

INTRODUCTION OF ROAD TECHNOLOGY AND POLICY MAKING

- International Joint Seminar of VJU and NILIM -

November 25th, 2022

- On November 25th, 2022, NILIM held the International Joint Seminar online with VJU*, Hanoi.
- The theme of this seminar is “Introduction of Road Technology and Policy Making”. NILIM presented our technologies about maintenance and management of road structures, disaster prevention and recovery, and policies of MLIT. VJU presented characteristics of soft clays in the red river delta.
- To begin with, the Director-General of NILIM and Program Director of VJU delivered greetings as organizers. Next, there were presentations and Q&A sessions and the seminar concluded with a successful address from VJU at last.
- The following is the outline and activities of the seminar. For the details, please see the next page and beyond.

* Vietnam Japan University was established in Hanoi in 2014 by JICA's Technical Cooperation Project. VJU has tried to develop human resources practically on an international level by conducting internships at Japanese companies. Japanese language is also taught as a required subject. VJU has been offering only Master's Courses but they also opened Undergraduate Courses in September, 2022.

1. TIME

November 25th, 2022 (Fri)

13:00-15:20 (Vietnam Time)

15:00-17:20 (Japan Time)

2. OUTLINE

- **Title**

Introduction of Road Technology and Policy Making

- **Attendees**

96 (Number of pre-registrations), including 14 from Japanese companies

- **Venue**

Online (ZOOM)

- **Contents**

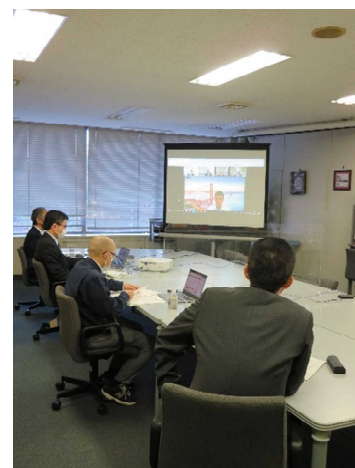
At the beginning, the Director-General of NILIM gave an opening address as the organizer and the Director for International Affairs, Planning Division, Road Bureau, MLIT addressed as the guest of honor. Then, the Road Structures Department gave a presentation on “Maintenance and Management of Road Structures in Japan”, the Road Traffic Department presented on “Efforts to Identify Passable Roads after Disasters from Road Traffic Big Data”, and the Sabo Department presented on “Prevention and Mitigation of Sediment Disasters in Japan”. VJU presented on “Compressibility Characteristics of Soft Clays in the Red River Delta”. There were vigorous Q&A sessions in each presentation. The joint seminar finished in great success with closing remarks by a lecturer from VJU.



Greeting by Director-General of NILIM



Commemorative screenshot of attendees



Participants of NILIM



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Seminar of VJU and NILIM-

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●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
- 2.Session
 - (1) Maintenance and management of road structures in Japan: Decade of road maintenance revolution
 - (2) Efforts to identify passable roads after disasters from road traffic big data
 - (3) Prevention and mitigation of sediment disasters in Japan
 - (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 (Japan Time)

Opening Address

- 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 (Japan Time)

Guest's Address

- Mr. FUKUI Takanori, Director for International Affairs, Planning Division, Road Bureau, Ministry of Land, Infrastructure, Transport and Tourism, Japan

■13:15~15:15 (Vietnam Time), 15:15~17:15 (Japan Time)

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 (Japan Time)

Closing

- Dr. Nguyen Ngoc Vinh, Lecturer, Master's Program in CIVIL Engineering(MCE), VNU Vietnam Japan University (VJU)

Chairman: Dr. Nguyen Tien Dung, Lecturer, Master's Program in CIVIL Engineering(MCE), VNU Vietnam Japan University (VJU)



Maintenance and Management of Road Structures in Japan: *Decade of Road Maintenance Revolution*

KATAOKA Shojiro

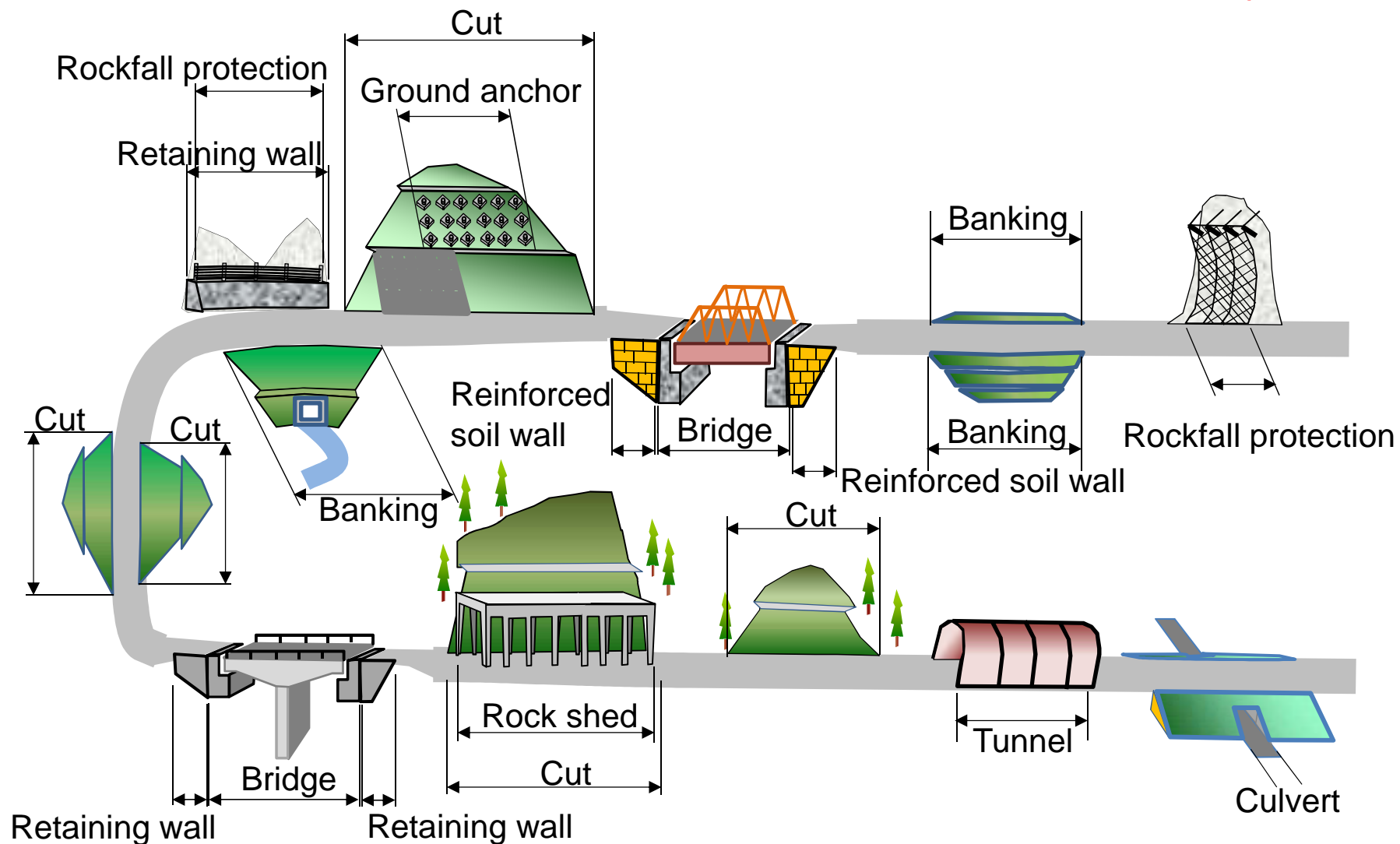
Research Coordinator for Road Structures Management

Road Structures Department, NILIM, MLIT, Japan

1. Introduction
2. Decade of Revolution from 2012
3. Contribution & Challenge by NILIM

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



Reinforced soil wall



Culvert



Shed

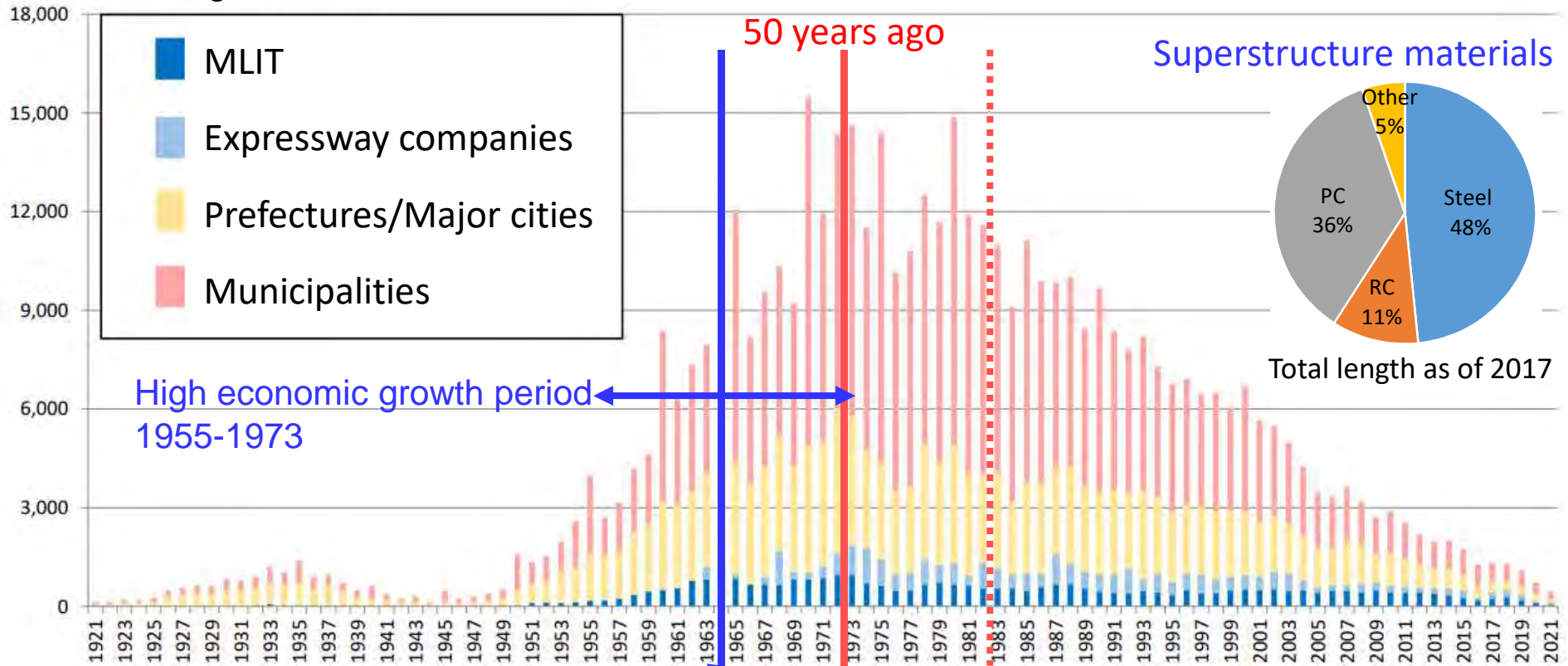
Various types of Earthworks



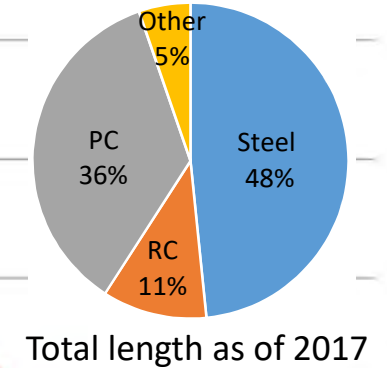
1G m Pavements

... because they are aging.

Number of bridges built



Superstructure materials



Bridges older than 50 years



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

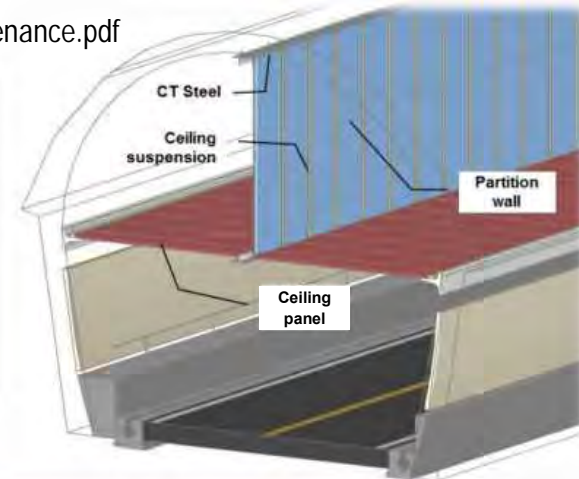


Dec 2, 2012

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



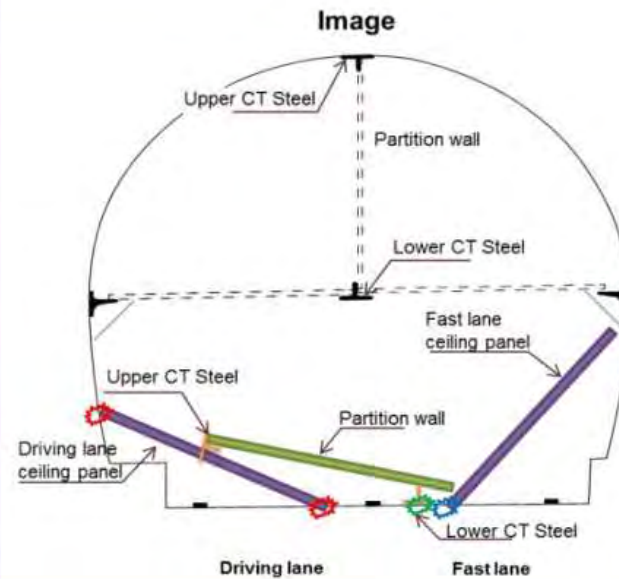
Sasago Tunnel (east bound) to Tokyo



driving lane

fast lane

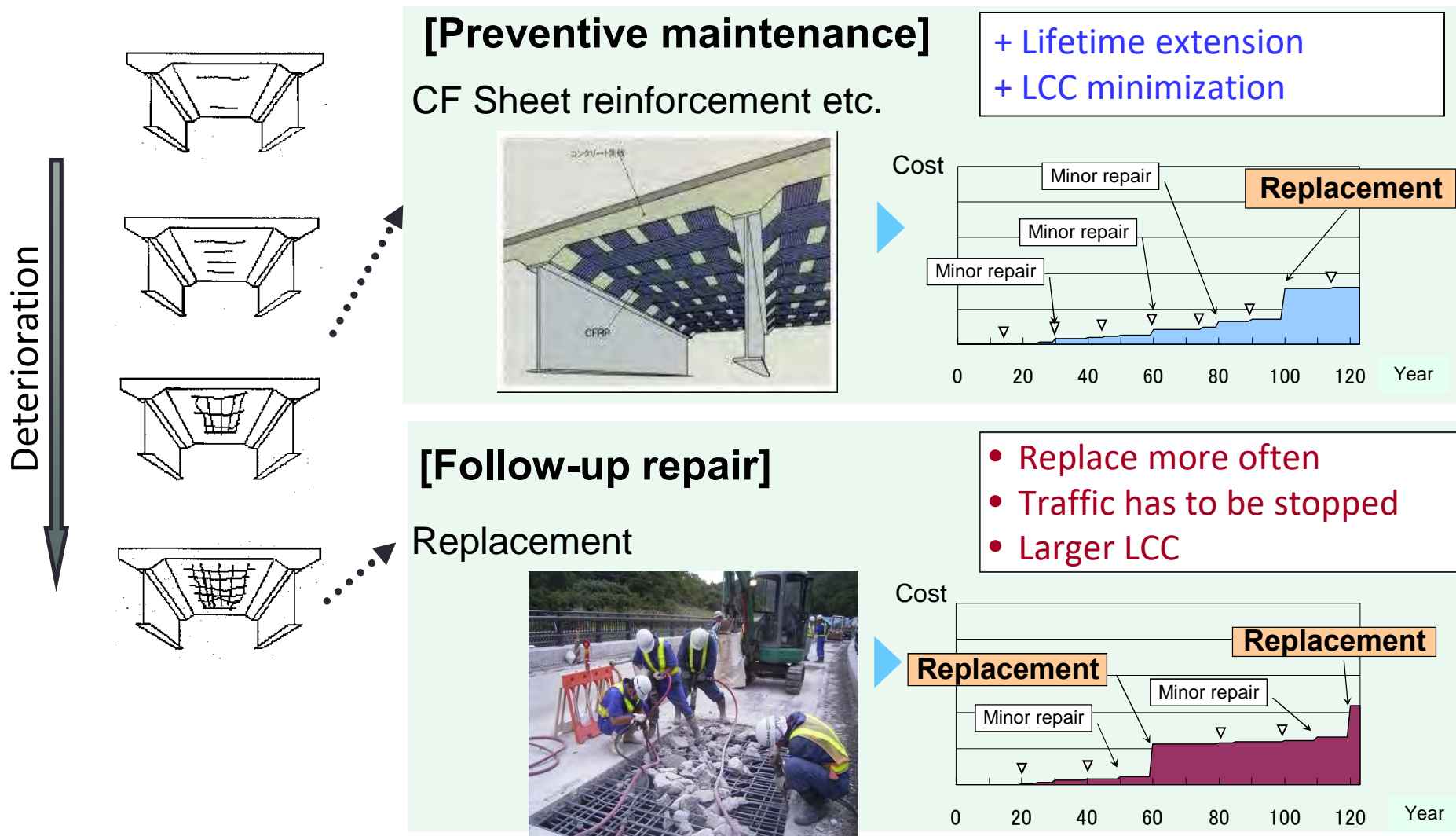
(Dec. 5, 2012)



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.



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)

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.

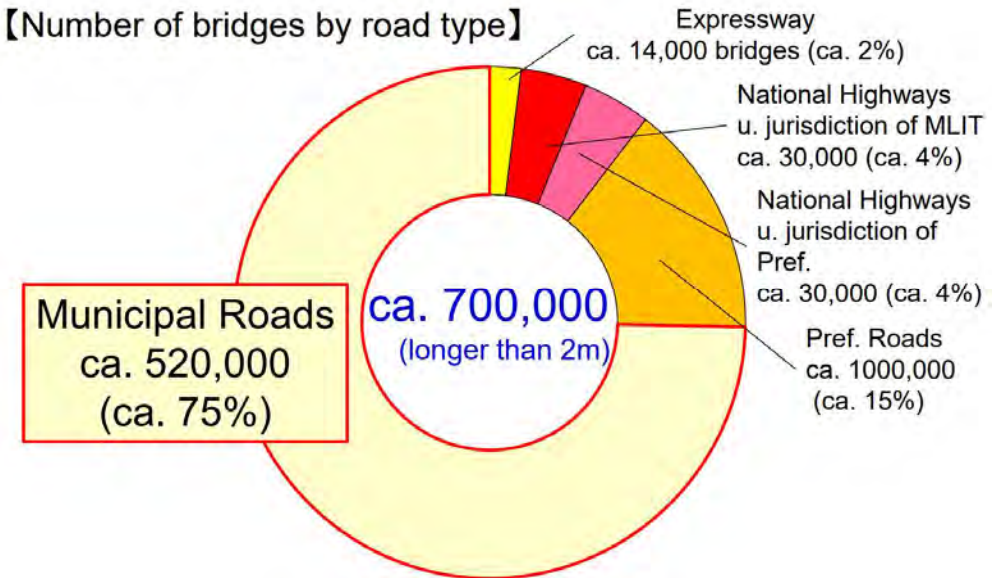


Close visual inspection of tunnel equipment and bridge

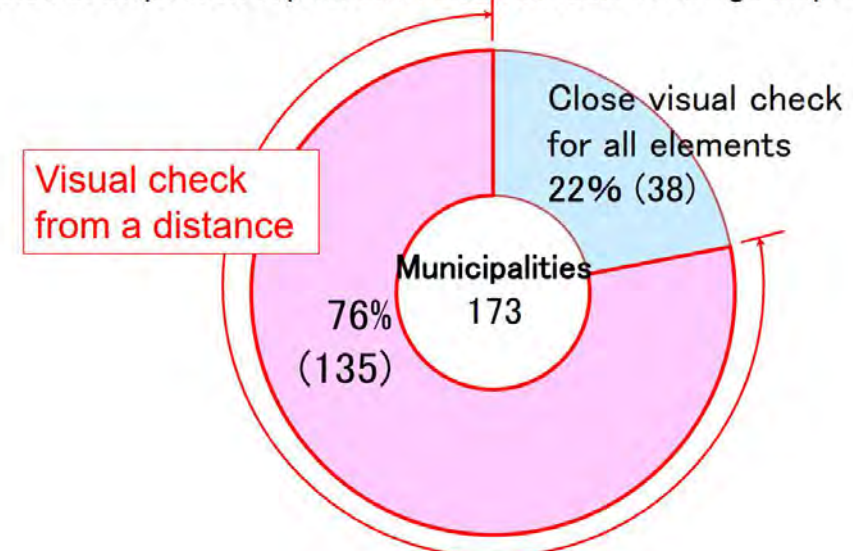
Dramatic changes in inspection

Municipalities must conduct the inspection every 5 years as well.

