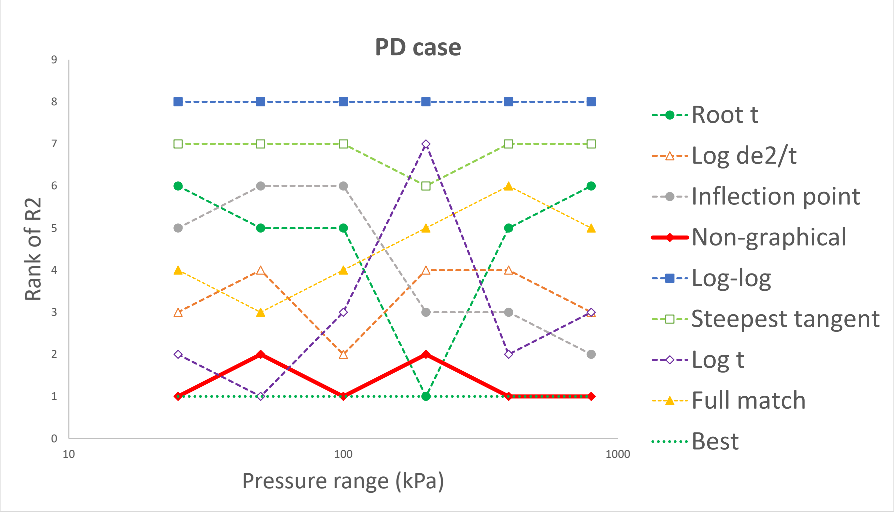
## 6.1. From implementation of the 1st objective

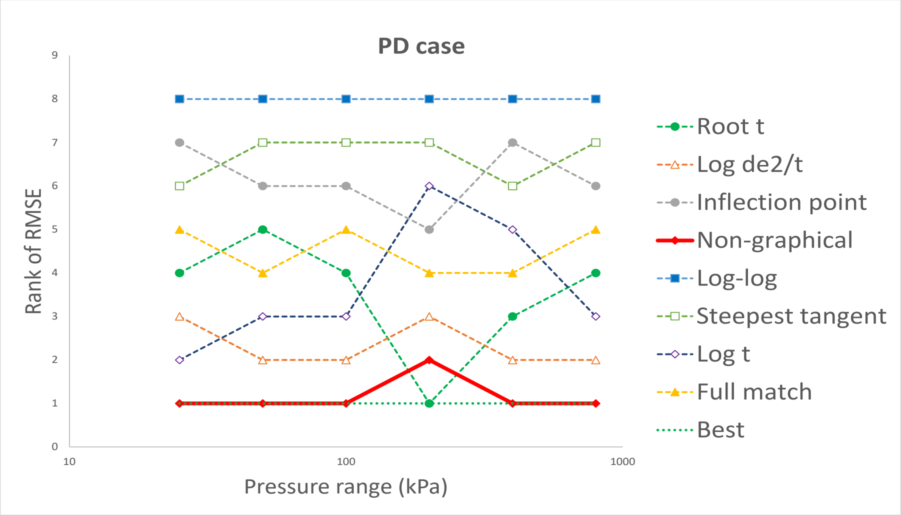
### Ranking the methods

Ranked position of the methods based on $R^2$ and *RMSE* values (*Intact samples*)



# 6. Analysis results and procedure

## 6.1. From implementation of the 1st objective

### Ranking the methods

Ranked position of the methods based on $R^2$ and *RMSE* values (*Intact samples*)

CD case

| No. | Method Name | Reliability Rank |
|---|---|---|
| 1. | Non-graphical method | Highest |
| 2. | Matching Log $de^2/t$ vs $U_r$ method | Middle |
| 3. | Root t method | |
| 4. | Log t method | |
| 5. | Full-match method | |
| 6. | Inflection point method | |
| 7. | Steepest tangent method | Lowest |
| 8. | Log-log method | |

PD case

| No. | Method Name | Reliability Rank |
|---|---|---|
| 1. | Non-graphical method | Highest |
| 2. | Matching Log $de^2/t$ vs $U_r$ method | Middle |
| 3. | Root t method | |
| 4. | Log t method | |
| 5. | Full-match method | |
| 6. | Inflection point method | |
| 7. | Steepest tangent method | Lowest |
| 8. | Log-log method | |

**Similar result was found on remolded samples.**

# 6. Analysis results and procedure

## 6.2. From implementation of the 2nd objective

### Ratio of $c_{r,PD}$ / $c_{r,CD}$ from analytical solution

*Theoretical equations for PD case* (**Barron, 1948**)

