# Flexural Strengthening Effect of RC Beam by Hybrid Bonding Method using Thermoplastic CFRP (熱可塑性FRPによる複合付着方法で曲げ補強されたRC梁の評価 )

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Bangladesh

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University：Kanazawa Institute of Technology(M.D)
Duration：2019.4-2021.3

Last year, I enjoyed the Japanese tea ceremony. It was aristocratic and nice !

I like to explore Japanese culture and infrastructure development and want to see more mountains, castles, park.

## Reason for Applying

I have been working for the Roads and Highways Department (RHD) since 2011. My responsibilities included Bridge infrastructure design and maintenance. My purpose in applying this program is to contribute to the strengthening of existing infrastructures to maintain serviceability performance and enhanced load-carrying capacity.

## Research

The main objectives of my research are ：

- To evaluate the performance of the flexural strengthening of RC beam specimen with an alternative, cost-effective thermoplastic CFRP material.
- Investigation of combined Near-surface mounted (NSM) and Externally bonded reinforcement technique (Hybrid Bonding method) applied to the strengthened specimen with a comparatively shorter span to depth ratio.

## Prospect

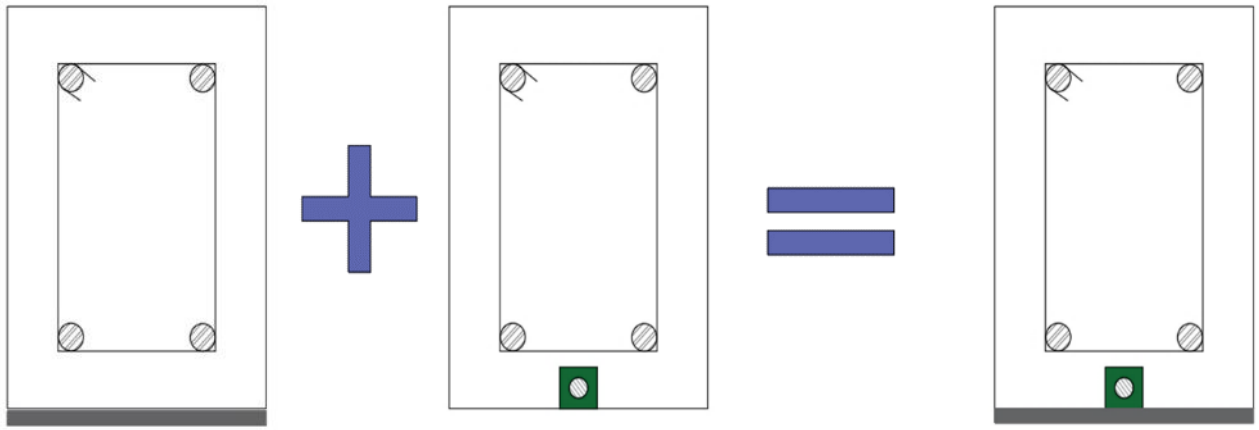
After graduation, I will continue to research in my country and contribute to the strengthening of the existing bridge infrastructures with a low cost solution.

## Daily life

I have been to many Bridge sites and enjoyed staying in Tokyo, Fukui, Nagoya, Gifu, and Nagasaki. At weekend, I like to visit the sea, mountains, castles, park with my family members.

# Introduction

- Conventional thermosetting Carbon Fiber Reinforced Polymer (CFRTS) is used in the repair and rehabilitation of concrete infrastructure.
- Thermosetting carbon FRP bar (CFRTS) is costly. Not widely used all over the world.
- Thermoplastic CFRP (CFRTP) may be an alternative, cost-effective material. CFRTP has Easy and fast production capability, More Lighter and exclusive bendability compared to CFRTS.



*Externally Bonded Reinforcement (EBR) Technique*

*Near Surface Mounted (NSM) Technique*

*Hybrid Bonding Technique*

# Objectives

- To investigate comparative behavior of CFRTP and CFRTS bar in flexural strengthening of RC Structure using hybrid bonding method.
- Validation of hybrid bonding method applied to specimen with a comparatively shorter span to depth ratio.

Thermoplastic CFRP roll ,160 meters long, weighs 12 kg!