【Number of bridges by road type】



Method of Inspection stipulated in their manuals on bridge inspection



Distant visual inspection became invalid.



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 .

道路橋定期点検要領
Guideline for Periodic Road Bridge Inspection

平成26年6月
国土交通省 道路局
Prepared by Road Bureau, MLIT (June 2014)

Damage on concrete parts	4. Cracking	3 / 4
Damage Category: IV	[Emergency rehabilitation stage] The structure needs emergency rehabilitation, because it is deficient or it will most likely become deficient.	
	Example Main girder has prominent cracks near the fulcrum, which substantially deteriorates the supporting capability of the girder.	
	Example Main parts have a significant number of cracks, showing the possibility of a fracture of inside steel.	
	Example Receiving beam and other critical parts have prominent cracks, which can cause a bridge collapse.	
	Example Girders and pillars in the substructure have prominent cracks, which can cause a bridge collapse if the deterioration proceeds.	
Remark If cause of cracks and influences on the parts are not easily determined, further detailed inspection should be done.		

道路トンネル定期点検要領
Guideline For Periodic Inspection
Of Road Tunnel

シェッド、大型カルバート等
定期点検要領
Guideline For Periodic Inspection
Of Shed and Large Culvert

橋歩道橋定期点検要領
Guideline For Periodic Inspection
Of Pedestrian Bridge

門型構造物等定期点検要領
Guideline For Periodic Inspection
Of Signage On Gantry

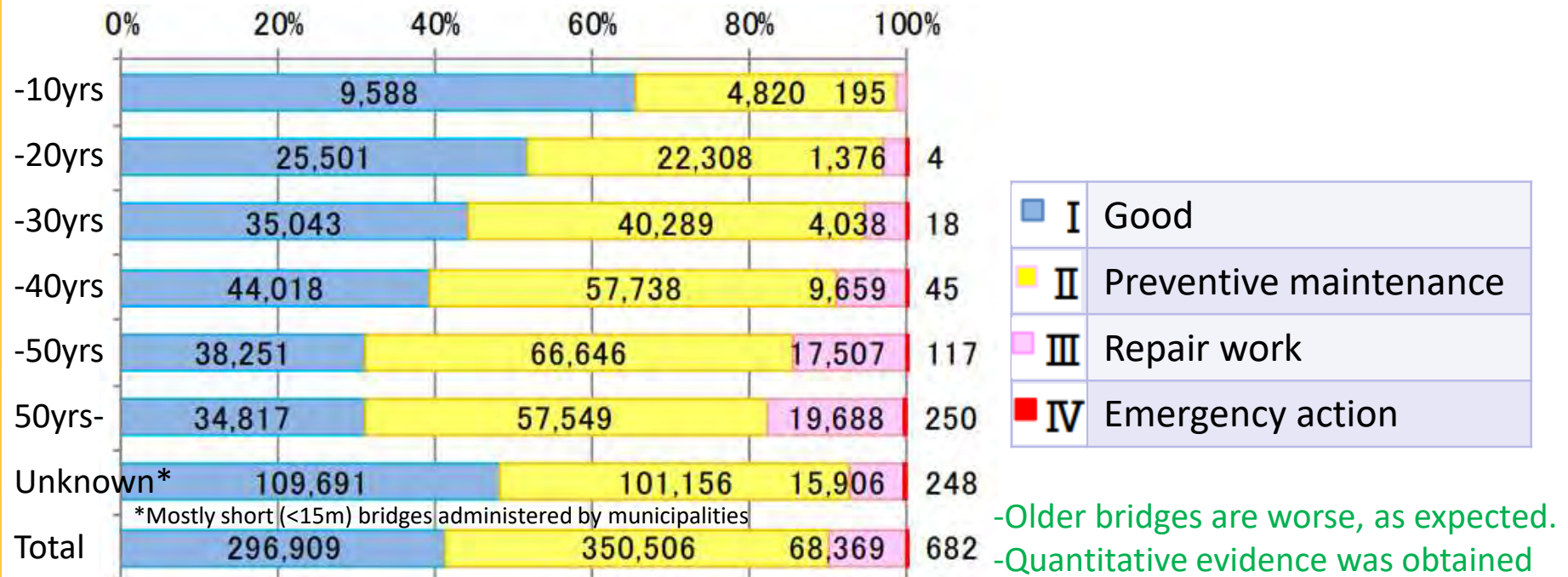
平成26年6月
国土交通省 道路局
Prepared by Road Bureau, MLIT (June 2014)

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)



-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.

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,)



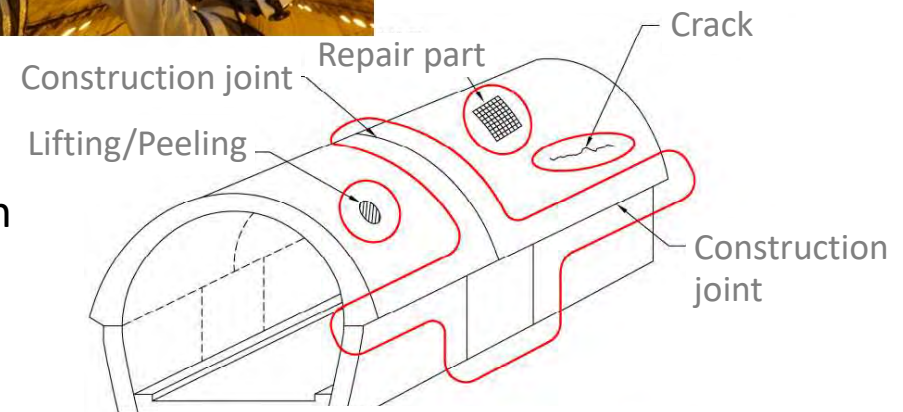
- Consuming:

Prevent over-checking

→ Illustrate necessary/unnecessary checking
in the guidelines or references

Cost-cut by new technology

→ Alternative method to close visual inspection

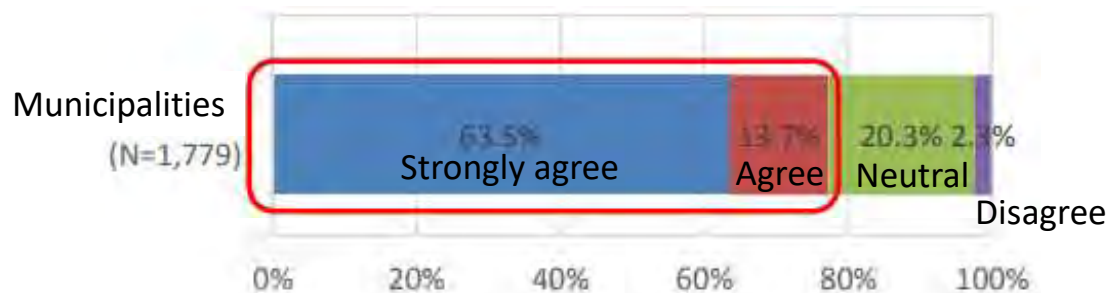


Hammering test area from 2nd-round

Support for using new technologies

Questionnaire to municipalities:

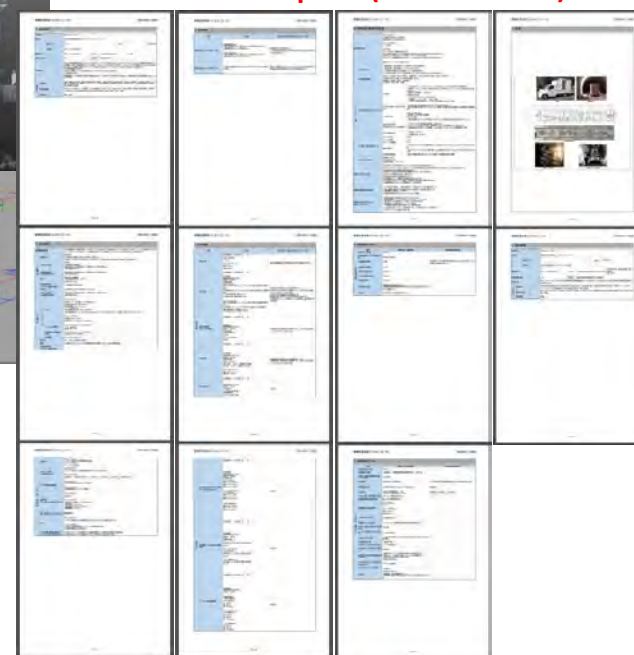
The cost required for the inspection is a burden.



→ Strong needs for cost-cut by new technologies



An example (one item)



→ What technologies are available?

→ Performance catalog of inspection support technologies

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

→ Guideline & Examples

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

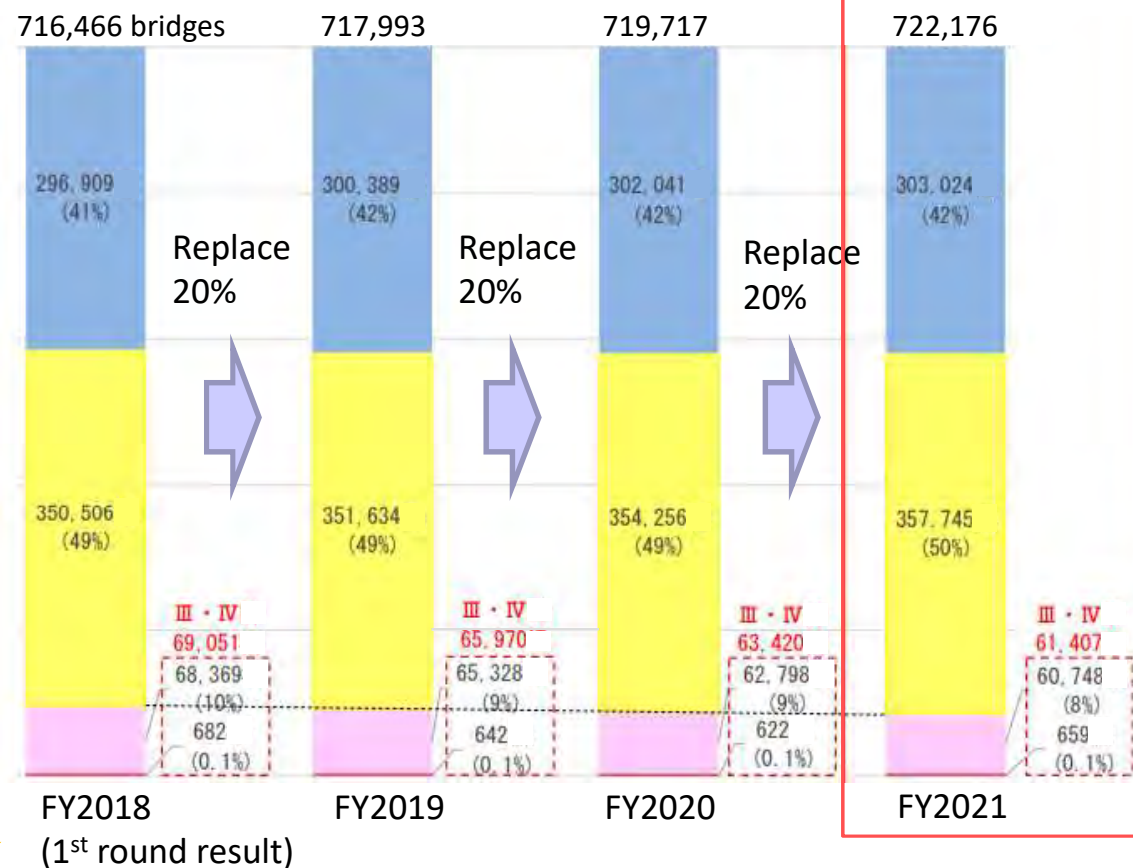
Decade of revolution from 2012 (3/3)

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

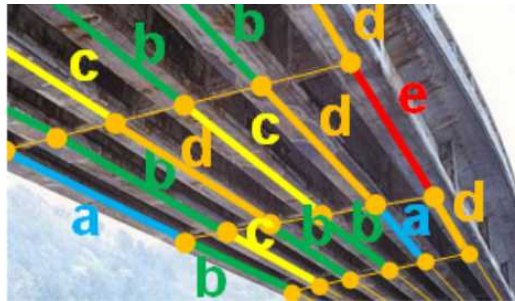
→ 20-30 years to erase III・IV.

2024.2? Re-revised national guidelines for periodic inspection

NILIM conducts research for the revisions and draft-making.

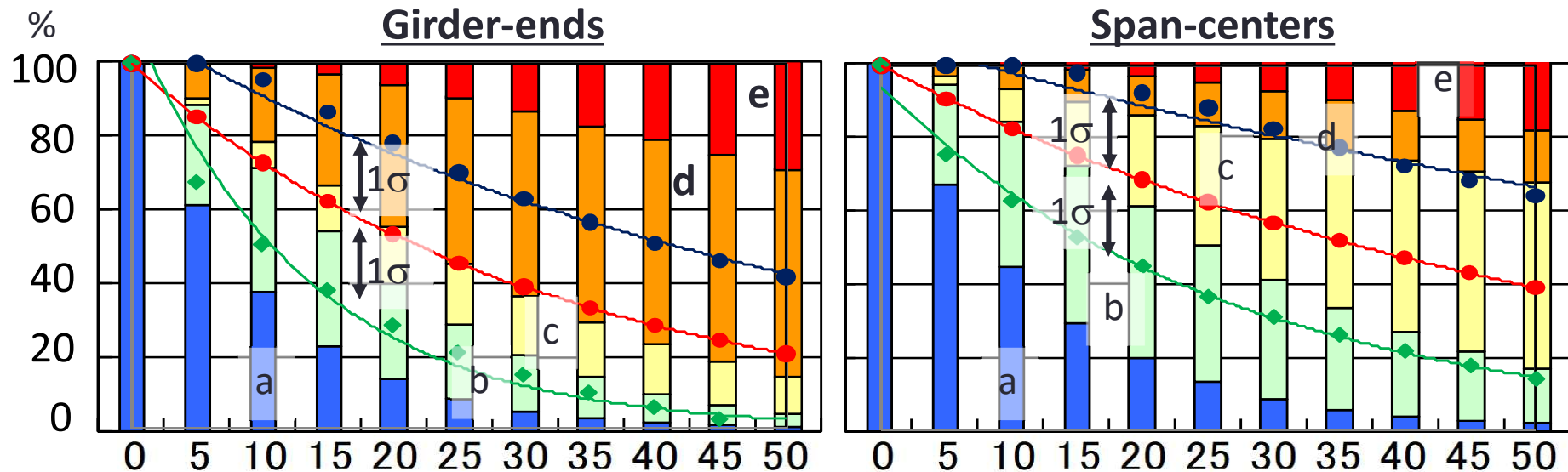
Contribution & Challenge by NILIM (1/2)

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



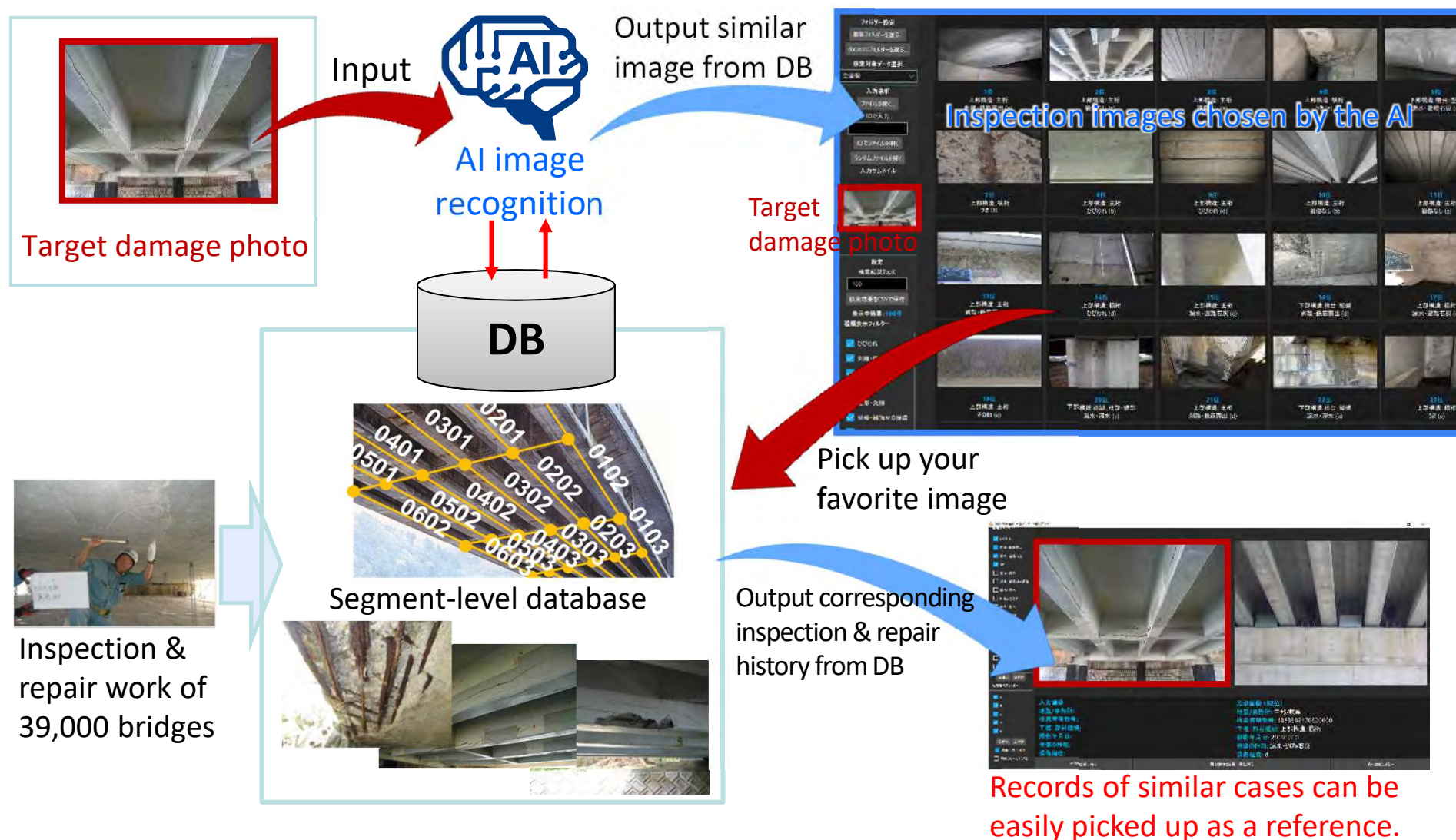
a-e: Damage extent of segment

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.

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



- 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...