$$U_r = 1 - exp(-32T_r)$$

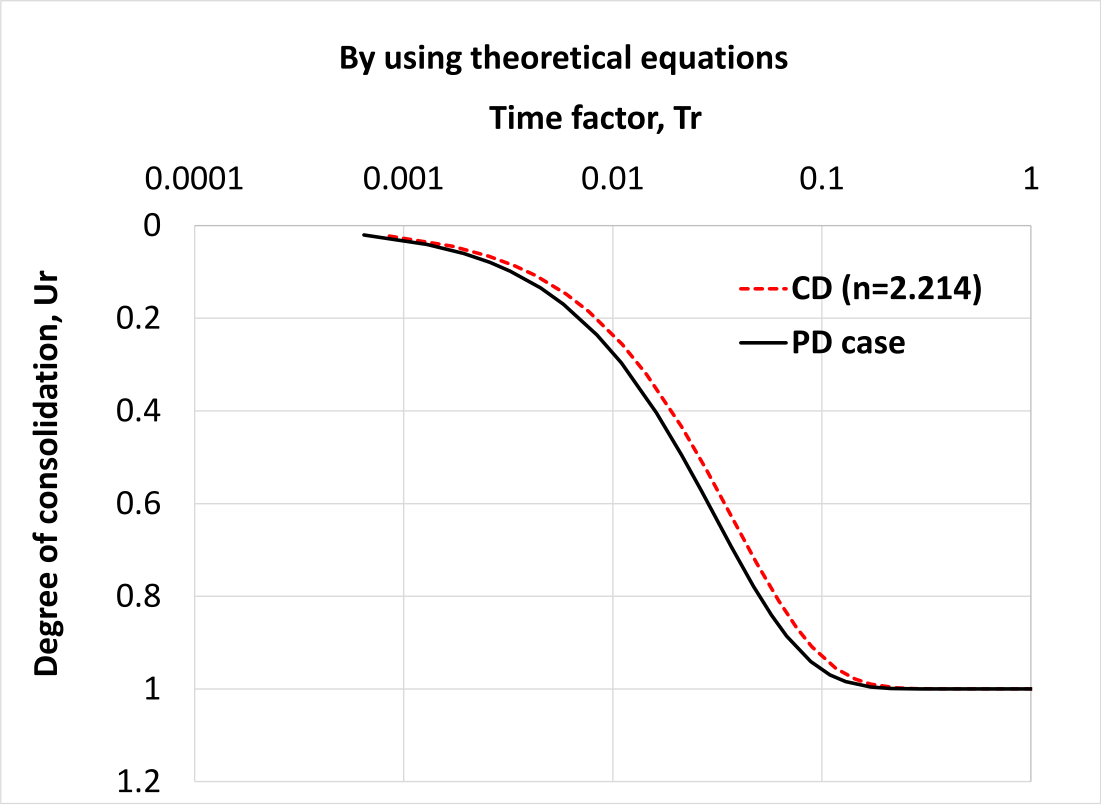
*Theoretical equations for CD case* (**Scott, 1963**)

$$U_r = 1 - exp\left(-\frac{8}{F(n)}T_r\right)$$

$$F(n) = \frac{n^2}{(n^2-1)}\ln(n) - \frac{(3n^2-1)}{4n^2}$$

$$T_r = \frac{C_r t}{D^2}$$

*Where, $U_r$= degree of consolidation; $T_r$ = time factor; n = drainage spacing ratio; D = diameter of soil sample*




***The theoretical curves at n = 2.214 indicate that the two tests (i.e., CD and PD) should result in very similar $c_r$ values (cr,PD/cr,CD ≈1.0).***

# 6. Analysis results and procedure

## 6.2. From implementation of the 2nd objective

### Correlation between $c_{r,PD}$ *and* $c_{r,CD}$

Procedures for the evaluation of correlations

1) For each method, determine the ratio of $c_{r,CD}$ and $c_{r,PD}$, or $c_{r,CD}$ and $c_v$, or $c_{r,PD}$ and $c_v$ for both *Intact and Remolded samples*.

2) Plot a ***normal distribution curve*** by using the probability density function of a normal random variable with mean ($\mu$) and variance ($\sigma^2$) as the y-axis and $c_{r,CD}/c_{r,PD}$ , or $c_{r,CD}/c_v$, or $c_{r,CD}/c_v$ as the x-axis.

3) Filtering the outliers ($c_{r,CD}/c_{r,PD}$ , or $c_{r,CD}/c_v$, or $c_{r,CD}/c_v$) which are out of ***the 68% interval area distribution***. In other words, remove the data less than ($\mu$ - $\sigma$) for the lower boundary and greater than ($\mu$ + $\sigma$) for the upper boundary.

4) Plot ($c_{r,CD}$ vs $c_{r,PD}$) graph with the filtered data.