Source: https://www.komatsumatere.co.jp/cabkoma/en/

# Methodology

## Test Method

- Four point bending test

## Evaluation method

- Load-carrying capacity (Flexure capacity)
- Deflection of specimens
- Failure modes
- Cracking behavior(crack nos. and spacing)
- Strain evaluation
- Bending stiffness

# Test Matrix

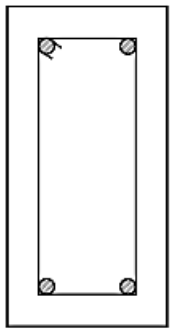
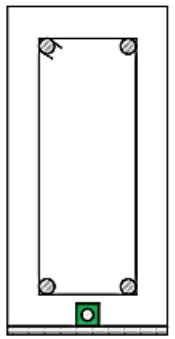
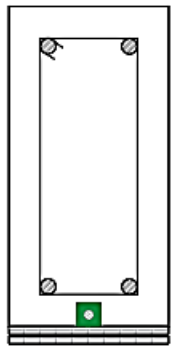


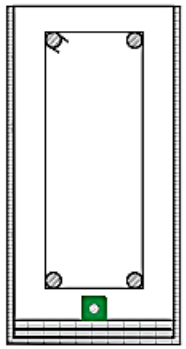
Fig: CB



HP9F1

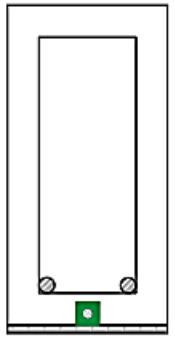


HP9F2

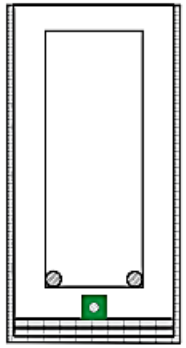


HP9F2A

Fig: 9.3 mm CFRTP NSM with CFRTS Fabric



HS8F1



HS8F2A

Fig: 8.0 mm CFRTS NSM with CFRTS Fabric

***FIG: Hybrid Strengthened beams***

# Test Matrix

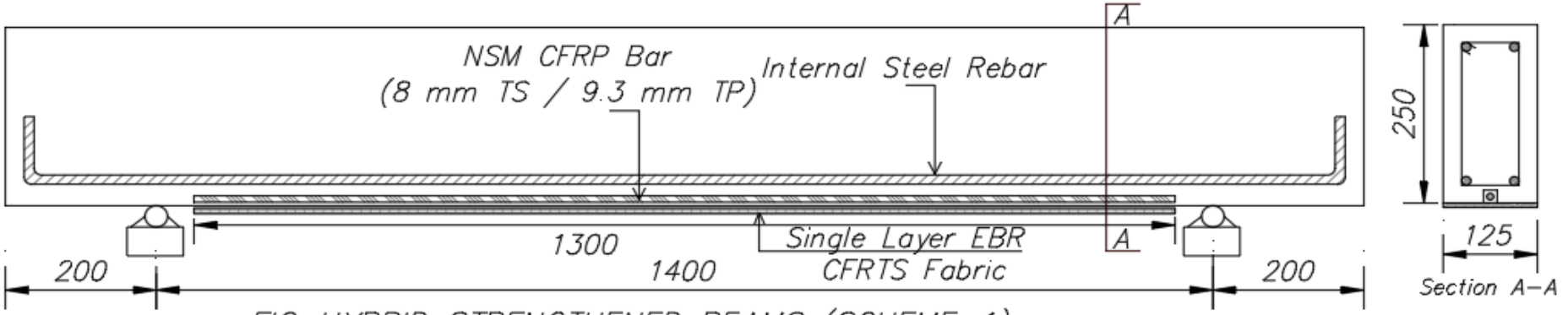



FIG: HYBRID STRENGTHENED BEAMS (SCHEME–1)