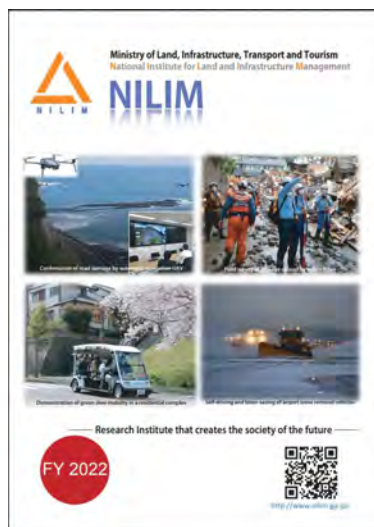
NILIM Website (English)

<http://www.nilim.go.jp/english/eindex.htm>

You Tube Channel

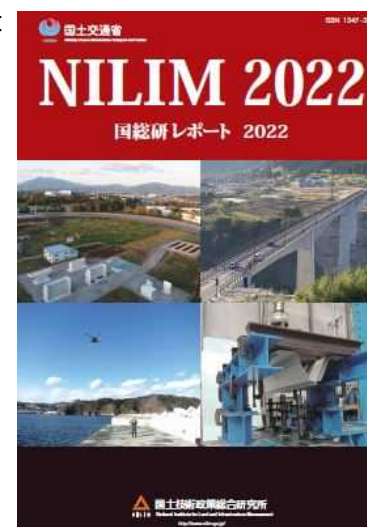
<https://www.youtube.com/channel/UC5l193hxlF1CrZ85DTBnm8Q>

Brochure



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

Annual Report



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



国総研

National Institute for Land and Infrastructure Management, MLIT, JAPAN

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

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1. Introduction

2. Traffic Record Display System

2.1 Outline

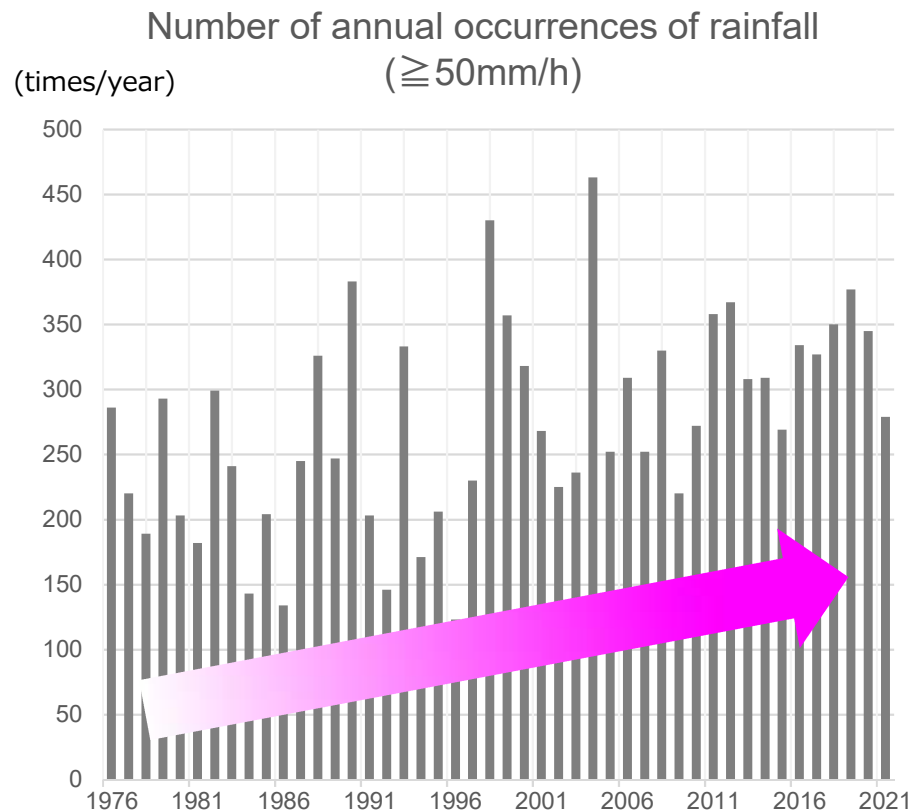
2.2 Issues & Improvements

3. Example of applying the system

4. Conclusion

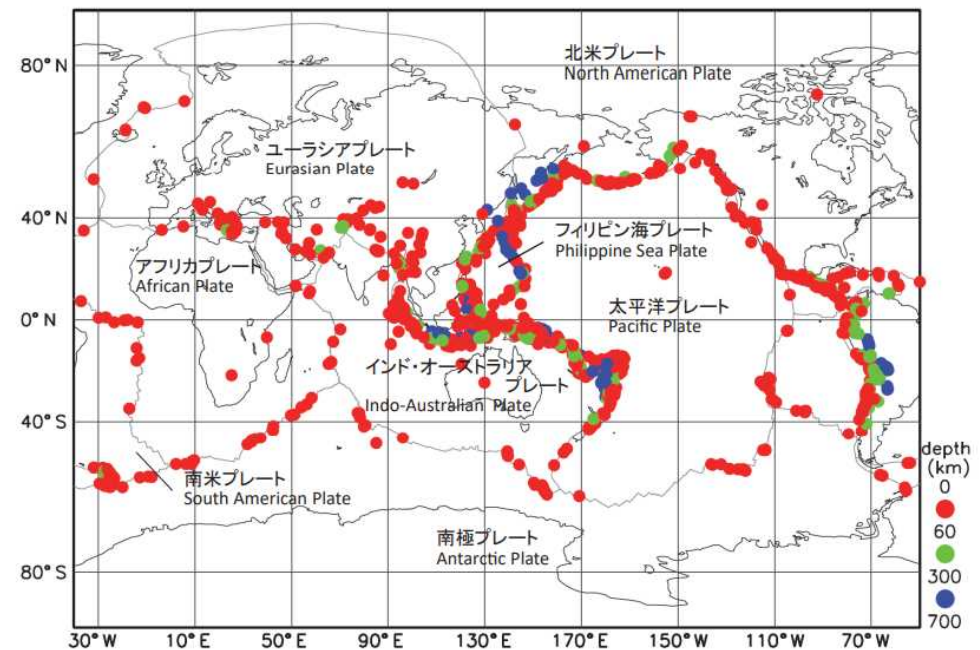
1. Introduction

- 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.



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>

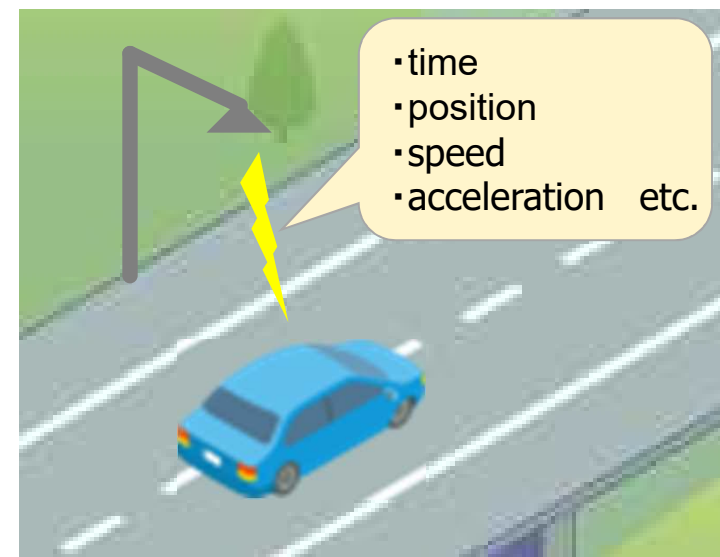
2. Traffic Record Display System

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.



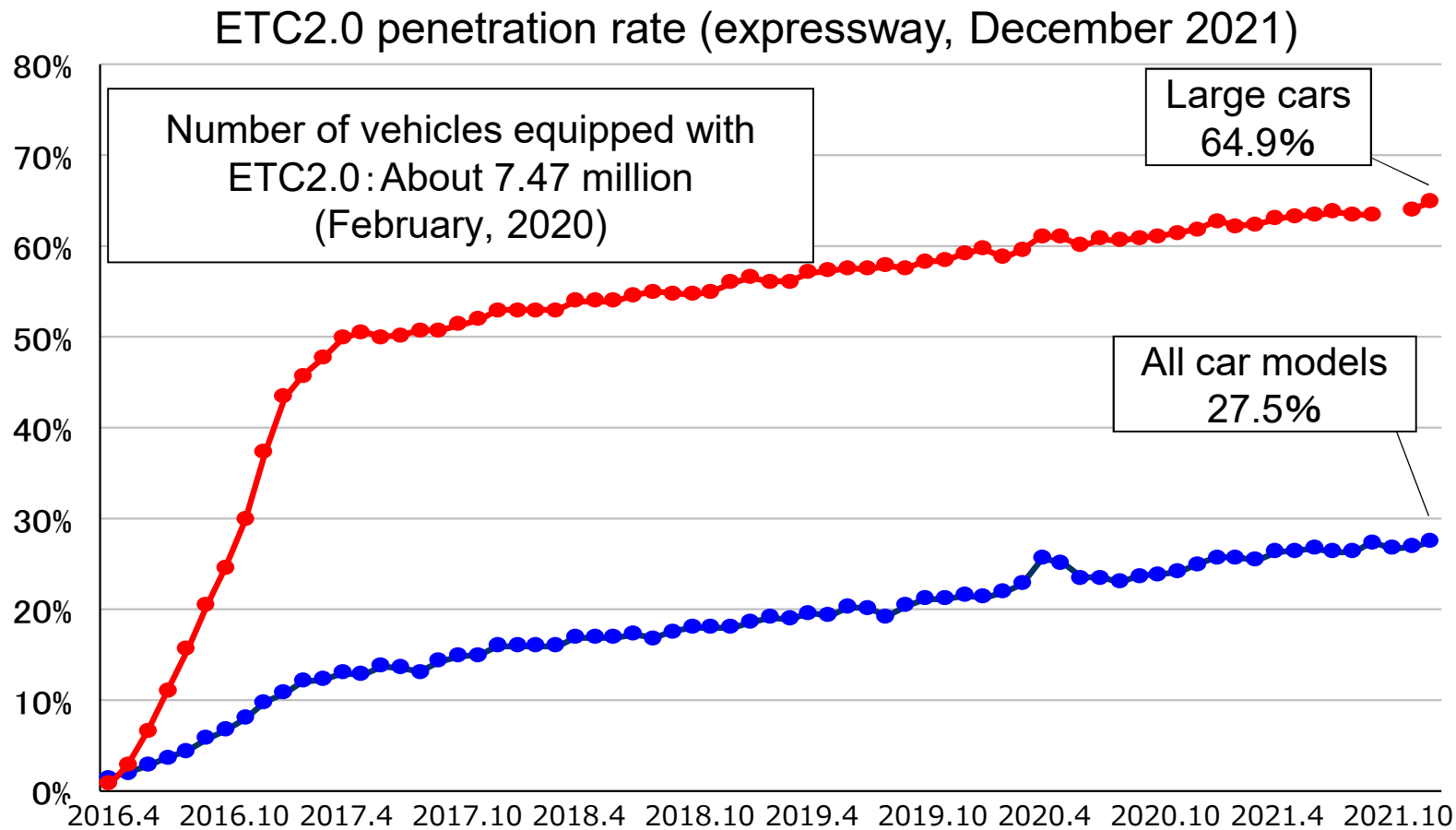
*E*lectronic *T*oll *C*ollection system



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.



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

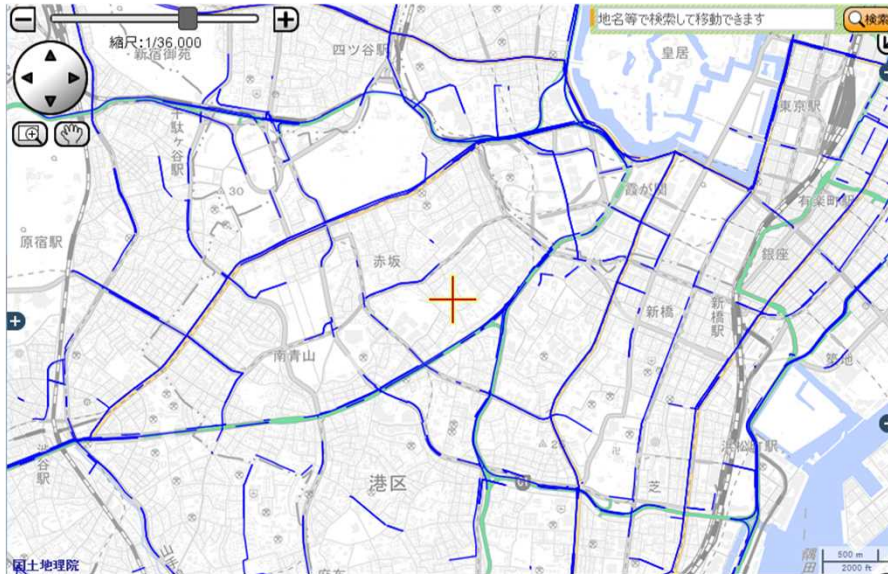
Improvement

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

2. Traffic Record Display System

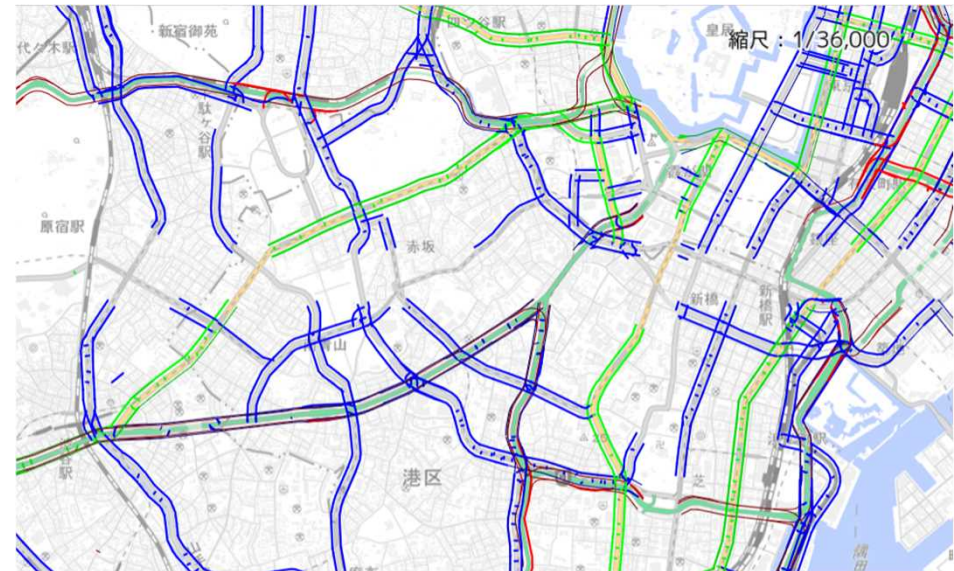
I . Display the traffic record

Before upgrade



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

After upgrade



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
















Example of display

2. Traffic Record Display System

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

(1) No. of categories		(3) Display for each road type						(4) Show/Hide
Categories <input type="text" value="5"/>		Express ways		Direct-controlled national highways		Other roads		Hide
		Color	Width	Color	Width	Color	Width	
			<input type="text" value="2"/>		<input type="text" value="2"/>		<input type="text" value="2"/>	<input type="checkbox"/>
			<input type="text" value="2"/>		<input type="text" value="2"/>		<input type="text" value="2"/>	<input type="checkbox"/>
			<input type="text" value="1"/>		<input type="text" value="1"/>		<input type="text" value="1"/>	<input type="checkbox"/>
			<input type="text" value="1"/>		<input type="text" value="1"/>		<input type="text" value="1"/>	<input type="checkbox"/>
			<input type="text" value="1"/>		<input type="text" value="1"/>		<input type="text" value="1"/>	<input type="checkbox"/>

(2) No. of passing vehicles	
MIN	MAX
<input type="text" value=""/>	<input type="text" value="20"/>
<input type="text" value="21"/>	<input type="text" value="40"/>
<input type="text" value="41"/>	<input type="text" value="60"/>
<input type="text" value="61"/>	<input type="text" value="80"/>
<input type="text" value="81"/>	<input type="text" value=""/>

Example display settings for number of passing vehicles

2. Traffic Record Display System

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.

☐ Show/Hide for each road type

<input checked="" type="checkbox"/> Expressways	} 1. Expressways
<input checked="" type="checkbox"/> Urban expressways	
<input checked="" type="checkbox"/> Direct-controlled national highways	} 2. Direct-controlled national highways
<input checked="" type="checkbox"/> Subsidized national highways	
<input type="checkbox"/> Principal local-roads	} 3. Other roads
<input checked="" type="checkbox"/> Prefectural roads	
<input type="checkbox"/> Ordinance-designated city roads	