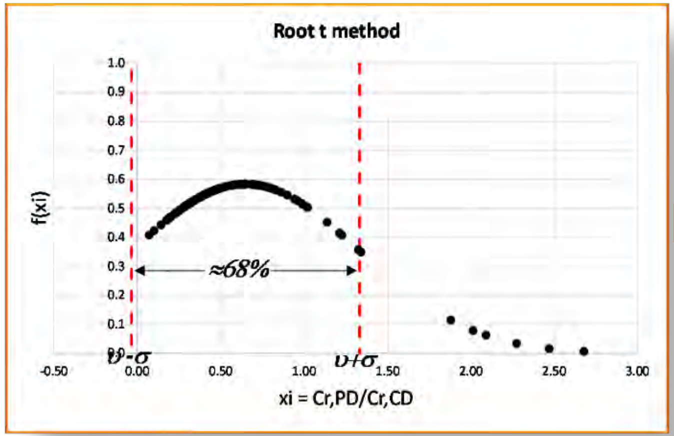
# 6. Analysis results and procedure

## 6.2. From implementation of the 2nd objective

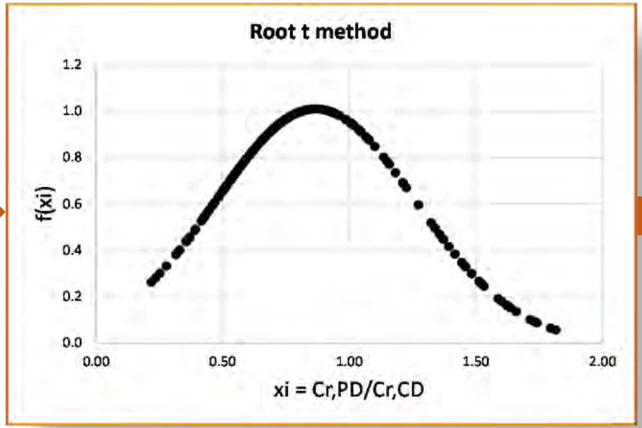
### Ratio of $c_{r,PD}/c_{r,CD}$ from experimental results

Correlation between $c_{r,PD}$ *and* $c_{r,CD}$ for the eight methods (*Intact samples*)

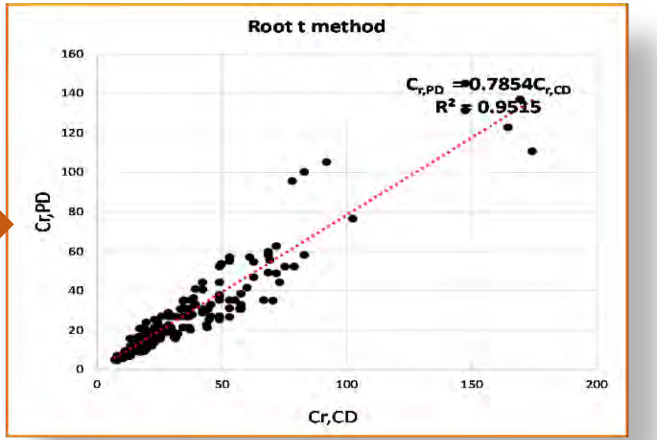
Example of correlation between $c_{r,PD}$ *and* $c_{r,CD}$ from Root t method (*Intact samples*)




Before removing the outliers




After removing the outliers




Getting correlation

# 6. Analysis results and procedure

## 6.2. From implementation of the 2nd objective

### Ratio of $c_{r,PD}/c_{r,CD}$ from experimental results

| Summary table for the correlation results between $c_{r,PD}$ *and* $c_{r,CD}$ for the eight methods (Intact samples) | | | | |
|---|---|---|---|---|
| No. | Method names | $c_{r,PD}$ vs $c_{r,CD}$ | | |
| | | $R^2$ | $\alpha(y=\alpha x)$ | No. of data point |
| 1. | Root t | 0.9515 | 0.7854 | 148 |
| 2. | Log ($de^2/t$) | 0.9332 | 0.708 | 179 |
| 3. | Inflection Point | 0.9065 | 0.6943 | 214 |
| 4. | Non-graphical | 0.9237 | 0.6705 | 204 |
| 5. | Log-Log | 0.9212 | 0.6998 | 194 |
| 6. | Steepest tangent | 0.8791 | 0.769 | 233 |
| 7. | Log t | 0.8992 | 0.7663 | 189 |
| 8. | Full-match | 0.9336 | 0.685 | 161 |

***Correlation between $c_{r,PD}$ and $c_{r,CD}$ for Intact samples: $c_{r,PD} \approx (0.6 – 0.8)\ c_{r,CD}$***

***Correlation between $c_{r,PD}$ and $c_{r,CD}$ for Remolded samples: $c_{r,PD} \approx (0.4 – 0.6)\ c_{r,CD}$***

# 6. Analysis results and procedure

## 6.2. From implementation of the 2nd objective

### Ratio of $c_{r,PD}/c_v$ from experimental results

Summary table for the correlation results between $c_{r,PD}$ *and* $c_v$ for the two standardized methods (Intact samples)

| No. | Method names | $c_{r,PD}$ *Vs* $c_v$ | | |
|---|---|---|---|---|
| | | $R^2$ | $\alpha(y=\alpha x)$ | No. of data point |
| 1. | Root t | 0.6205 | 1.2446 | 396 |
| 2. | Log t | 0.6652 | 1.7926 | 388 |

**Correlation between $c_{r,PD}$ and $c_v$ for *Intact Samples*: $c_{r,PD} \approx (1-2)\, c_v$**

Summary table for the correlation results between $c_{r,PD}$ *and* $c_v$ for the two standardized methods (Remolded samples)

| No. | Method names | $c_{r,PD}$ *Vs* $c_v$ | | |
|---|---|---|---|---|
| | | $R^2$ | $\alpha(y=\alpha x)$ | No. of data point |
| 1. | Root t | 0.9505 | 0.6251 | 17 |
| 2. | Log t | 0.8616 | 0.7113 | 20 |