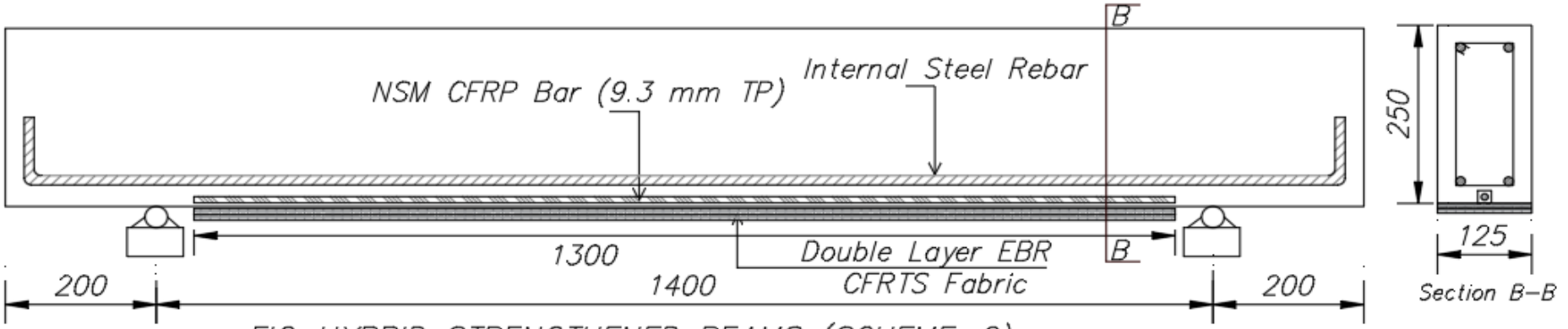



FIG: HYBRID STRENGTHENED BEAMS (SCHEME–2)

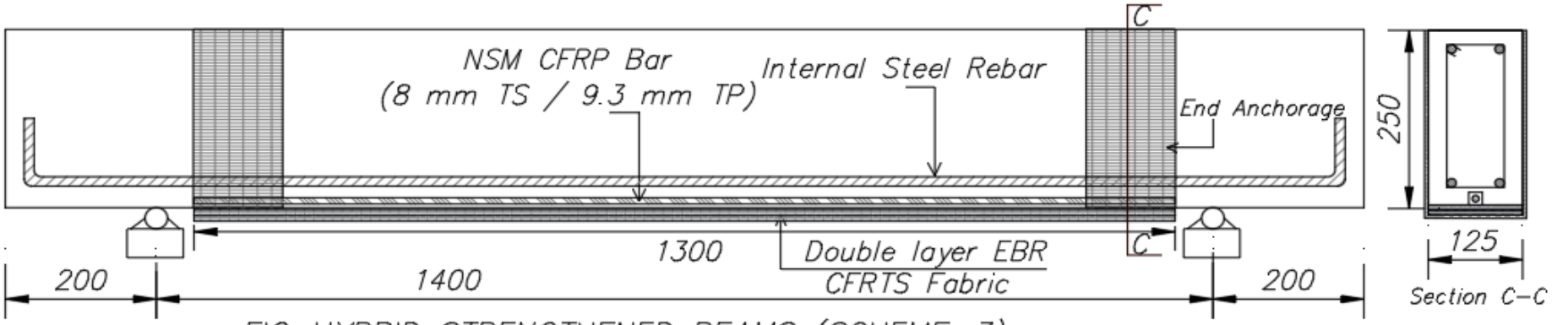



FIG: HYBRID STRENGTHENED BEAMS (SCHEME–3)

# Specimen and material properties

| W/C(%) | s/a(%) | Mix composition (kg/m³) | | | | |
|---|---|---|---|---|---|---|
| | | W | C | S | G | Ad |
| 44.8 | 45.1 | 167 | 373 | 775 | 960 | 2.61 |

| Material | Mechanical property | Result |
|---|---|---|
| Concrete | Compressive strength (Mpa) | 43.86 |
| | Flexure Strength (Mpa) | 3.93 |
| | Elastic Modulus (Gpa) | 31.7 |
| Steel 13 mm (SD345) (Internal bottom reinforcement) | Yield stress (MPa) | 384 |
| | Ultimate Strength (Mpa) | 552 |
| | Elongation (%) | 20 |
| Steel 10 mm (SD345) (Internal top reinforcement) | Yield stress (MPa) | 373 |
| | Ultimate strength(Mpa) | 539 |
| | Elongation (%) | 23 |
| Steel 6 mm (SD295A) (Internal shear reinforcement) | Yield stress (MPa) | 411 |
| | Ultimate strength (Mpa) | 534 |
| | Elongation (%) | 17 |