地図表示 表示設定 最新情報

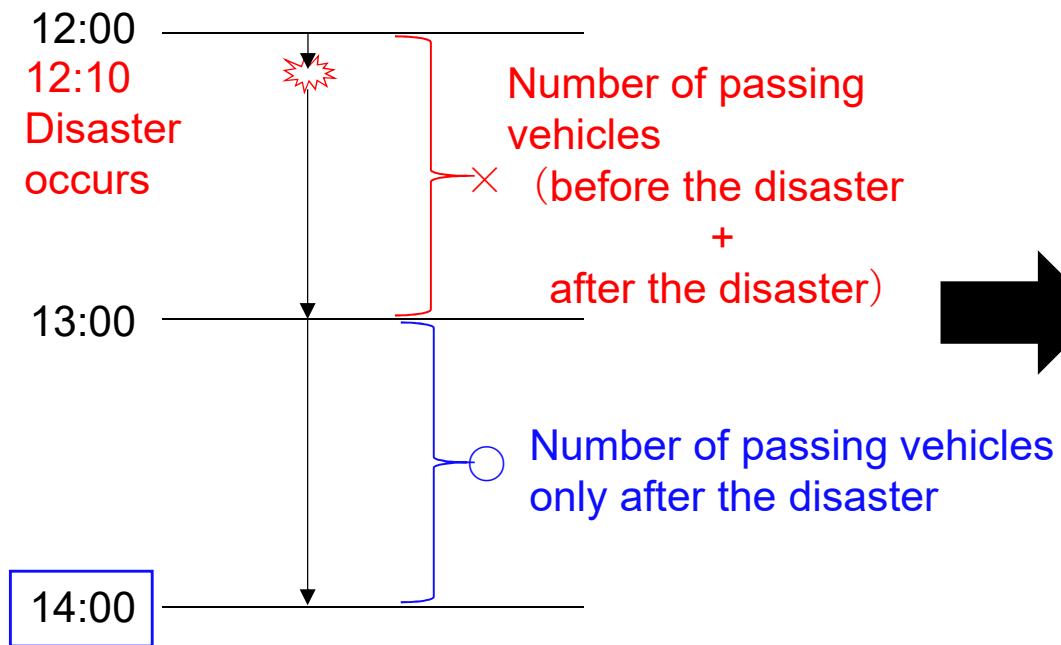
Opacity

Example of display by road type

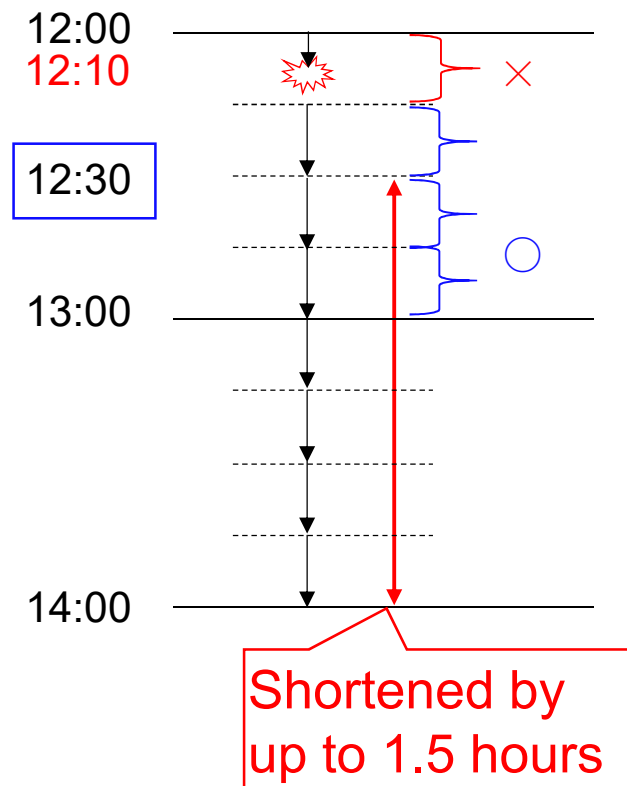
2. Traffic Record Display System


Ⅲ. Immediacy of data

Before



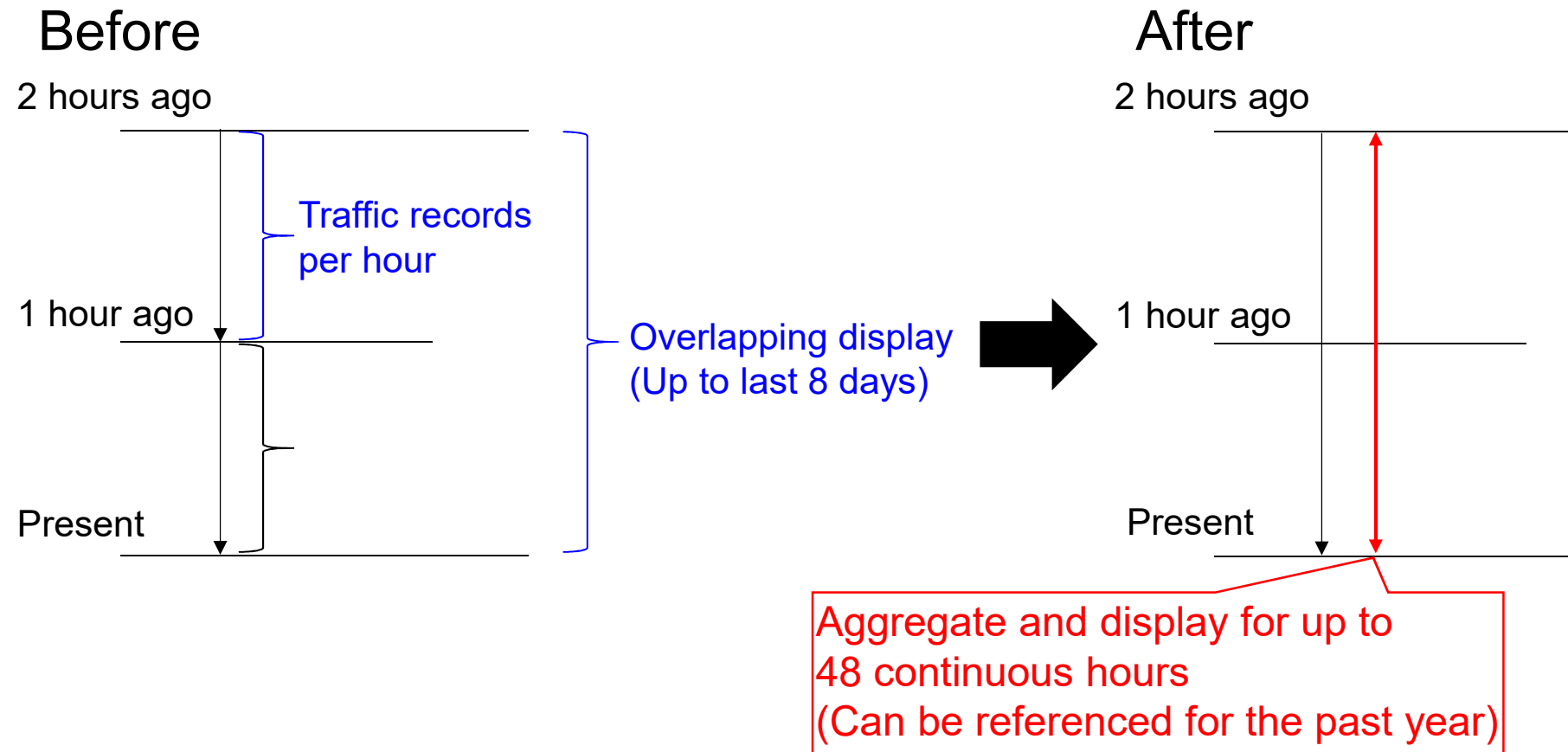
After



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

2. Traffic Record Display System

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

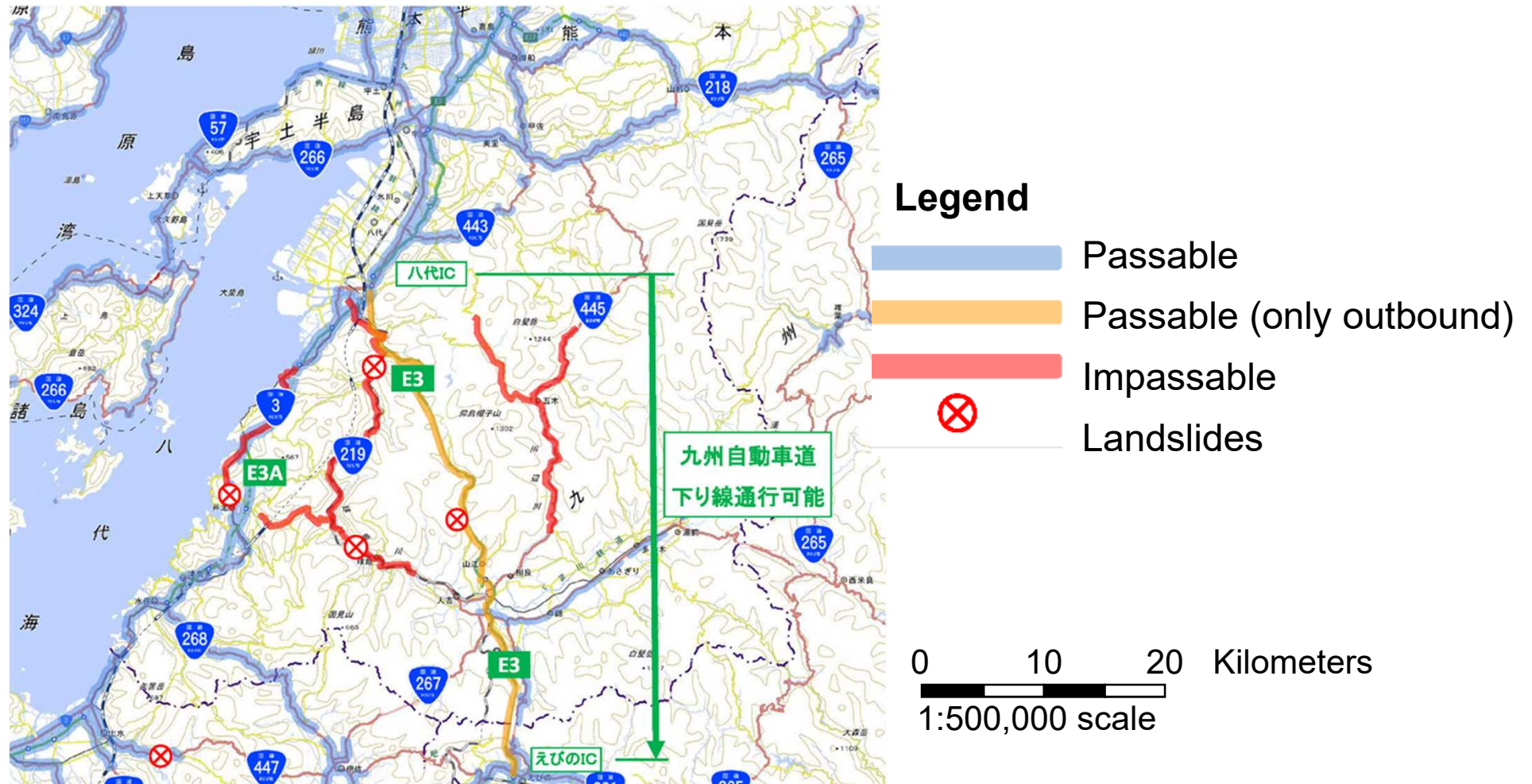
Completely or partially destroyed	Flooded
6,129	6,825

Kumamoto, Kyushu



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

4. Conclusion

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



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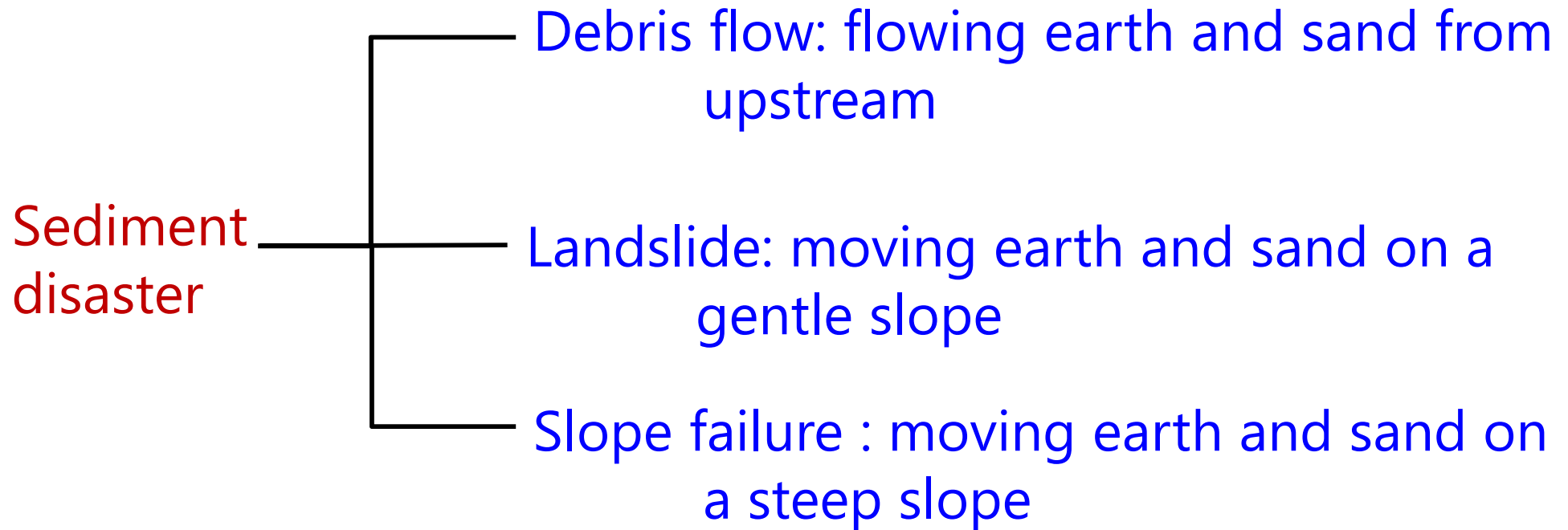
1. Sediment disasters in Japan
2. Non structural measures
(Land-use regulation and control)



1. Sediment disasters in Japan

What is sediment disasters?

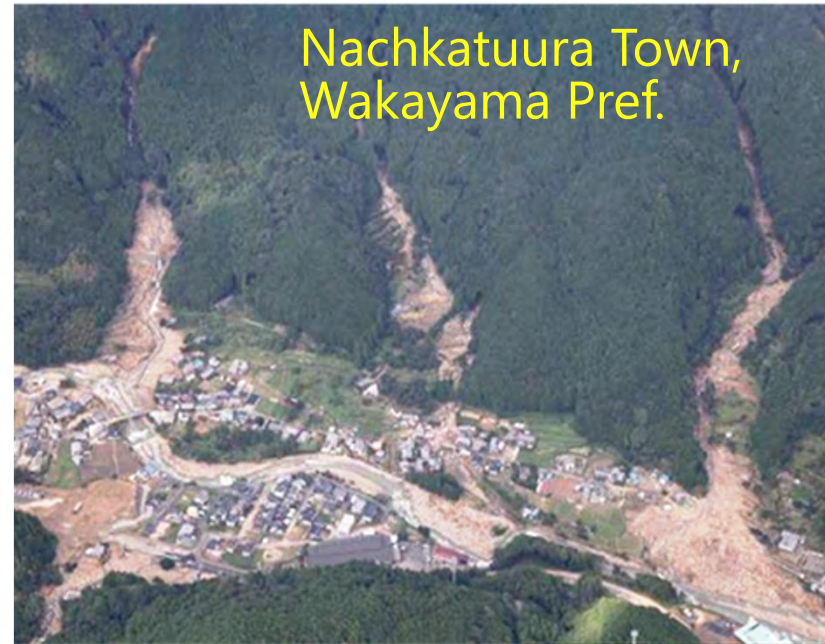
Sediment disasters can be generally classified in a debris flow, a landslide, and a slope failure



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



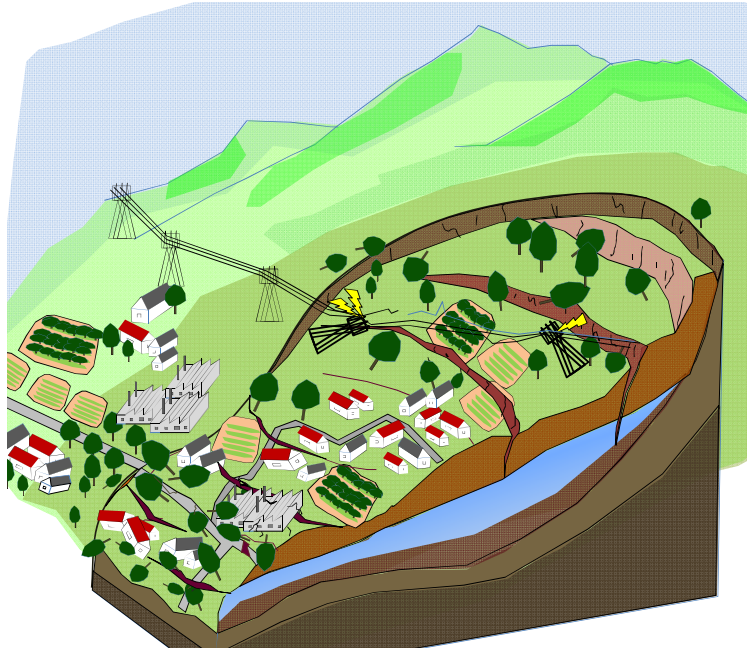
Nachkatuura Town,
Wakayama Pref.



Aso City,
Kumamoto Pref.

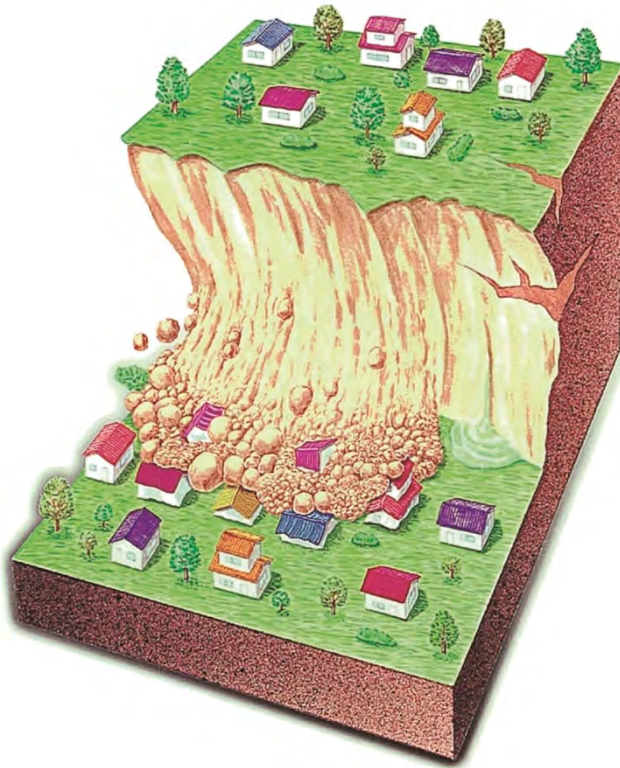
Part of soil, stone and gravel making up a hillside and river bed is intermingled with water from long-continuing or localized rainfall, etc. and is carried instantly downstream. The flow is called a “debris flow”. The velocity being 20-40 km/hour depending on the magnitude, the debris flow easily destroy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

Landslide



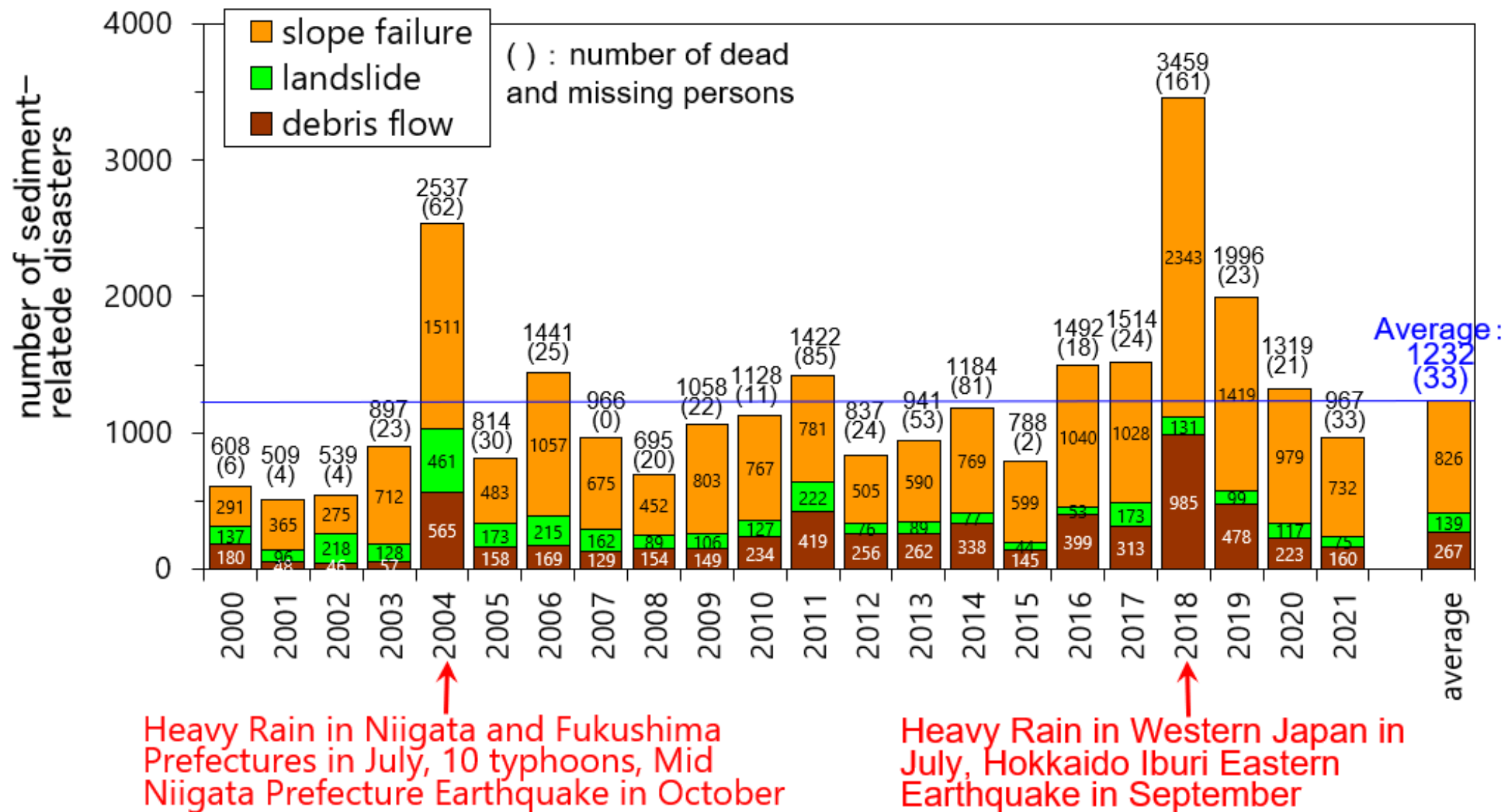
A landslide is a phenomenon in which soil mass on a slope moves slowly along the slip surface downward the slope under the influence of ground water and other causes. Since landslides occur over an extensive area and a large amount of soil mass is moved in general, it can cause serious damages.