**Correlation between $c_{r,PD}$ and $c_v$ for *Remolded Samples*: $c_{r,PD} \approx (0.5-1)\, c_v$**

# 6. Analysis results and procedure

## 6.2. From implementation of the 2nd objective

### Ratio of $c_{r,CD}/c_v$ from experimental results

| Summary table for the correlation results between $c_{r,CD}$ and $c_v$ for the two standardized methods (Intact samples) | | | | |
|---|---|---|---|---|
| No. | Method names | $c_{r,CD}$ Vs $c_v$ | | |
| | | $R^2$ | $\alpha(y=\alpha x)$ | No. of data point |
| 1. | Root t | 0.7021 | 2.3249 | 344 |
| 2. | Log t | 0.6914 | 2.7567 | 348 |

**Correlation between $c_{r,PD}$ and $c_v$ for *Intact Samples:* $c_{r,CD} \approx (2-3)\ c_v$**

| Summary table for the correlation results between $c_{r,CD}$ and $c_v$ for the two standardized methods (Remolded samples) | | | | |
|---|---|---|---|---|
| No. | Method names | $c_{r,CD}$ Vs $c_v$ | | |
| | | $R^2$ | $\alpha(y=\alpha x)$ | No. of data point |
| 1. | Root t | 0.8304 | 1.6278 | 25 |
| 2. | Log t | 0.9018 | 1.7782 | 23 |

**Correlation between $c_{r,PD}$ and $c_v$ for *Remolded Samples*: $c_{r,CD} \approx (1-2)\ c_v$**

# 6. Analysis results and procedure

## 6.2. From implementation of the 2nd objective

### Numerical analysis

Finding influent facts that cause the correlation between $c_{r,PD}$ *and* $c_{r,CD}$ is not equal to one.

Steps performed under the numerical analysis

1) Construct a soil model in *PLAXIS* software with the dimension of (*60 mm x 20 mm*) by inputting typical required parameters for soft clay as mentioned in *Table 1a and 1b* from Appendix.

   - For CD case, by installing sand-stone in the middle with different ***n*** values (*slide 28*).

2) Apply pressure by inputting various permeability rate in horizontal direction (i.e., $k_x = k_y$, $2k_y$, $3k_y$, $4k_y$, $5k_y$) in order to see the variation in correlation between $c_{r,PD}$ *and* $c_{r,CD}$ is whether due to changes in coefficient of permeability in horizontal direction or not.

3) Find $c_{r,CD}$ with different *n* values (i.e., ***n* = 2.214, 3, 5, 7, 10**) as shown in **slide no.28** at $k_x = 3k_y$ condition (typical case) by analyzing the results obtained from *PLAXIS* software with Root t method.

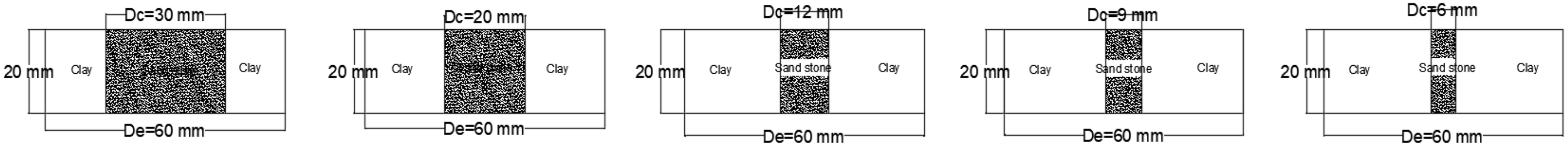
4) Find $c_{r,PD}$ as well by analyzing the results obtained from *PLAXIS* software with Root t method.

# 6. Analysis results and procedure

## 6.2. From implementation of the 2nd objective

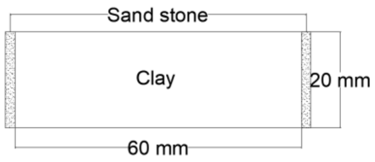
### Numerical analysis

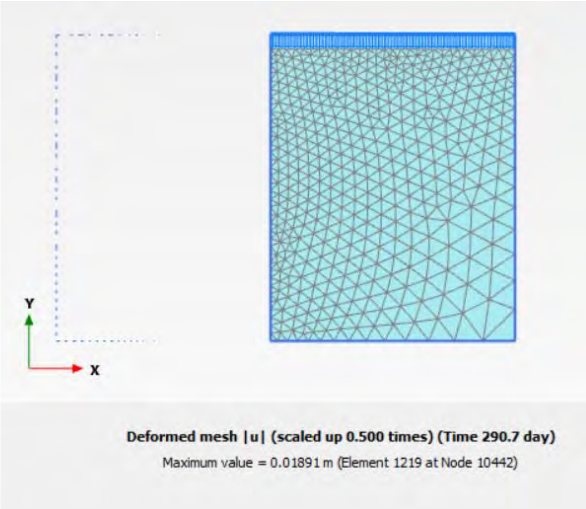
***Configuration of variation in sand drain ratio ($n=D_e/D_c$) for CD case (Numerical Analysis)***




***n = 2.214*** ***n = 3*** ***n = 5*** ***n = 6.667≈7*** ***n = 10***

***Configuration of sand-stone position in PD case (Numerical Analysis)***




Example of soil domain from *PLAXIS* software (CD case, 10 kPa, $k_x = 3k_y$)