# Mechanical Property of strengthening material

| Material | Mechanical property | Result |
|---|---|---|
| **CFRTP strand rod 9.3 mm $\varphi$** | Ultimate strength (kN) | ≥80 |
| | Elastic modulus (GPa) | 160 |
| | Ultimate strain (%) | 1.82 |
| **CFRTS bar 8 mm $\varphi$** | Ultimate strength (kN) | 103.5 |
| | Elastic modulus (GPa) | 152 |
| | Ultimate strain (%) | 1.36 |
| **CFRTS fabric (0.167 mm)** | Ultimate strength (GPa) | 3.4 |
| | Elastic modulus (GPa) | 230 |
| | Ultimate strain (%) | 1.48 |
| **Epoxy adhesive curing condition 20 ±1°C, 7 days** | Bending strength (Mpa) | ≥40 |
| | Tensile strength (MPa) | ≥30 |
| | Tensile shear strength (MPa) | ≥12.5 |
| **Epoxy primer** | Viscosity (mPa·s)( at 23℃) | 400 |

# Internal steel and strengthening material

Fig: Rebar framework

Fig: CFRTP bar($\emptyset = 9.3$ mm)

Fig: CFRTS bar($\emptyset = 8$ mm)

Fig: CFRTS Fabric (t=0.167 mm )