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



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

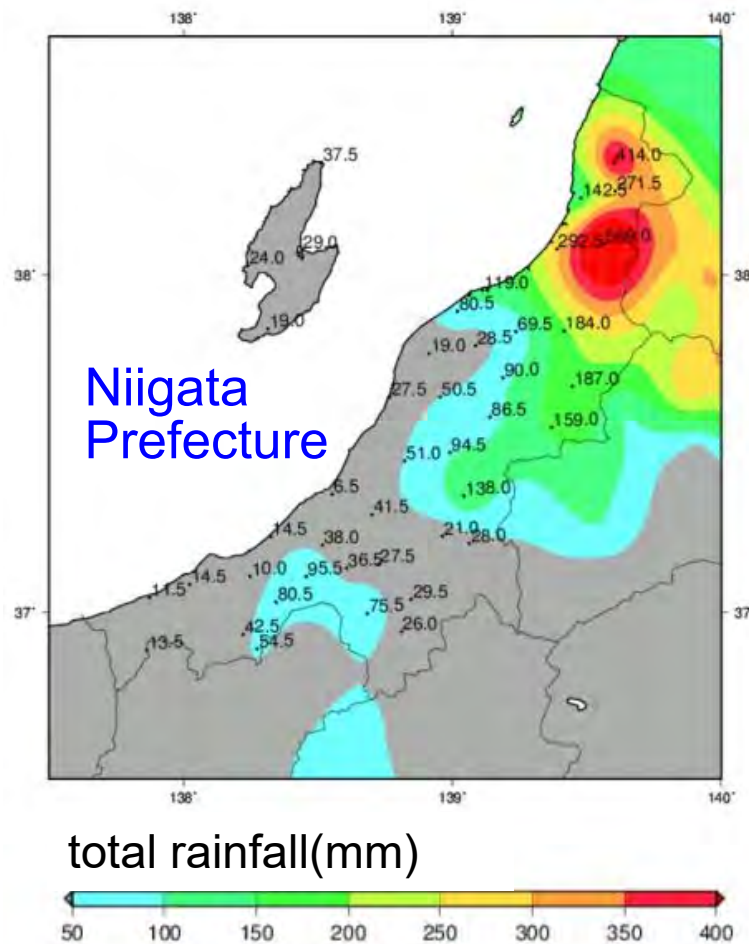


Figure: Japan Meteorological Agency(JMA)

Arakawa River



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

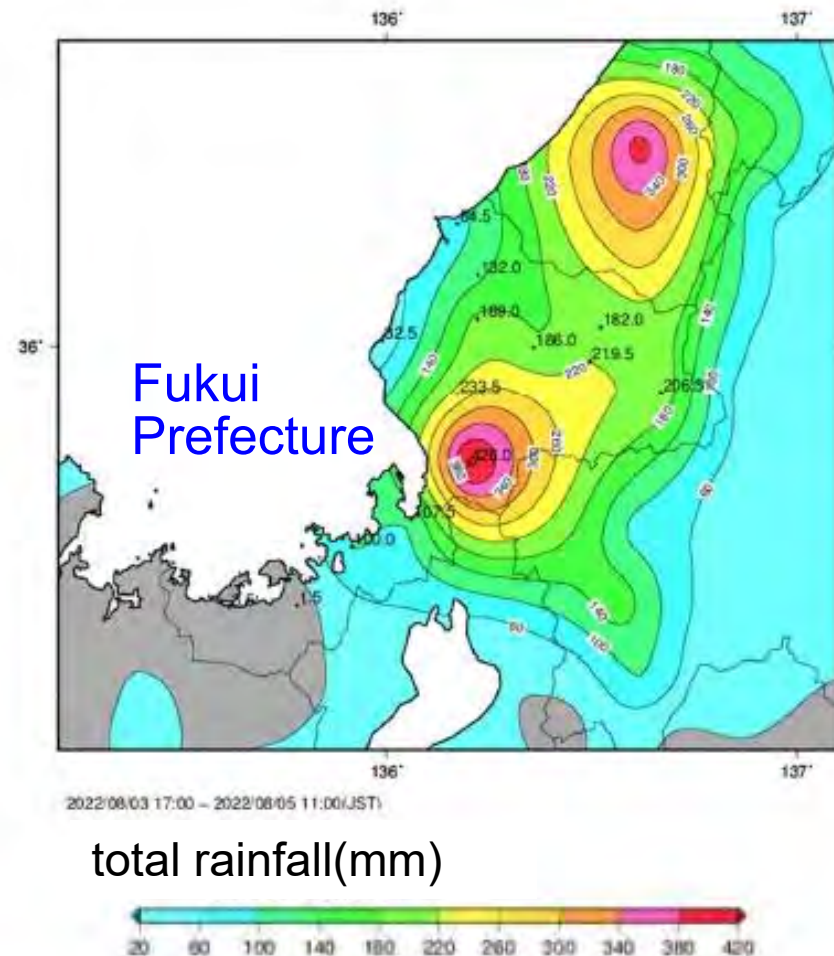


Figure: Japan Meteorological Agency(JMA)



National Road No.8

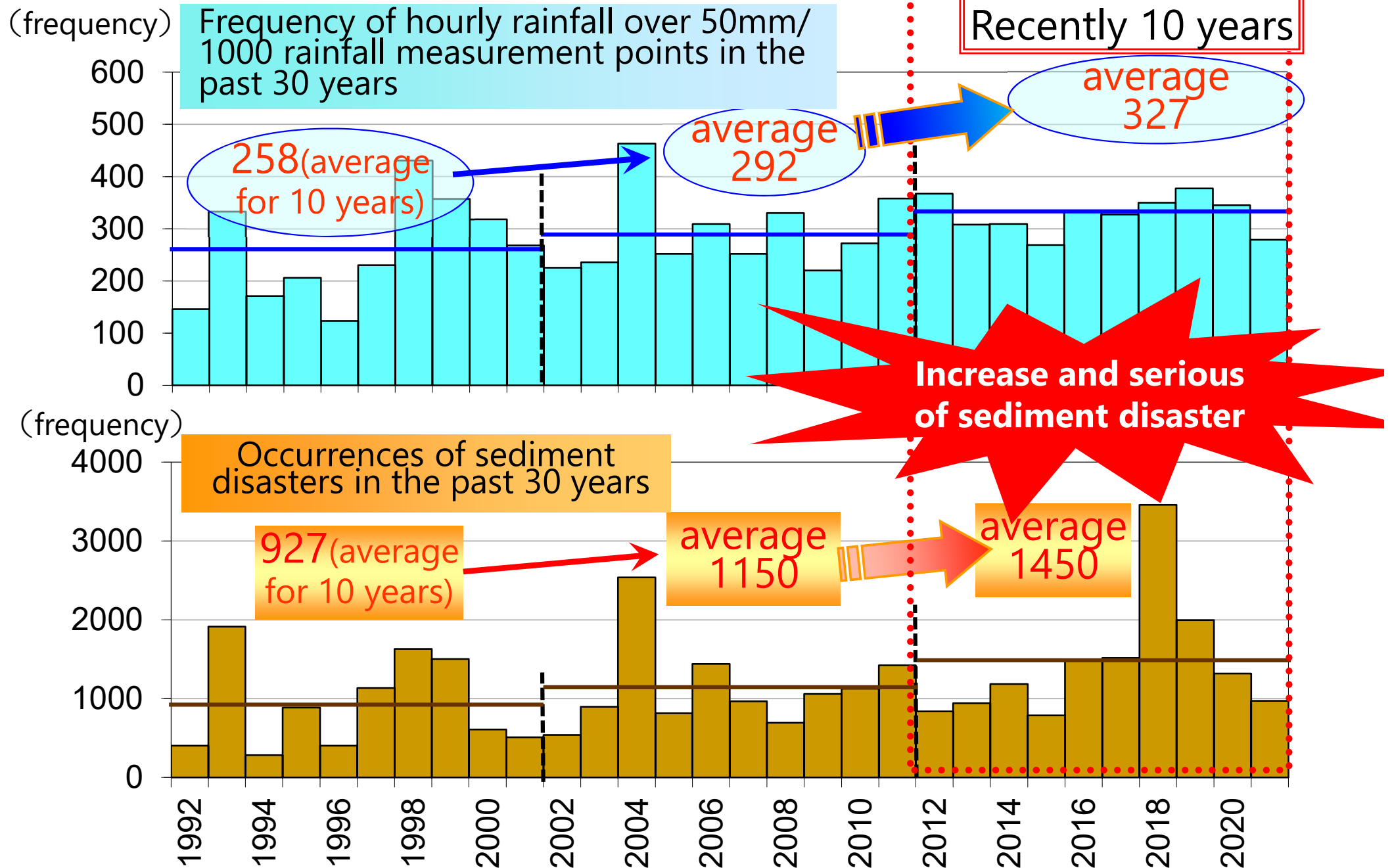


Hokuriku Expressway

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

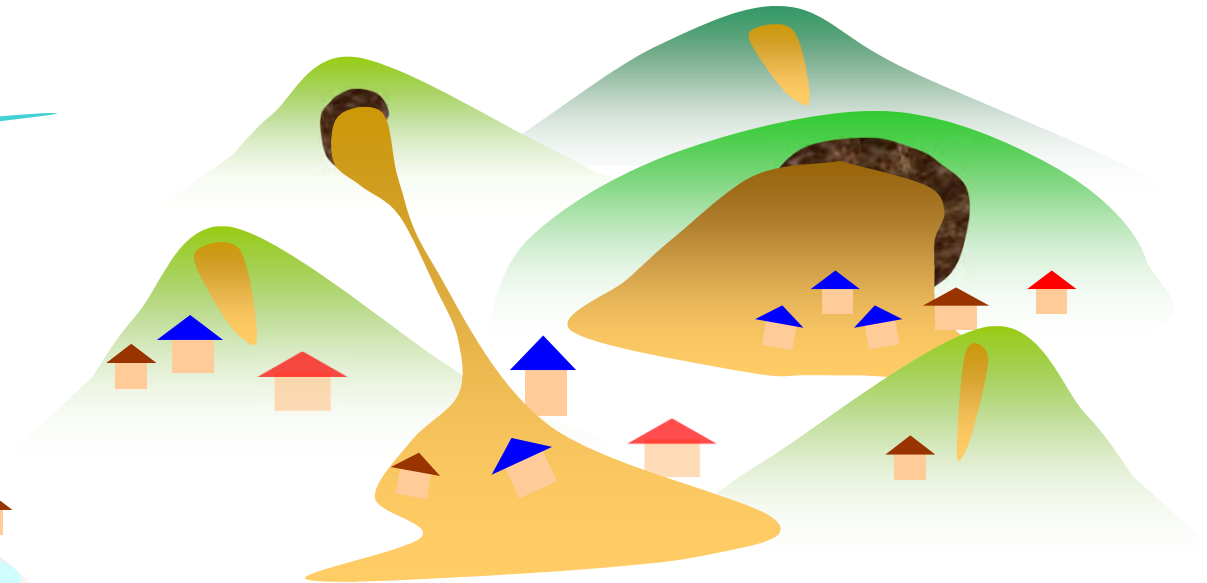
Flood disaster



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

Sediment disaster



Keywords of sediment disasters

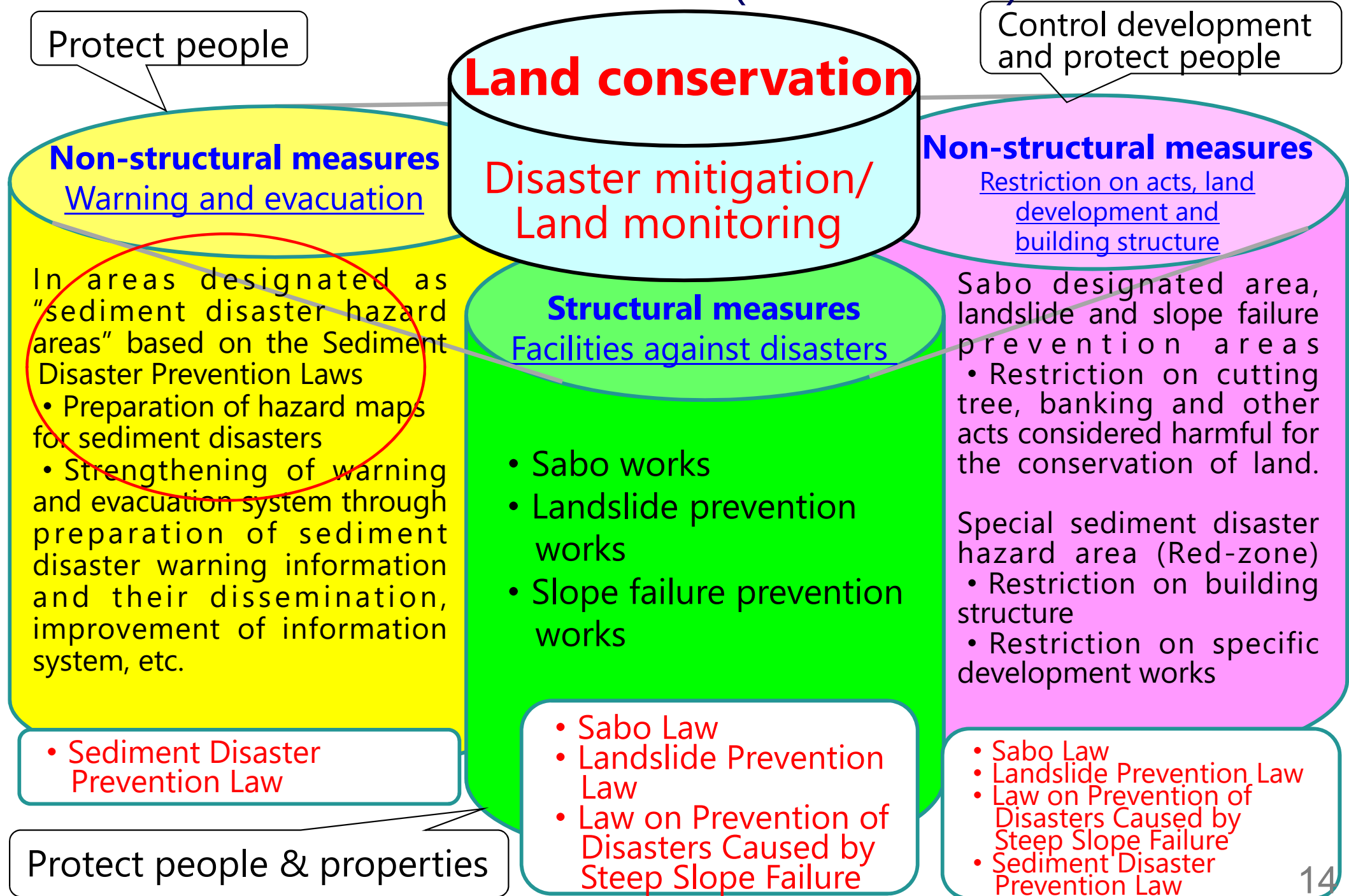
1. Sediment disaster points exist everywhere on slope
2. Basic and trigger factors are various (rain, rising groundwater level, earthquake, geomorphology, geology, etc.)
3. Unpredictable (sudden) phenomena (ex. earthquake→slope failure, rain→debris flow)
4. Phenomena can not be recognized because of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



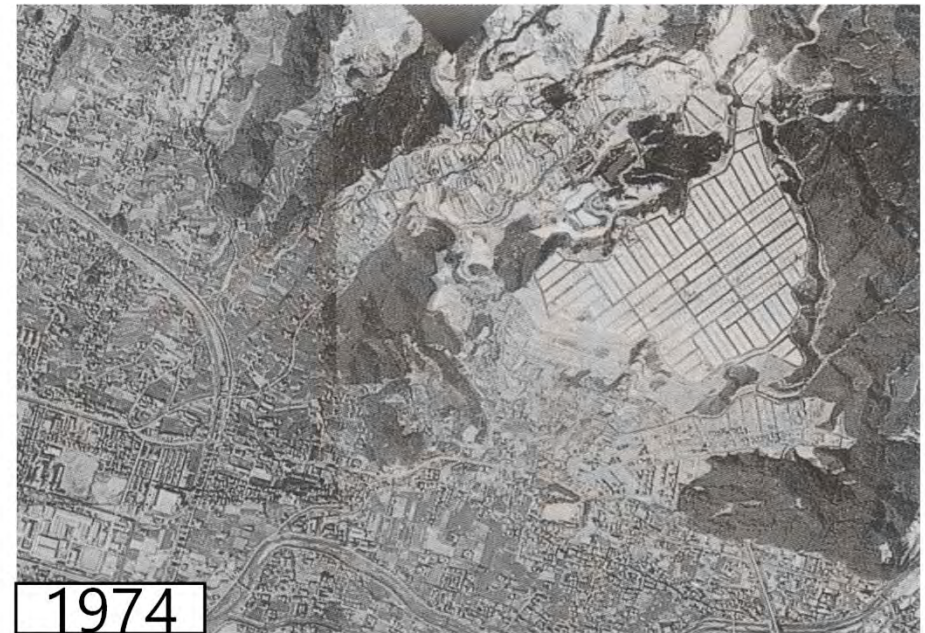
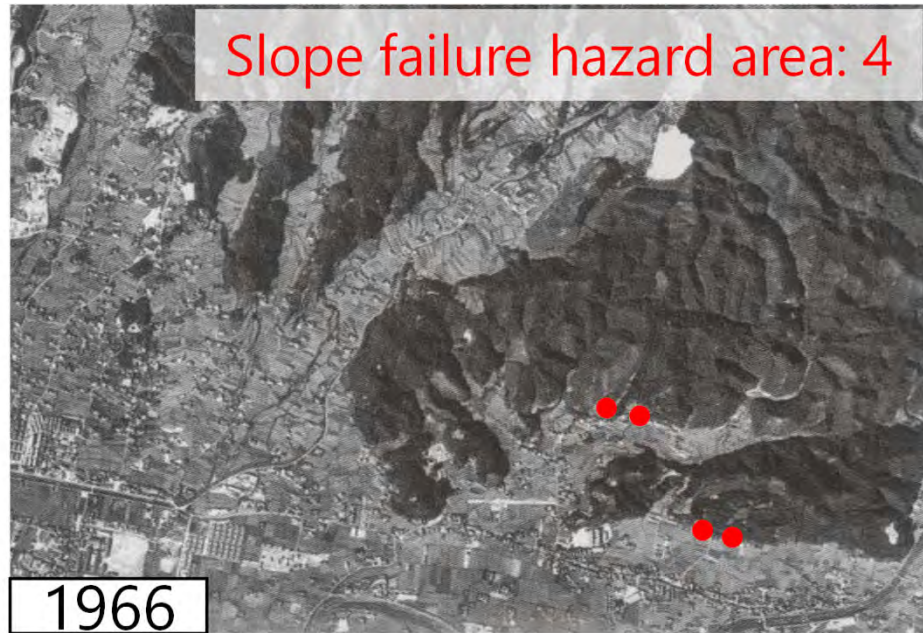
2. Non structural measures (Land-use regulation and control)

- Sediment Disaster Prevention Law

Three strategies for preventing sediment disasters (sabo works)



Urbanization and sediment disasters



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



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

Implement basic survey

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



Implementation of basic survey [Prefectural government]

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

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.