# 6. Analysis results and procedure

## 6.2. From implementation of the 2nd objective

### Numerical analysis

Finding influent facts that cause the correlation between $c_{r,PD}$ *and* $c_{r,CD}$ is not equal to one.

| Summary table for the correlation results between $c_{r,PD}$ *and* $c_{r,CD}$ by using Root t method (10 kPa). | | | | |
|---|---|---|---|---|
| $k_x$ (m/day) | $k_y$(m/day) | $c_{r,CD}$ (mm$^2$/min), ***n* =2.14** case | $c_{r,PD}$ (mm$^2$/min) | $c_{r,PD}/c_{r,CD}$ |
| *k* | *k* | 2.074 | 1.632 | 0.79 |
| *2k* | *k* | 4.296 | 3.345 | 0.78 |
| ***3k*** | ***k*** | **6.247** | **4.730** | **0.76** |
| *4k* | *k* | 8.024 | 6.324 | 0.79 |
| *5k* | *k* | 9.906 | 7.973 | 0.80 |

***Correlation between $c_{r,PD}$ and $c_{r,CD}$ from numerical analysis: $c_{r,PD} \approx (0.7 – 0.8)\ c_{r,CD}$***

***The correlation results from Intact samples and Numerical analysis are almost the same.***

# 6. Analysis results and procedure

## 6.2. From implementation of the 2nd objective

### Numerical analysis

Finding influent facts that cause the correlation between $c_{r,PD}$ *and* $c_{r,CD}$ is not equal to one.

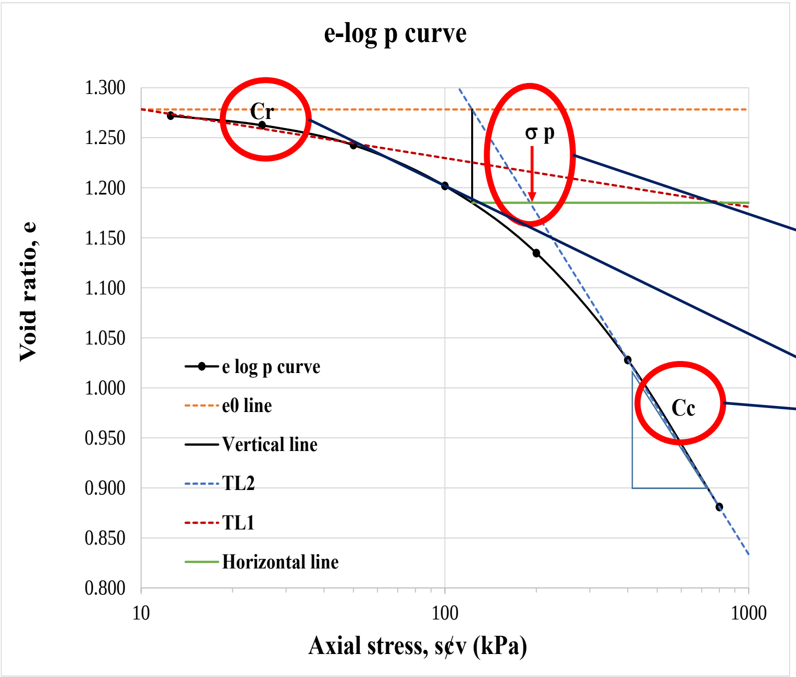
| Table showing the variation in $c_{r,CD}$ *and* $c_{r,PD}/c_{r,CD}$ results based on different ***n*** values (10 kPa). | | | | | |
|---|---|---|---|---|---|
| $k_x$ (m/day) | $k_y$ (m/day) | ***n* (*D<sub>e</sub>*/*D<sub>c</sub>*)** | **$c_{r,CD}$ (mm²/min)** | $c_{r,PD}$ (mm²/min) | **$c_{r,PD}/c_{r,CD}$** |
| 3*k* | *k* | **2.214** | **6.25** | 4.730 | **0.76** |
| 3*k* | *k* | **3** | **4.30** | 4.730 | **1.1** |
| 3*k* | *k* | **5** | **1.88** | 4.730 | **2.52** |
| 3*k* | *k* | **6.667≈7** | **1.00** | 4.730 | **4.73** |
| 3*k* | *k* | **10** | **0.72** | 4.730 | **6.57** |

***The results from numerical analysis are showing that the correlation ratio ($c_{r,PD}/c_{r,CD}$) was found to be highly influenced by n values (i.e., $D_e/D_c$). In other words, the drainage length has a high influent effect on the results of correlation ratio ($c_{r,PD}/c_{r,CD}$).***