# strengthening procedure and test setup

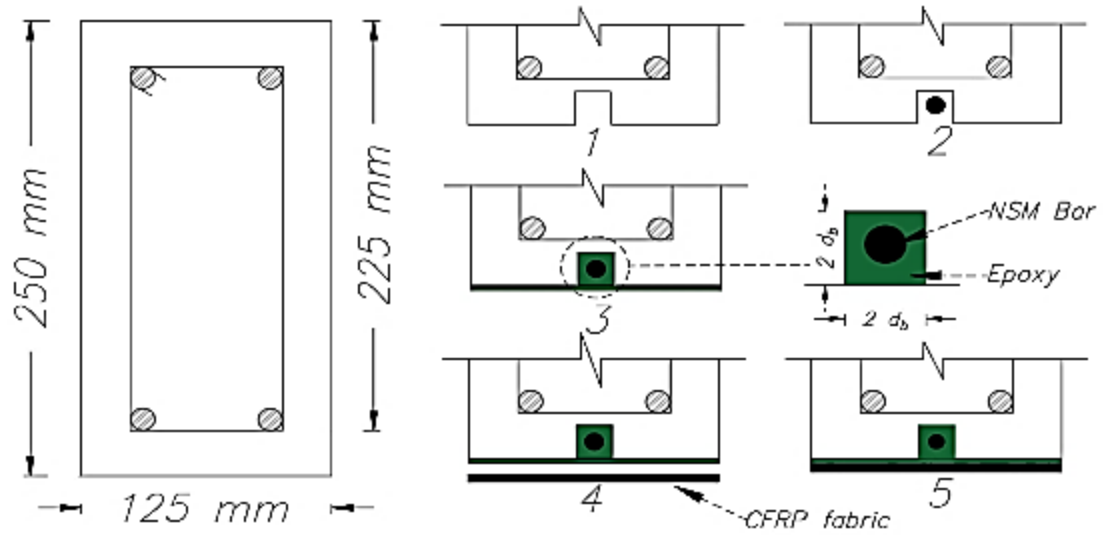



*FIG: Sequence of specimen preparation*

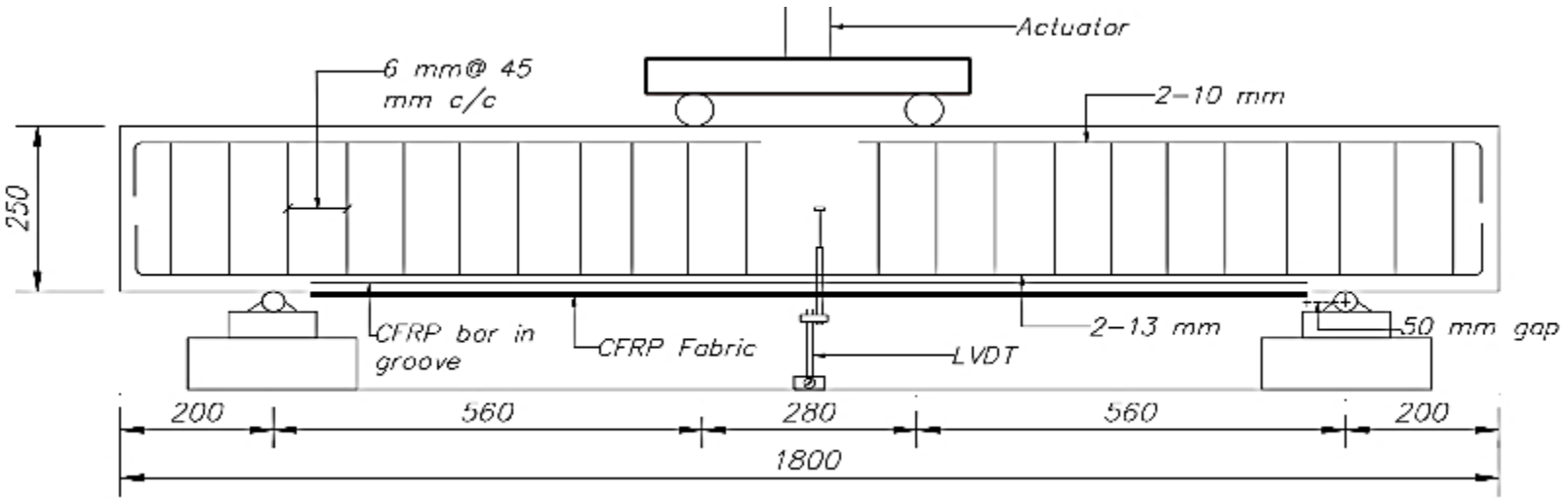



*FIG: Beam Details and Test setup*

# Preparation of Hybrid Strengthening

Fig: Making groove and grinding bottom soffit of specimen