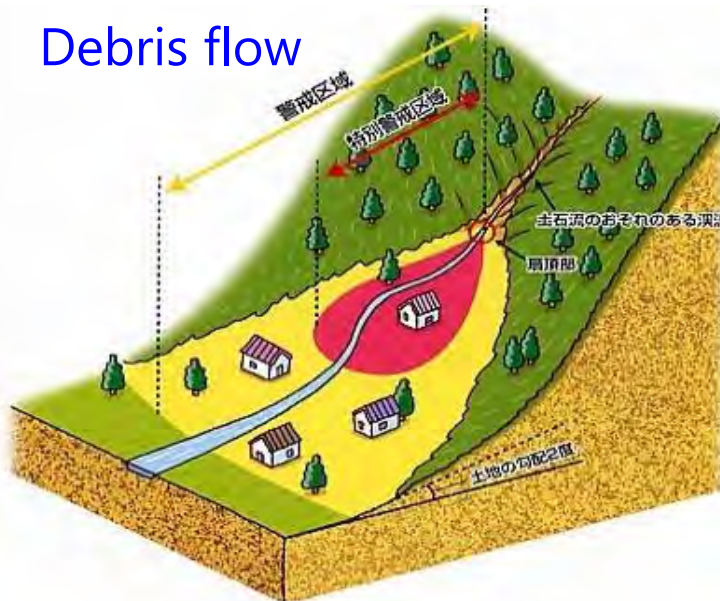
Landslide

- 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)

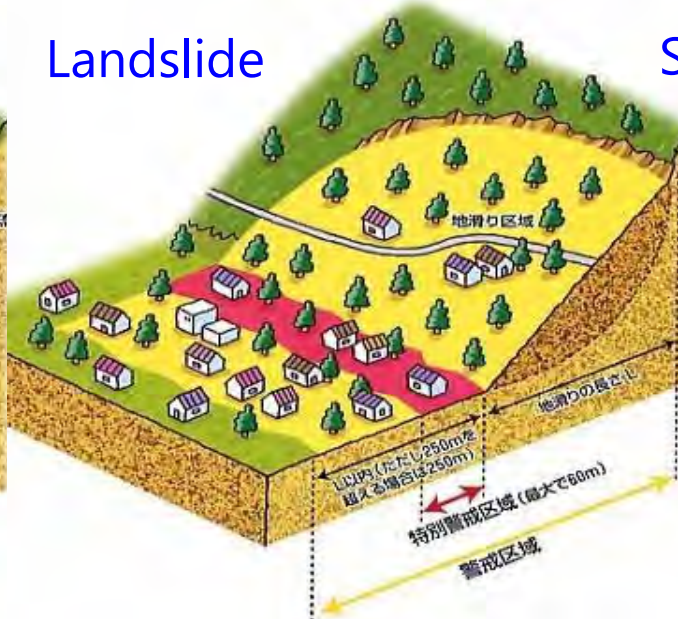
Slope failure

- 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)

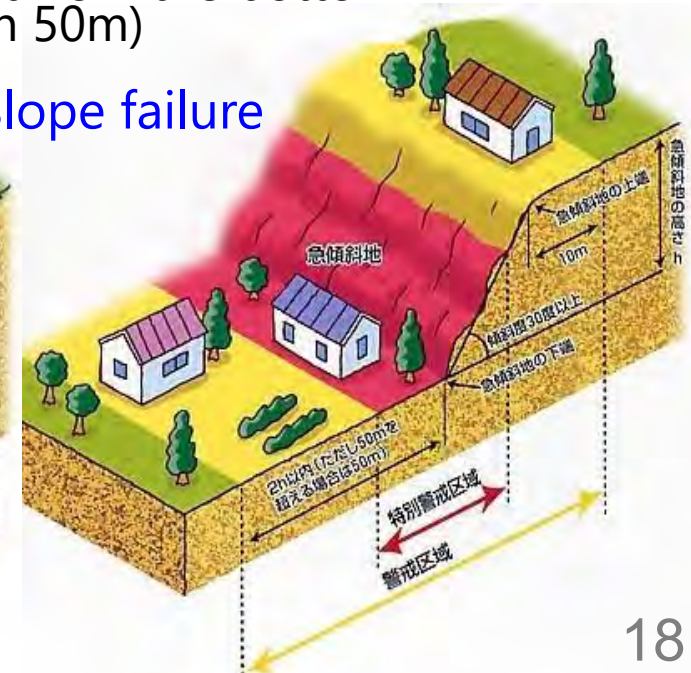
Debris flow



Landslide

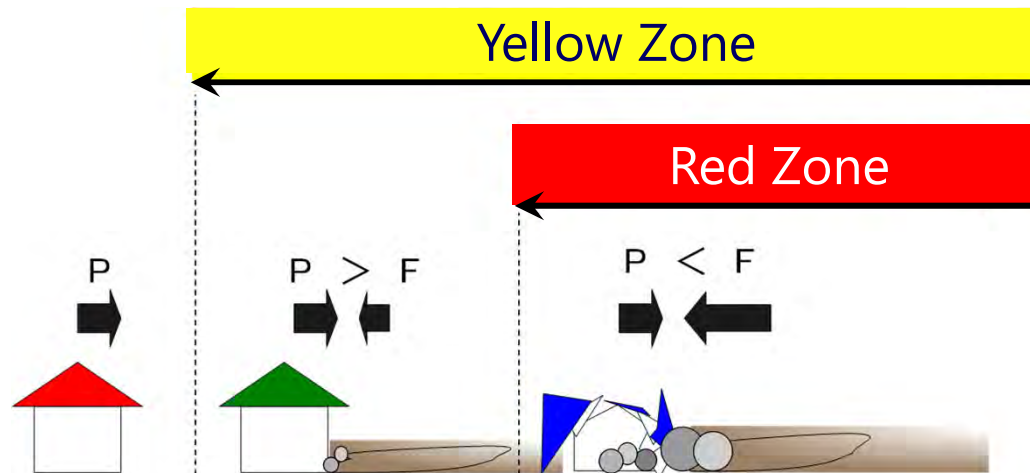


Slope failure



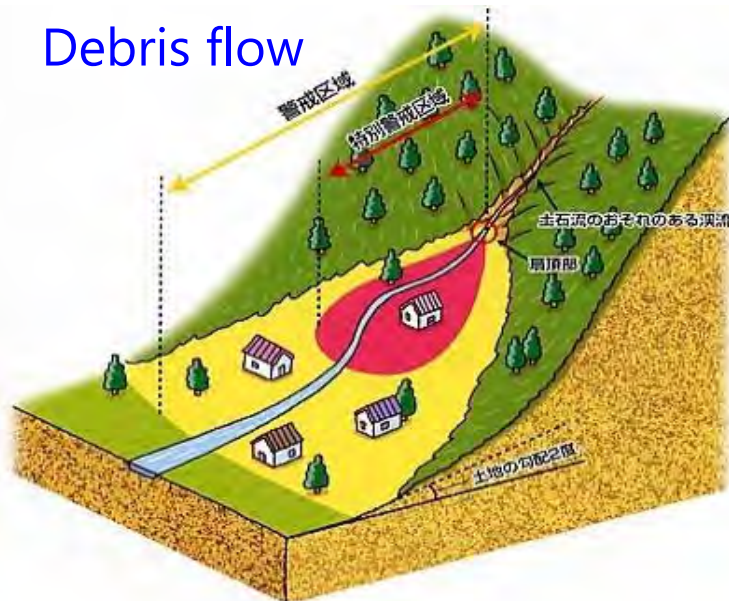
Determination of special sediment disaster hazard area (Red Zone)

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.

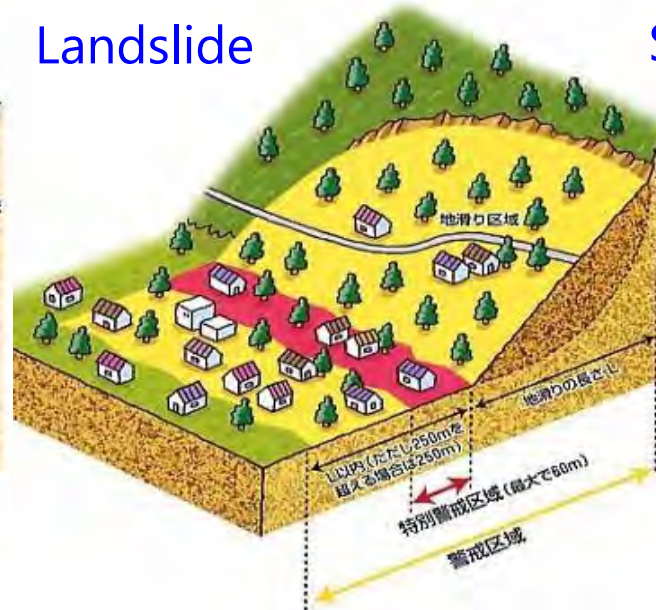


*In case of a landslide, the above-stated force is the magnitude of force that acts on a building in 30 minutes after debris and rocks starts to act on the building by the sliding land block. The landslide hazard area is an area included within a 60m-distance from the bottom end of the landslide area.

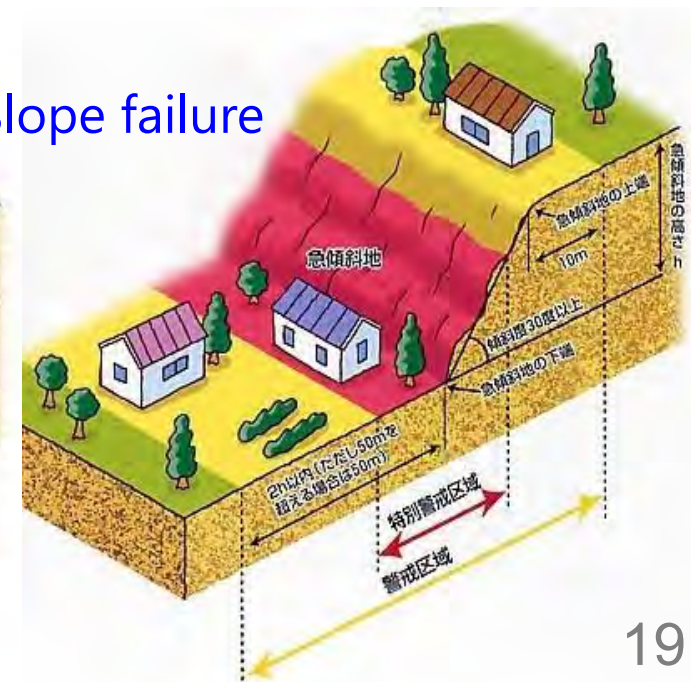
Debris flow



Landslide





Slope failure



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



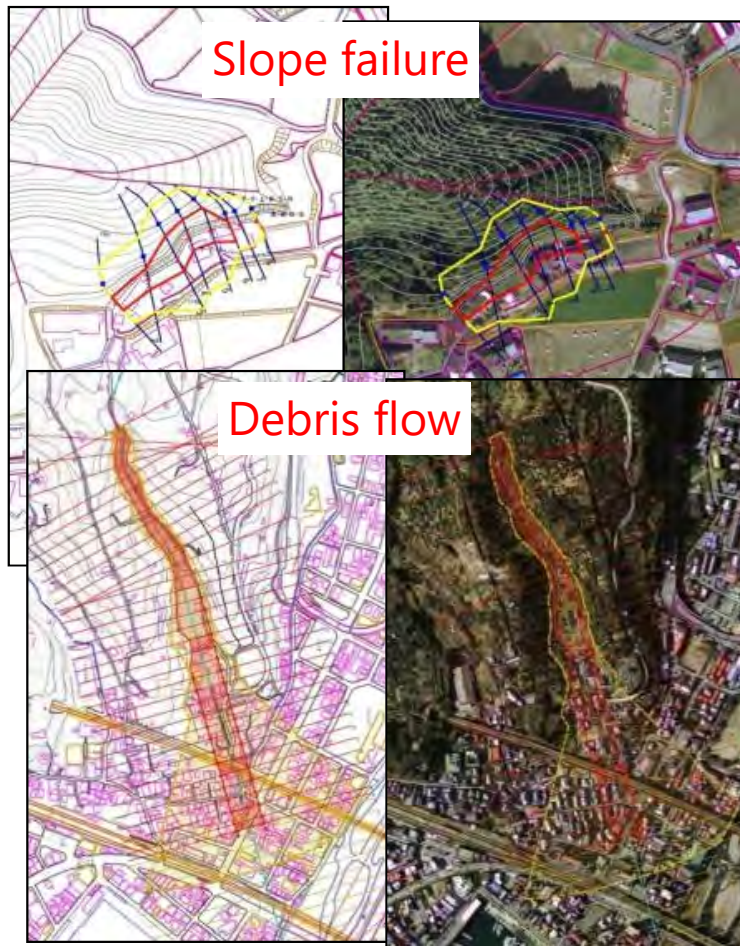
Example of sediment disaster hazard area (Yellow & Red Zone)

-  Sediment disaster hazard area (Yellow zone)
-  Special sediment disaster hazard area (Red zone)



Sediment disaster hazard map

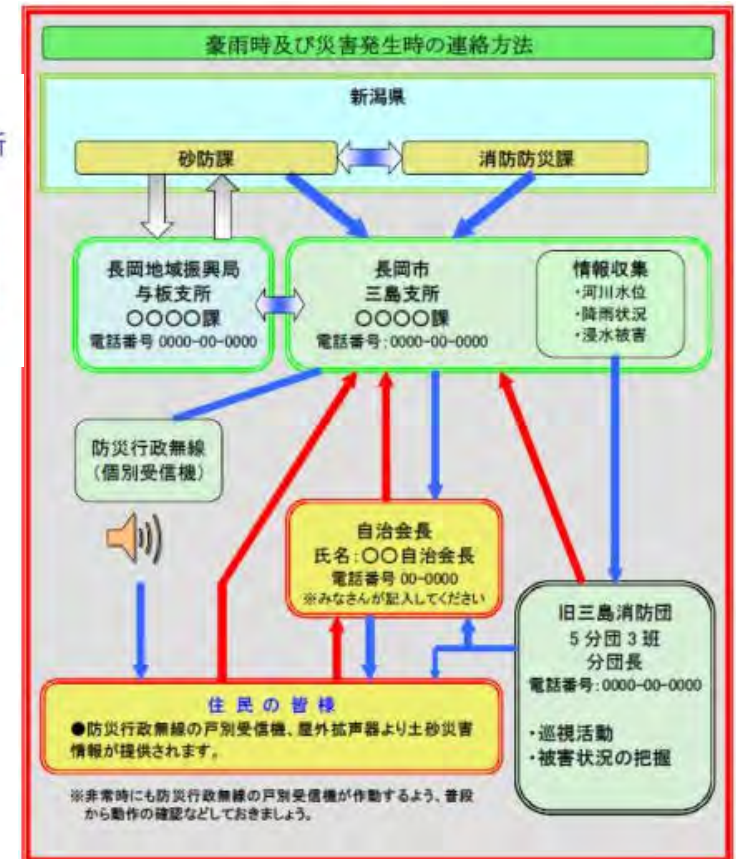
A hazard map against sediment disaster shows the relation between debris flow, landslide, and slope-failure hazard areas and evacuation places, evacuation routes, method of transmitting information at the event of sediment disaster, and necessary matters in order to ensure smooth warning and evacuation.



Sediment disaster hazard area



Evacuation places and disaster classification



Method of transmitting information

Examples of sediment disaster hazard map



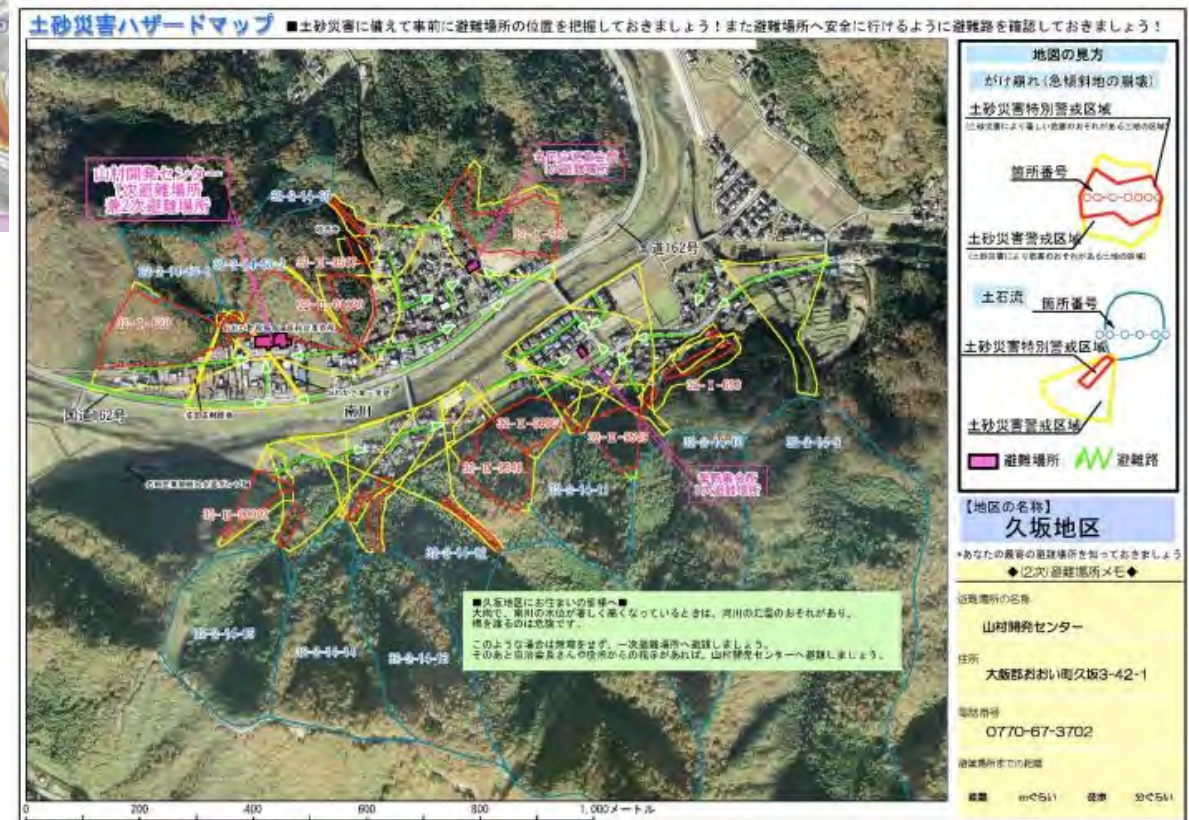
Kouchi district, Saeki Ward, Hiroshima City



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

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Compressibility Characteristics of Soft Clays in the Red River Delta

*Presented by
Khin Phyu Sin*



Content

1. Introduction
2. Objective of the research
3. Methods used in this study for the determination of c_r , c_v , C_c , C_r , σ'_p
4. Location of the Study sites
5. Sample collections
6. Analysis results and procedure
7. Conclusions