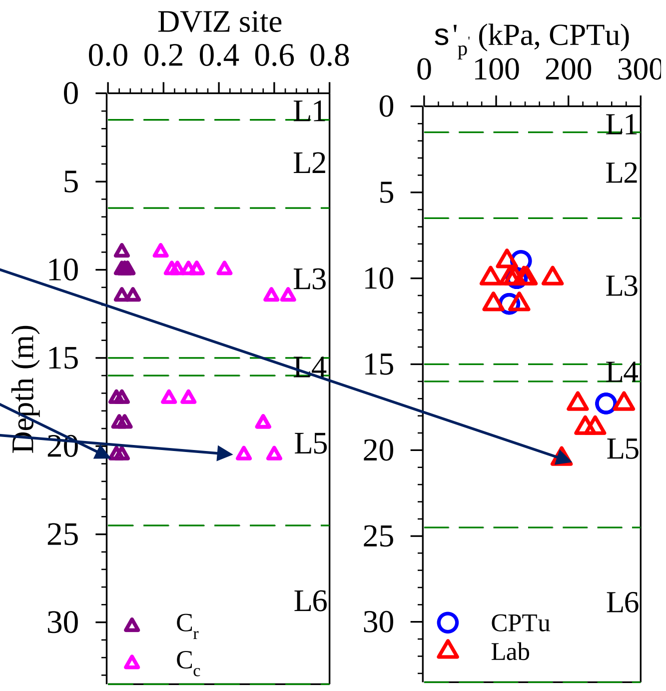
# 6. Analysis results and procedure

## 6.3. From implementation of the 3rd objective

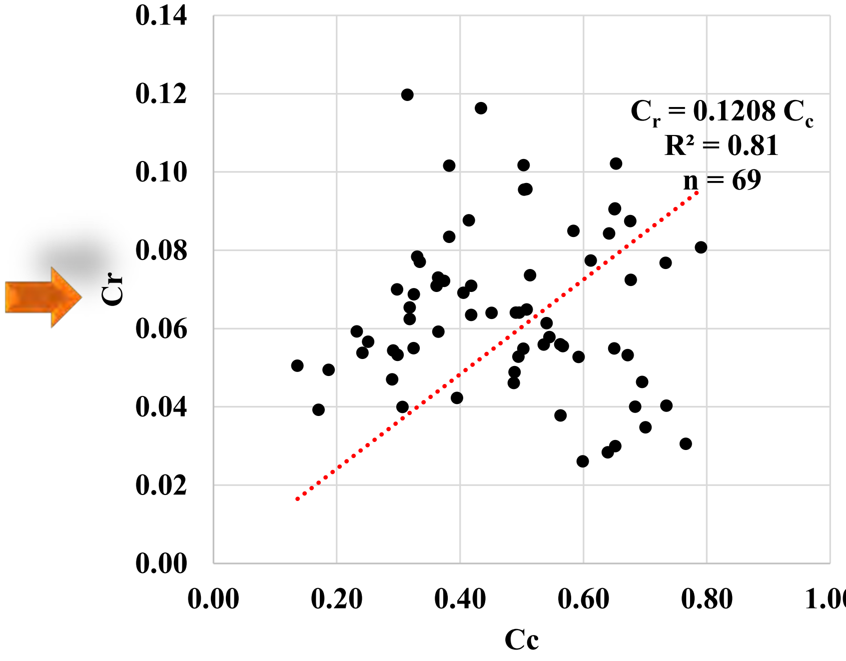
### Evaluation of compression index ($C_c$), recompression index ($C_r$) and preconsolidation stress ($\sigma'_p$)




Silver (1970)'s method




Example taken from DVIZ site at the depth of 20 to 20.5 m



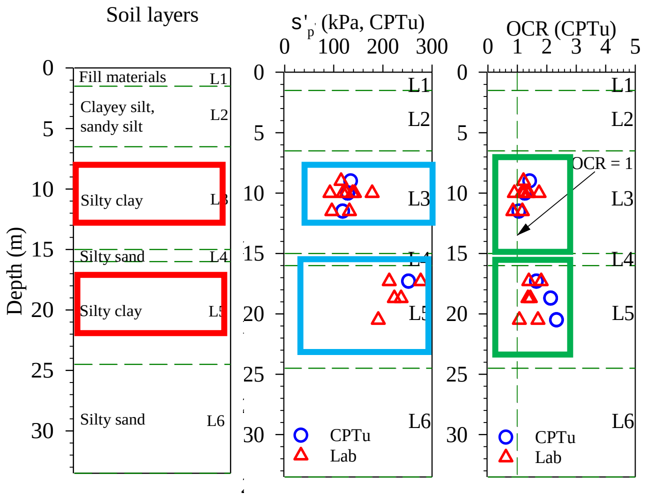

**Summary table for the correlation results between $C_c$ and $e_0$ and $C_r$ and $C_c$**

| Correlation | $R^2$ | No. of data point |
|---|---|---|
| $C_c = 0.3864\ e_0$ | 0.9475 | 69 |
| $C_r = 0.1208\ C_c$ | 0.81 | 69 |