References

Appendix

1. Introduction

Geological condition of the RRD

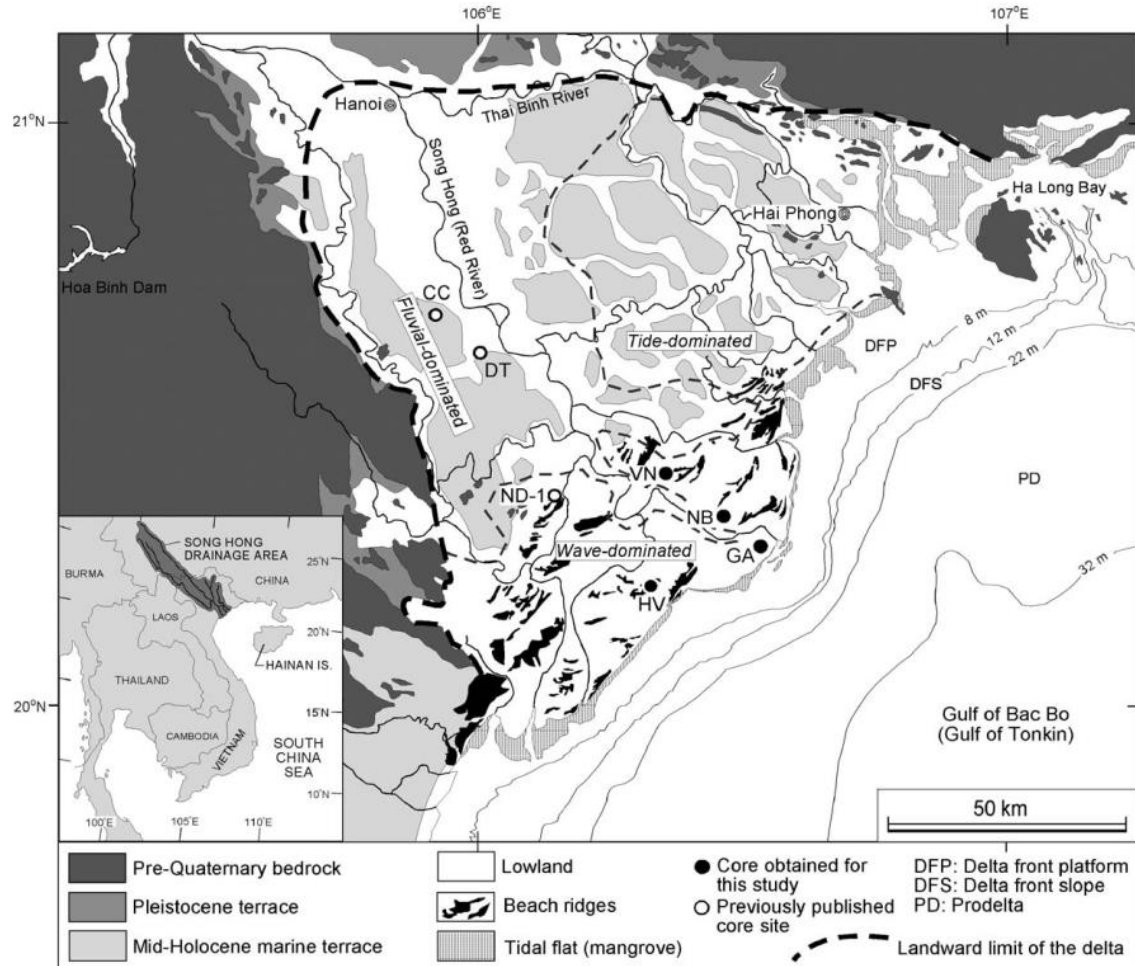
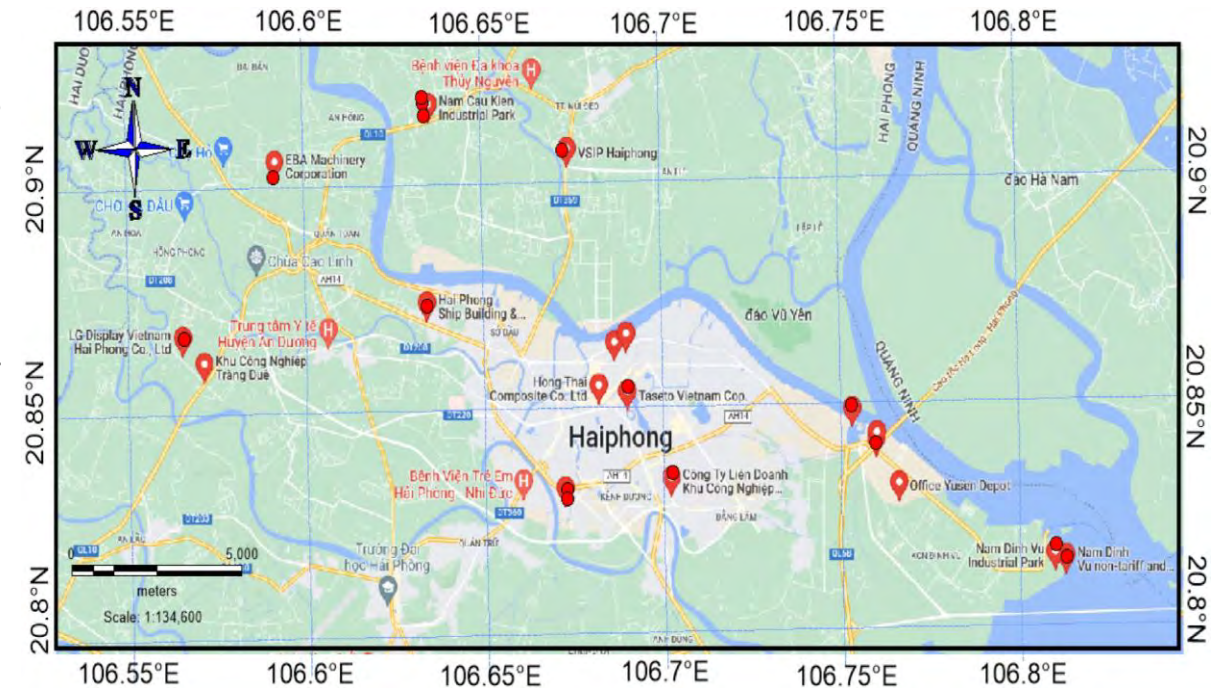
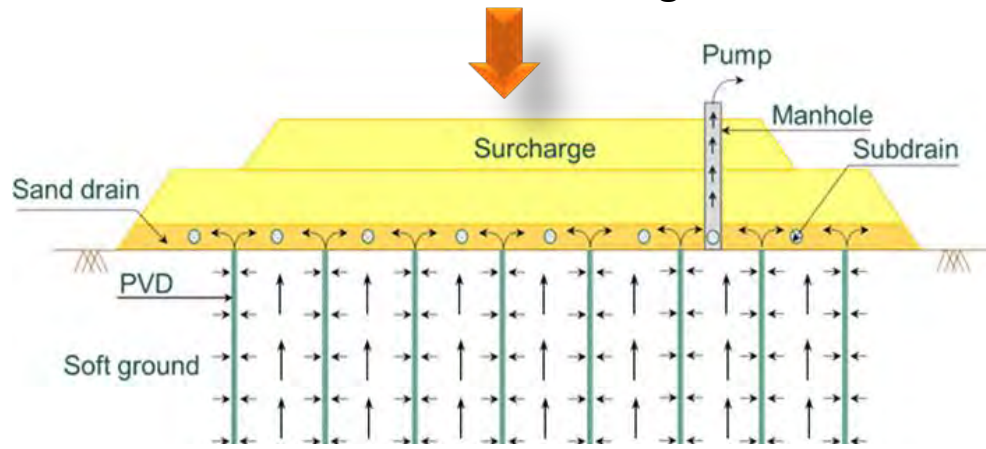


Figure 1. Quaternary geological and topographical map of RRD and adjacent areas (Tanabe et al., 2006)

- 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


$$c_r \left(\frac{\partial^2 u}{\partial r^2} + \frac{1}{r} \frac{\partial u}{\partial r} \right) + c_v \frac{\partial^2 u}{\partial z^2} = \frac{\partial u}{\partial t} \quad \leftarrow \text{Eq. 1.} \quad \text{where } c_r \text{ and } c_v = \text{horizontal and vertical coefficients of consolidation of soil}$$

Settlement of the improved ground at any time t


$$S_t = U_t S_c = \left(1 - \frac{u}{u_0} \right) S_c = f(c_r, c_v, t, S_c) \quad \leftarrow \text{Eq. 2.} \quad \text{where } S_c = \text{ultimate consolidation settlement}$$

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 (σ'_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 σ'_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 (σ'_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)

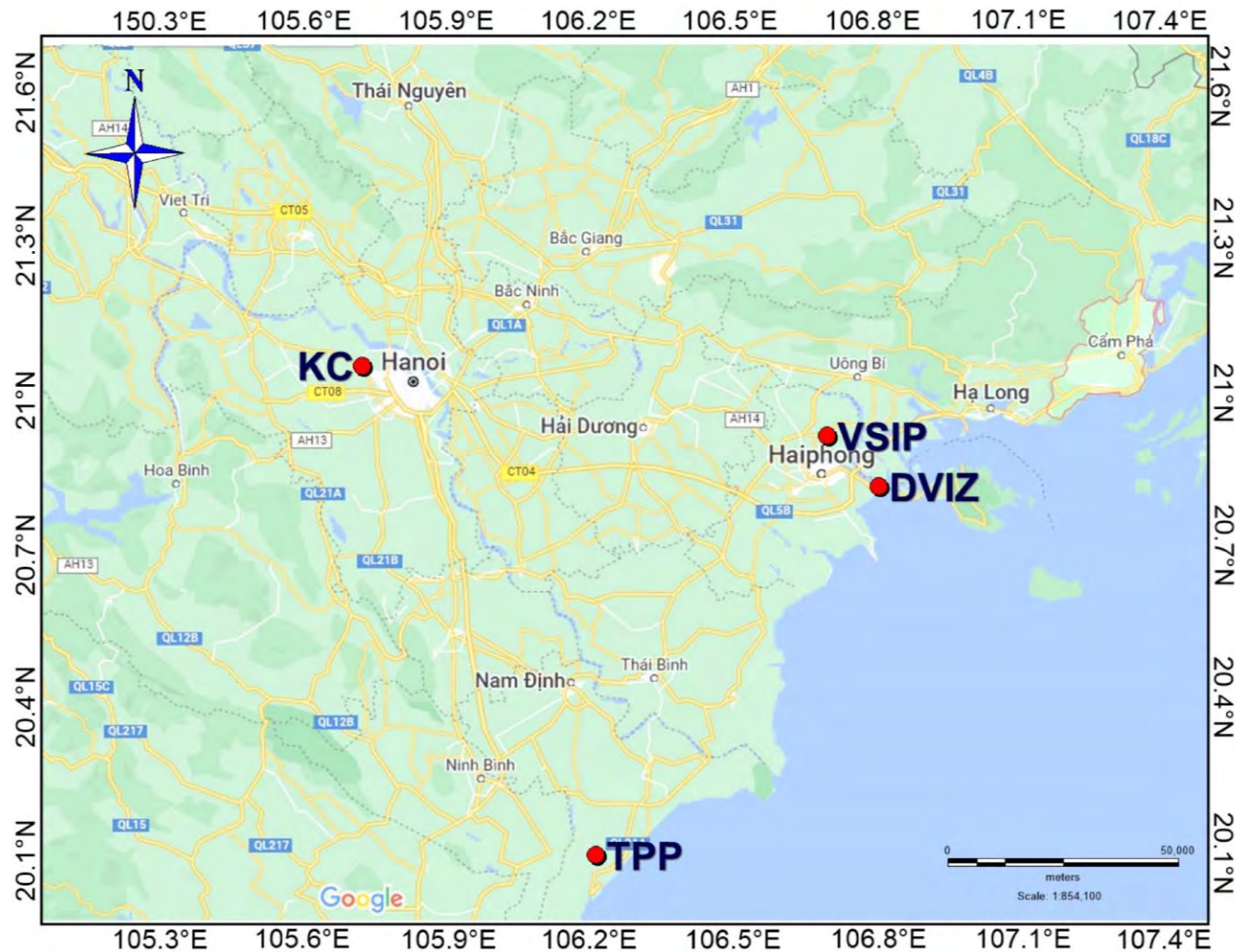
Table 3. Standardized methods used to determine the vertical coefficient of consolidation, c_v

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 (σ'_p) from Oedometer test

1.	Casagrande (1936)'s method
2.	Silva (1970)'s method

4. Location of the Study sites

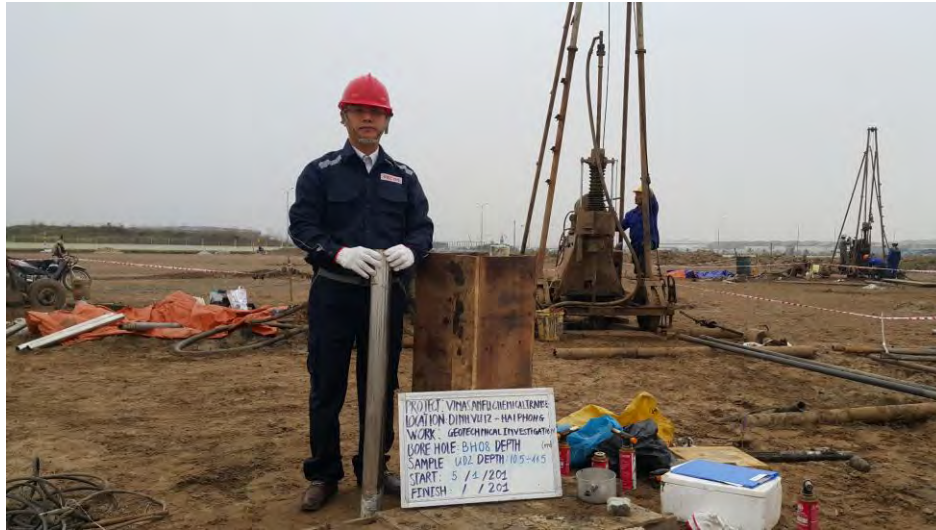


Study sites for this research were taken from supervisor's research projects. They are:

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

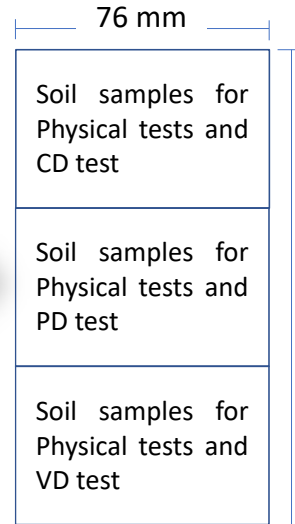
5.3. Laboratory tests



Sample tubes stored in the lab



Sample cutting in the lab



Parts of the sample taken for the tests

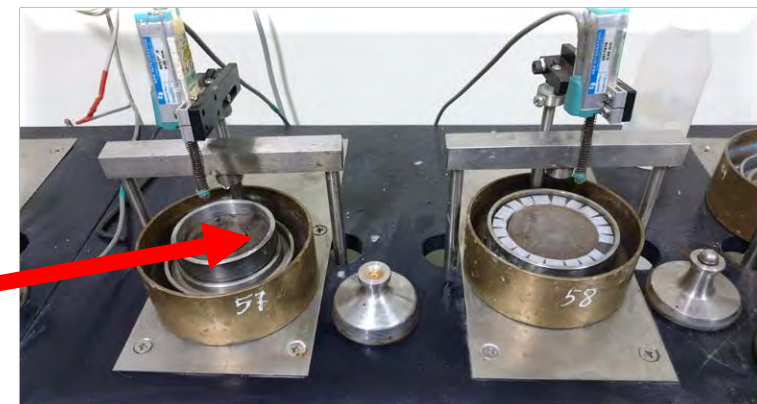


Physical tests, i.e., water content, specific gravity...

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 ($n = D_e/D_c = 2.05$).

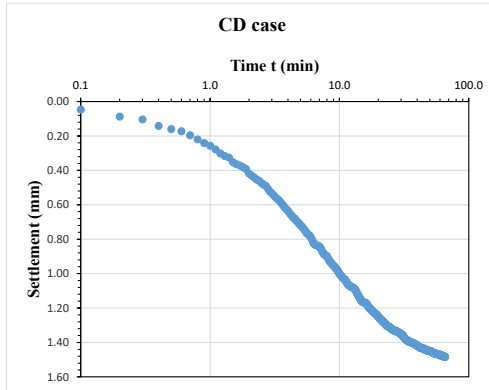
Actual manufactured ratio: $n = 62/28 = 2.214$ (some difference due to water jet cutting error)



Performing the radial consolidation test in the lab

6. Analysis results and procedure

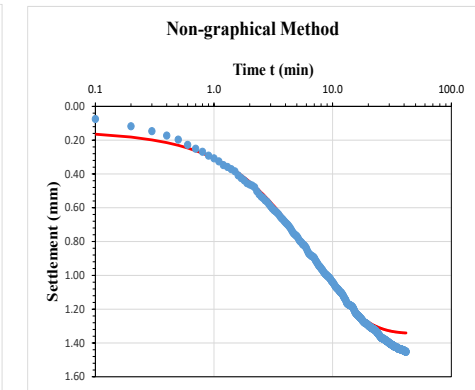
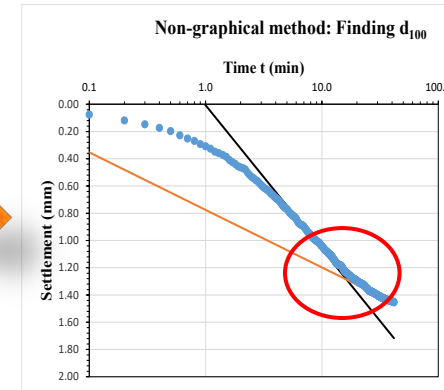
6.1. From implementation of the 1st objective Procedure for getting c_r values



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 $\log(d_r^2/t)$ 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



Exmpl from Non-grphical method for analysaing in Excel to get c_r

	Sample name	Method name	Pressure (kPa)	d_o (mm)	d_{100} (mm)	C_r (mm ² /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 (d_r^2/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)

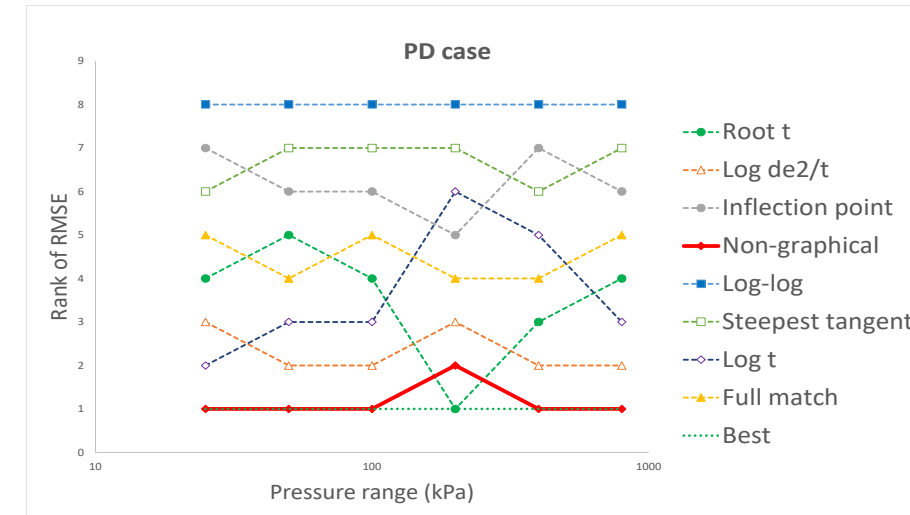
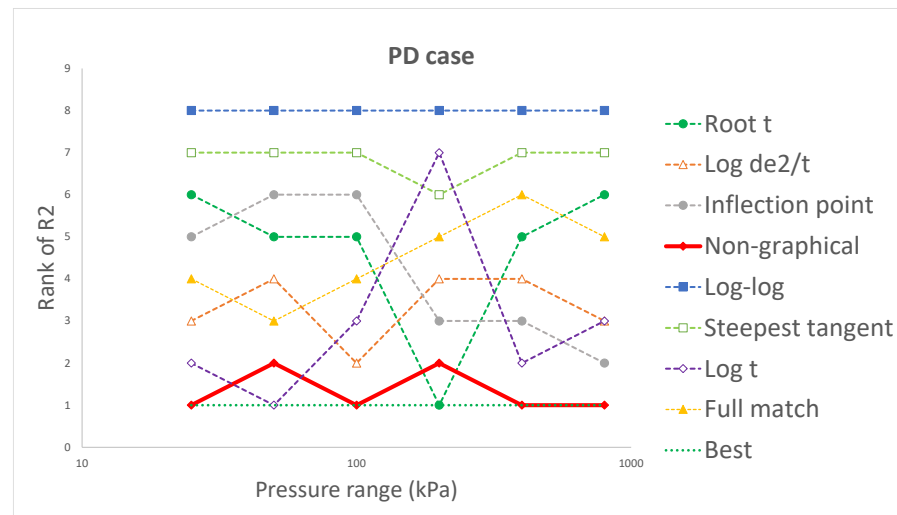
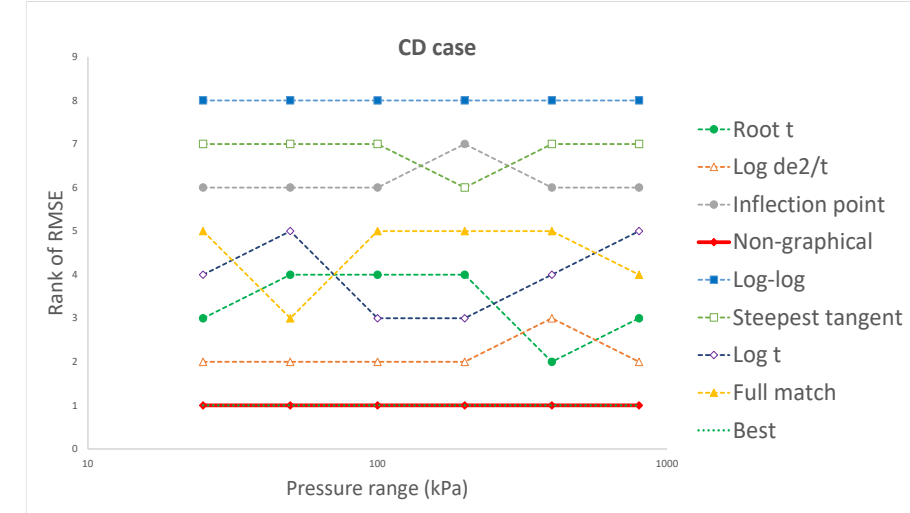
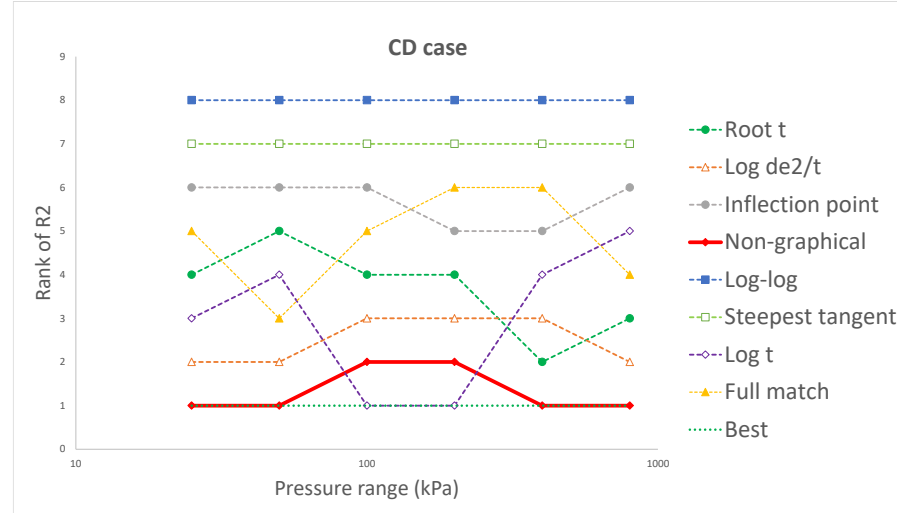
1. For each method, determine $c_{r,CD}$ (or $c_{r,PD}$) from the time (t) and **measured settlement (δ_m) data** curve (as mentioned in slide No.19 and 20).
2. For each method, calculate the **estimated settlement of the sample (δ_e)** by using the theoretical consolidation equation with the inputs of c_r , d_0 , d_{100} .
3. For each method, plot a graph of δ_m vs δ_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](#))