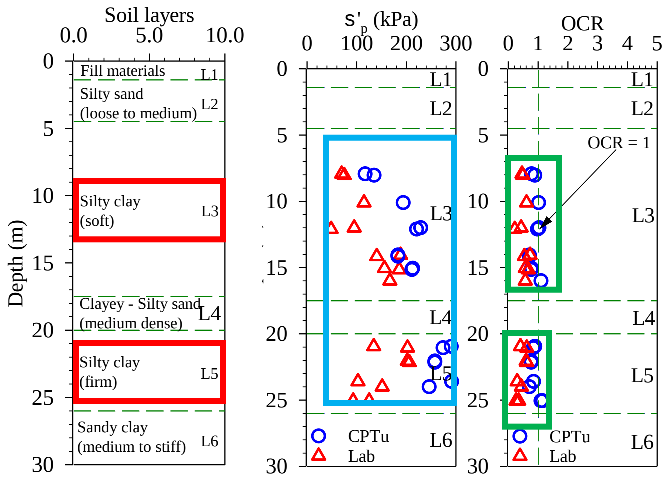
# 6. Analysis results and procedure

## 6.3. From implementation of the 3rd objective

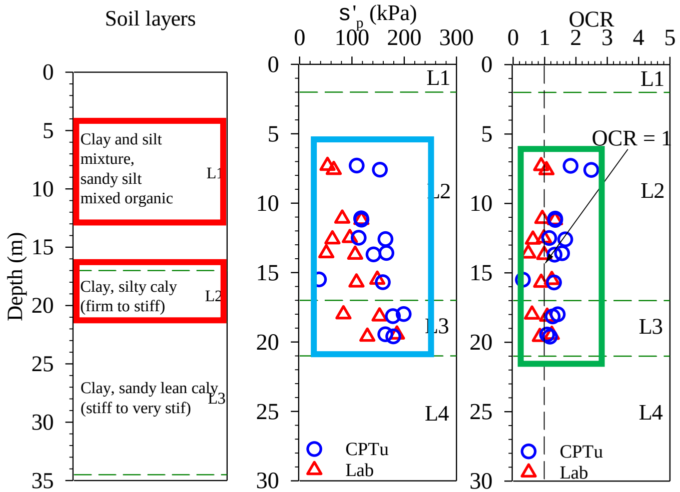
### Evaluation of compression index ($C_c$), recompression index ($C_r$) and preconsolidation stress ($\sigma'_p$)



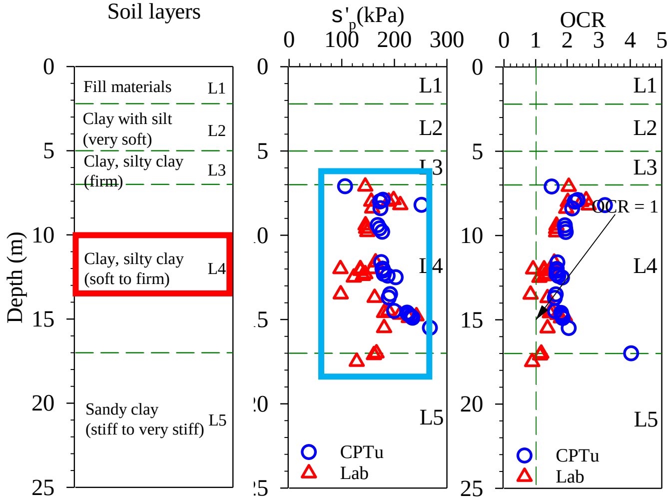

DVIZ site




KC site




TPP site




VSIP site

- In general, the OCR profiles indicate that the clays at the test sites are normally consolidated (OCR ≈ 1)
- Preconsolidation stress value ($\sigma'_p$) from Lab test is typically smaller than that from CPTu test. This indicate that the $\sigma'_p$ from lab test is influence from soil disturbance effect.

# 7. Conclusions

*Based on the results obtained from the four study sites, some key findings on the compressibility characteristics of soft clay from RRD can be highlighted as follows:*

***1. For the 1st objective***

- *$c_{r,PD}$ and $c_{r,CD}$ values were determined from 8 existing methods. The results indicate that Non-graphical results in highest reliability and the Log-log and Steepest tangent methods result in lowest reliability. In addition, the reliability of the methods also depends on applied pressure.*

***2. For the 2nd objective***

- *Theoretically, the ratio ($c_{r,PD}/c_{r,CD}$) from analytical solution (at n = 2.214) is approximately 1.0. Experimental results from* intact soil samples show that *$c_{r,PD}$ = (0.6 – 0.8 )$c_{r,CD}$ and from remolded sample $c_{r,PD} \approx$ (0.4 – 0.6) $c_{r,CD}$. These results indicate that the drainage length of actual soil has significant influence to the ratio → for the same soil sample the test with different n value would give different $c_{r,CD}$ value.*
- Results from numerical study (with n = 2.214) show that *$c_{r,PD}$ = 0.76$c_{r,CD}$, which agree well with the experimental results.*

***3. For the 3rd objective***

- *The OCR from laboratory test and CPTu test indicate that the soft clays at the test sites are predominantly normally consolidated (i.e., OCR $\approx$ 1.0). Primary correlations of $C_c$ = 0.3864 $e_0$ and $C_r$ = 0.1208 $C_c$ could be suggested for the clays at the test sites.*

# References


Tanabe, S., Saito, Y., Lan Vu, Q., Hanebuth, T. J., Lan Ngo, Q., & Kitamura, A. (2006). Holocene evolution of the Song Hong (Red River) delta system, northern Vietnam. Sedimentary Geology, 187(1–2):29–61. https://doi.org/10.1016/j.sedgeo.2005.12.00

Tanabe, S., Saito, Y., Sato, Y., Suzuki, Y., Sinsakul, S., Tiyapairach, S., Chaimanee, N. (2003). Stratigraphy and Holocene evolution of the mud-dominated Chao Phraya delta, Thailand. Quaternary Science Reviews 22:2345–2361. http://doi:10.1016/S0277-3791(03)00138-0.

Funabiki, A., Haruyama, S., Quy, N. V., Hai, P. V., & Thai, D. H. (2007. Holocene delta plain development in the Song Hong (Red River) delta, Vietnam. Journal of Asian Earth Sciences, 30(3–4):518–529. https://doi.org/10.1016/j.jseaes.2006.11.013

Berry, P. L., & Wilkinson, W. B. (1969). The Radial Consolidation of Clay Soils. *Géotechnique*, *19*(2), 253–284. https://doi.org/10.1680/geot.1969.19.2.253

Briaud, J. (2013). Geotechnical Engineering: Unsaturated and Saturated Soils (1st ed.). Wiley, pp. 414–415.

Chaney, R., Demars, K., Sridharan, A., Prakash, K., & Asha, S. (1996). Consolidation Behavior of Clayey Soils Under Radial Drainage. *Geotechnical Testing Journal*, *19*(4), 421. https://doi.org/10.1520/gtj10719j

Chaney, R., Demars, K., Robinson, R., & Allam, M. (1998). Analysis of Consolidation Data by a Non-Graphical Matching Method. *Geotechnical Testing Journal*, *21*(2), 140. https://doi.org/10.1520/gtj10752j

Chung, S. G., Park, T. R., Hwang, D. Y., & Kweon, H. J. (2018). Full-Match Method to Determine the Coefficient of Radial Consolidation. *Geotechnical Testing Journal*, *42*(5), 20170459. https://doi.org/10.1520/gtj20170459

Dung, N. T. and Giao, P. H. (2005). Review of some methods to determine the preconsolidation pressure and application for Mekong soft clay, In Proceedings of the International Workshop of Hanoi Geo-engineering, Hanoi, Vietnam, pp. 44-54.

Dung, N.T., Khin, P., Pham, Q., & Vu, A. (2022, June). A comparative study on CPTu-based soil classification methods: Case studies. *Cone Penetration Testing 2022*, pp. 610–616. https://doi.org/10.1201/9781003308829-88

Dung, N. T., Pham, Q., & Khin, P. (2021). A Comparative Study on the Applicability of CPTu-based Soil Classification Methods for Offshore Test Sites. *4th Asia Pacific Meeting on Near Surface Geoscience & Engineering*. https://doi.org/10.3997/2214-4609.202177078

FHWA-NHI-16-072 (2017). Geotechnical Engineering Circular No.5 Geotechnical Site Characterization, US Dept. of Transportation, Federal Highway Administration, pp. 8-26.

Head, K. H., & Epps, R. (2011). *Manual of Soil Laboratory Testing, Third Edition: Volume Two: Permeability, Shear Strength and Compressibility Tests* (3rd ed.). Whittles Publishing.

Phach, P. V., Lai, V. C., Shakirov, R. B., Le, D. A., & Tung, D. X. (2020). Tectonic Activities and Evolution of the Red River Delta (North Viet Nam) in the Holocene. Geotectonics, 54(1), 113–129. https://doi.org/10.1134/s0016852120010094

Robinson, R. G. (1997). Determination of radial coefficient of consolidation by the inflection point method. *Géotechnique*, *47*(5), 1079–1081. https://doi.org/10.1680/geot.1997.47.5.1079

Sridhar, G., & Robinson, R. (2011b). Determination of radial coefficient of consolidation using log <i>t</i> method. *International Journal of Geotechnical Engineering*, *5*(4), 373–381. https://doi.org/10.3328/ijge.2011.05.04.373-381

Suits, L. D., Sheahan, T. C., & Robinson, R. G. (2009). Analysis of Radial Consolidation Test Data Using a log-log Method. *Geotechnical Testing Journal*, *32*(2), 101034. https://doi.org/10.1520/gtj101034

Tanabe, S., Saito, Y., Lan Vu, Q., Hanebuth, T. J., Lan Ngo, Q., & Kitamura, A. (2006). Holocene evolution of theSong Hong (Red River) delta system, northern Vietnam. Sedimentary Geology, 187(1–2), 29–61.

Vinod, J. S., Sridharan, A., & Indraratna, B. (2010). Determination of Coefficient of Radial Consolidation Using Steepest Tangent Fitting Method. *Geotechnical and Geological Engineering*, *28*(4), 533–536. https://doi.org/10.1007/s10706-010-9330-8

Yen, H. P. H., Nhan, T. T. T., Nghi, T., Toan, N. Q., Khien, H. A., Lam, D. D., van Long, H., Thanh, D. X., Hung, N. T., Trang, N. T. H., Dien, T. N., Tuyen, N. T., Truong, T. X., Dung, T. T., Thao, N. T. P., & Lan, V. Q. (2021b). Late Pleistocene-Holocene sedimentary evolution in the coastal zone of the Red River Delta. *Heliyon*, *7*(1), e05872. https://doi.org/10.1016/j.heliyon.2020.e05872

William, N. (2019). *ISE STATISTICS FOR ENGINEERS AND SCIENTISTS (ISE HED IRWIN INDUSTRIAL ENGINEERING)* (5th ed.). McGraw-Hill Education.


Thank You!