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

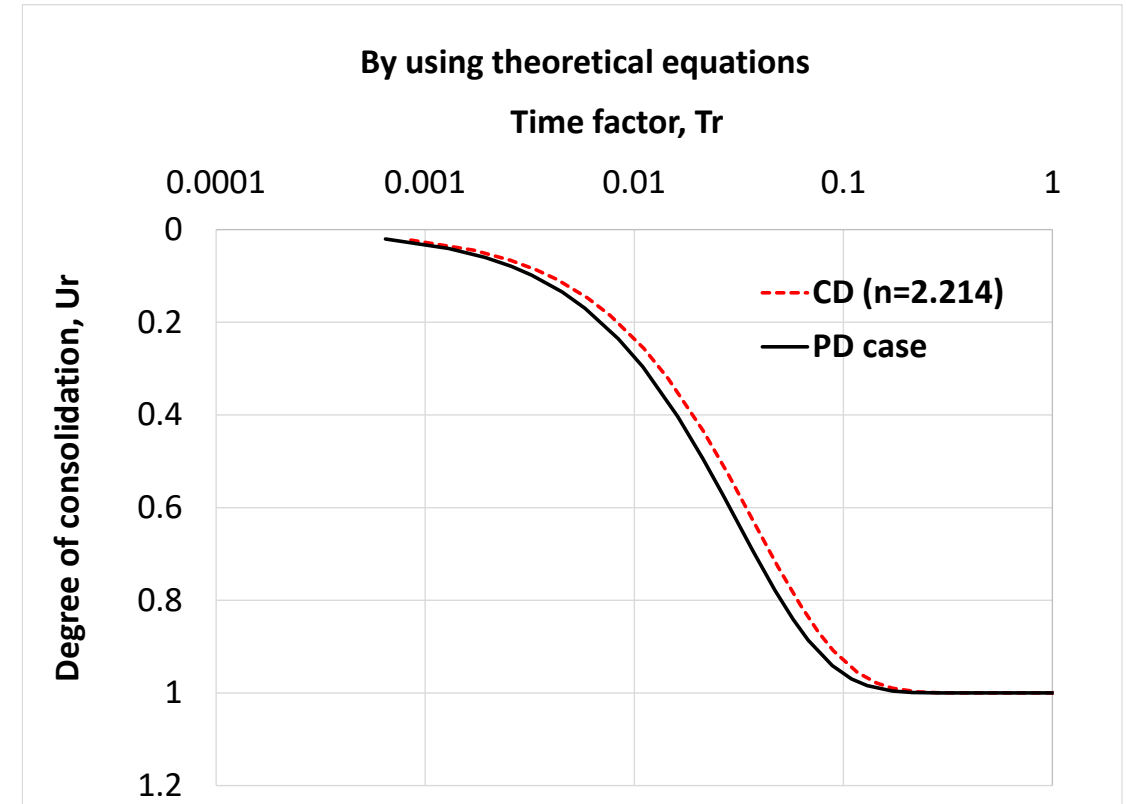
Theoretical equations for CD case ([Scott, 1963](#))

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

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

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

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 ($c_{r,PD}/c_{r,CD} \approx 1.0$).

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 (μ) and variance (σ^2) as the y-axis and $c_{r,CD}/c_{r,PD}$, or $c_{r,CD}/c_v$, or $c_{r,PD}/c_v$ as the x-axis.
- 3) Filtering the outliers ($c_{r,CD}/c_{r,PD}$, or $c_{r,CD}/c_v$, or $c_{r,PD}/c_v$) 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.

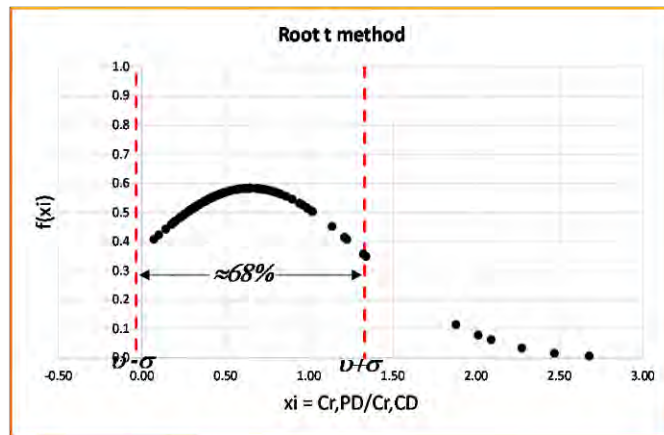
6. Analysis results and procedure

6.2. From implementation of the 2nd objective

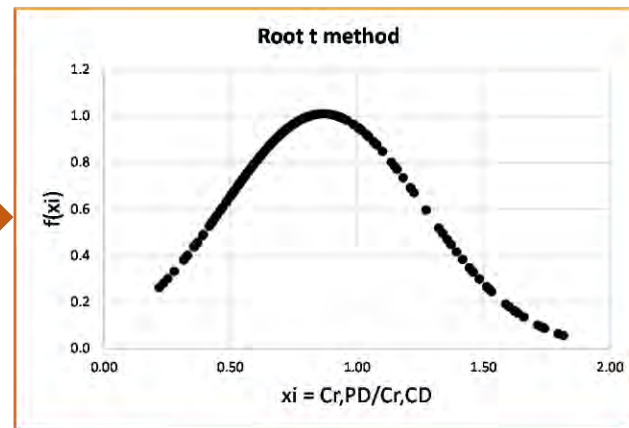
Ratio of $c_{r,PD}/c_{r,CD}$ from experimental results

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

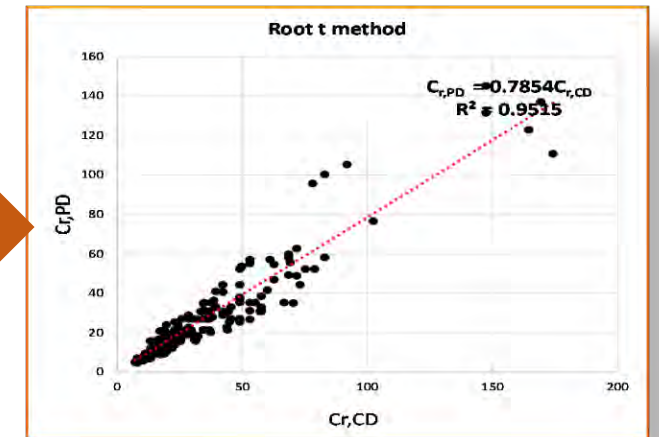
Example of correlation between $c_{r,PD}$ and $c_{r,CD}$ from Root t method (*Intact samples*)



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

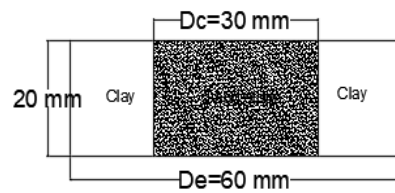
- 1) Construct a soil model in *PLAXIS* software with the dimension of (60 mm x 20 mm) by inputting typical required parameters for soft clay as mentioned in *Table 1a and 1b* from Appendix.
 - For CD case, by installing sand-stone in the middle with different n values (*slide 28*).
- 2) Apply pressure 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

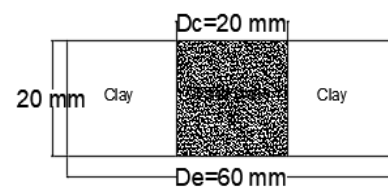
6.2. From implementation of the 2nd objective

Numerical analysis

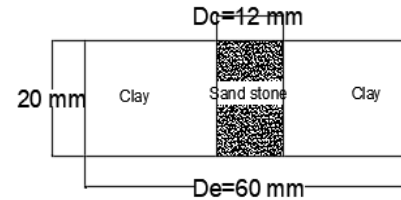
Configuration of variation in sand drain ratio ($n=D_e/D_d$) for CD case (Numerical Analysis)



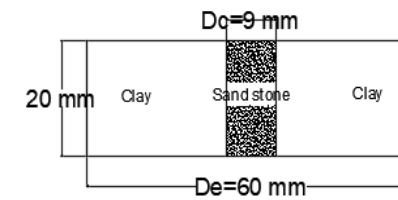
$$n = 2.214$$



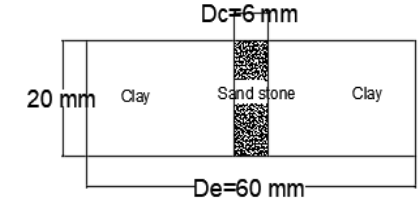
$$n = 3$$



$$n = 5$$

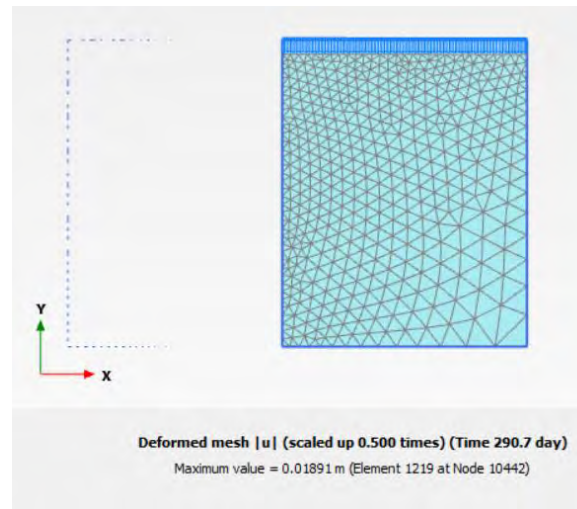
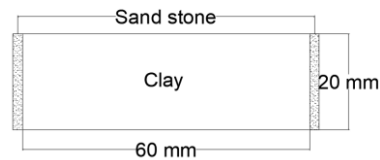


$$n = 6.667 \approx 7$$



$$n = 10$$

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.

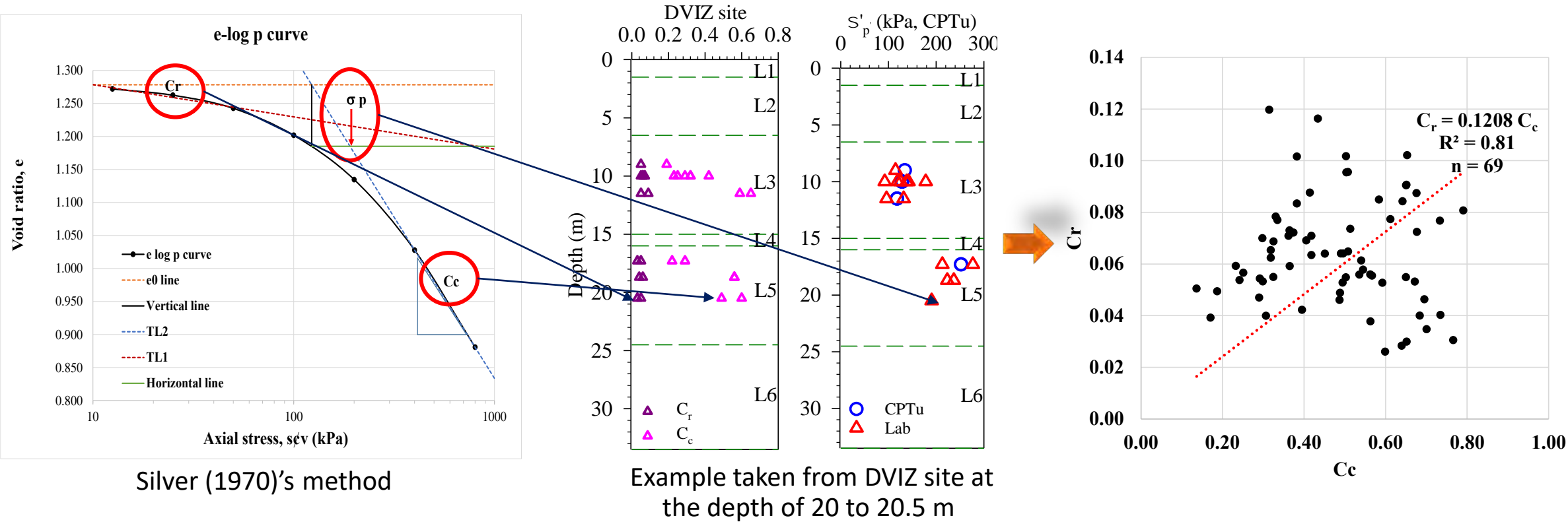
Table showing the variation in $c_{r,CD}$ and $c_{r,PD}/c_{r,CD}$ results based on different n values (10 kPa).					
k_x (m/day)	k_y (m/day)	$n (D_e/D_d)$	$c_{r,CD}$ (mm ² /min)	$c_{r,PD}$ (mm ² /min)	$c_{r,PD}/c_{r,CD}$
3k	k	2.214	6.25	4.730	0.76
3k	k	3	4.30	4.730	1.1
3k	k	5	1.88	4.730	2.52
3k	k	6.667≈7	1.00	4.730	4.73
3k	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_d). 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 (σ'_p)

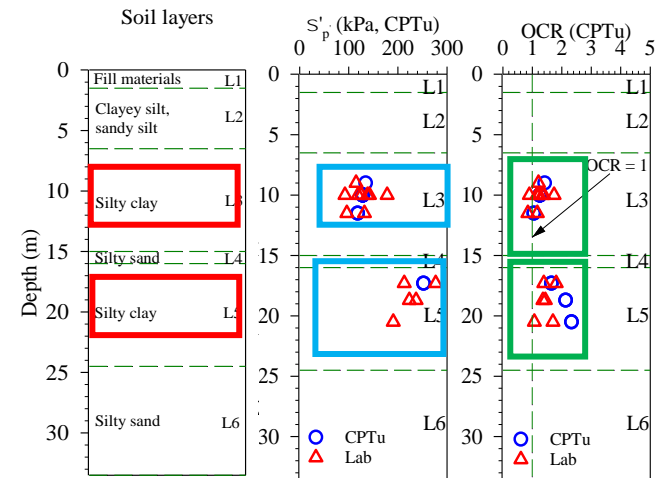


Summary table for the correlation results between C_c and e_0 and C_r and C_c		
Correlation	R^2	No. of data point
$C_c = 0.3864 e_0$	0.9475	69
$C_r = 0.1208 C_c$	0.81	69

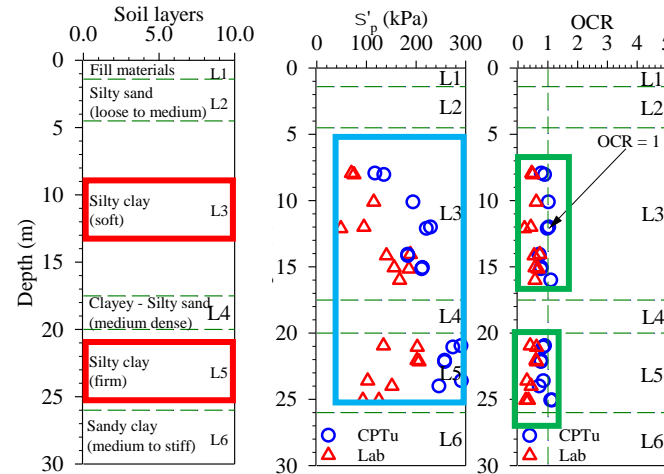
6. Analysis results and procedure

6.3. From implementation of the 3rd objective

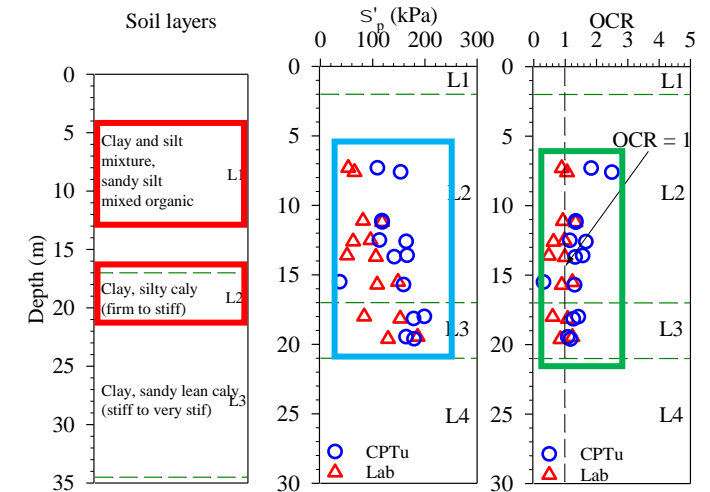
Evaluation of compression index (C_c), recompression index (C_r) and preconsolidation stress (σ'_p)



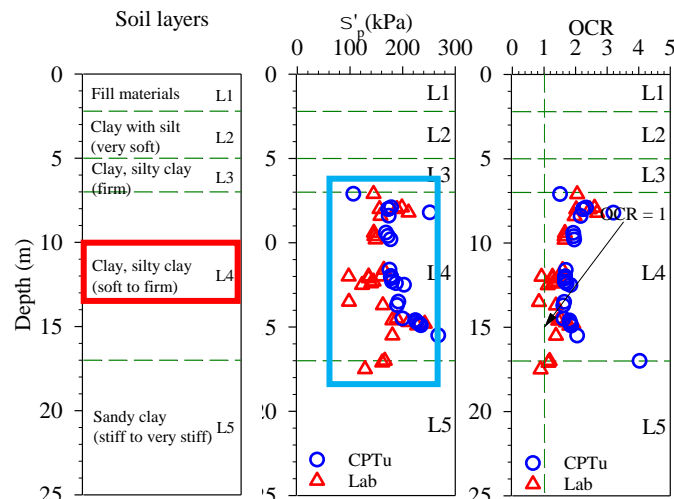
DVIZ site



KC site



TPP site



VSIP site

- In general, the OCR profiles indicate that the clays at the test sites are normally consolidated ($OCR \approx 1$)
- Preconsolidation stress value (σ'_p) from Lab test is typically smaller than that from CPTu test. This indicates that the σ'_p from lab test is influenced by 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 \rightarrow 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.

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