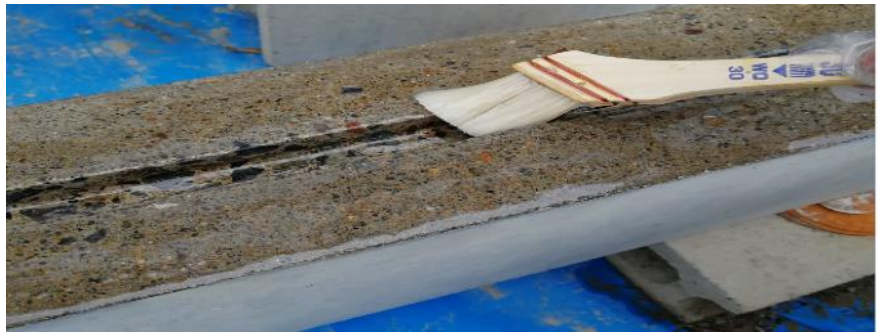


Fig: Applying Primer and NSM CFRP bar

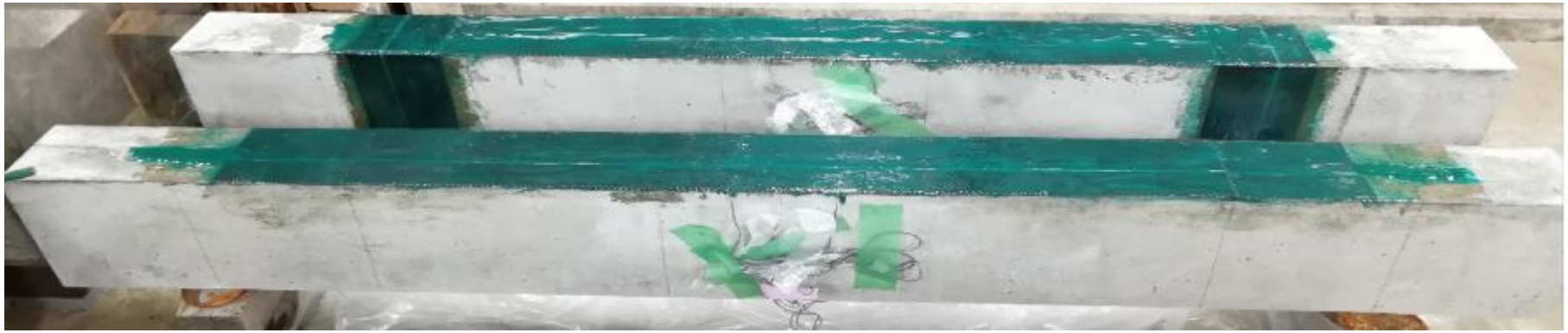


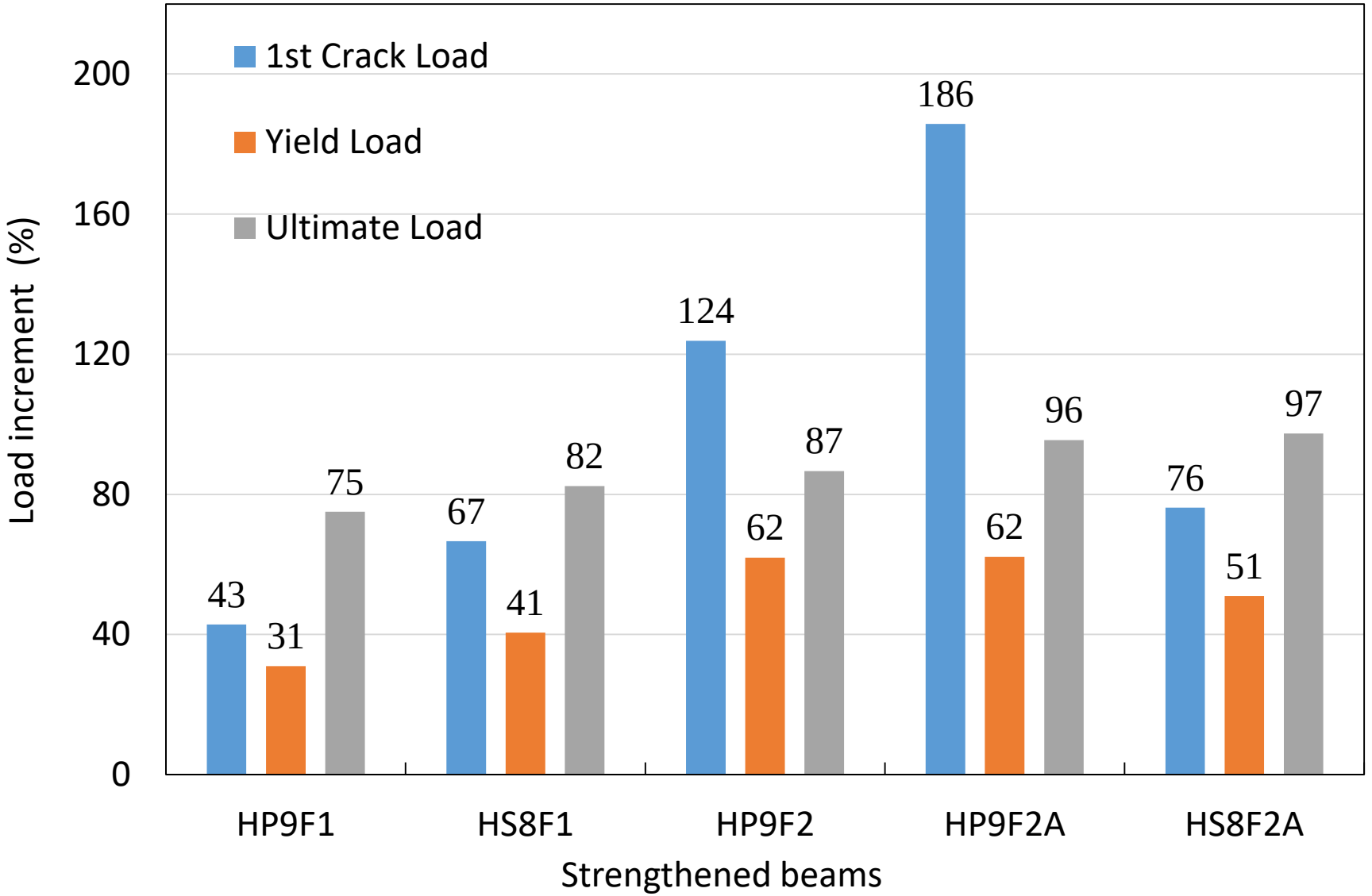
Fig: Attached EBR CFRP by Epoxy adhesive

# Result and Discussion

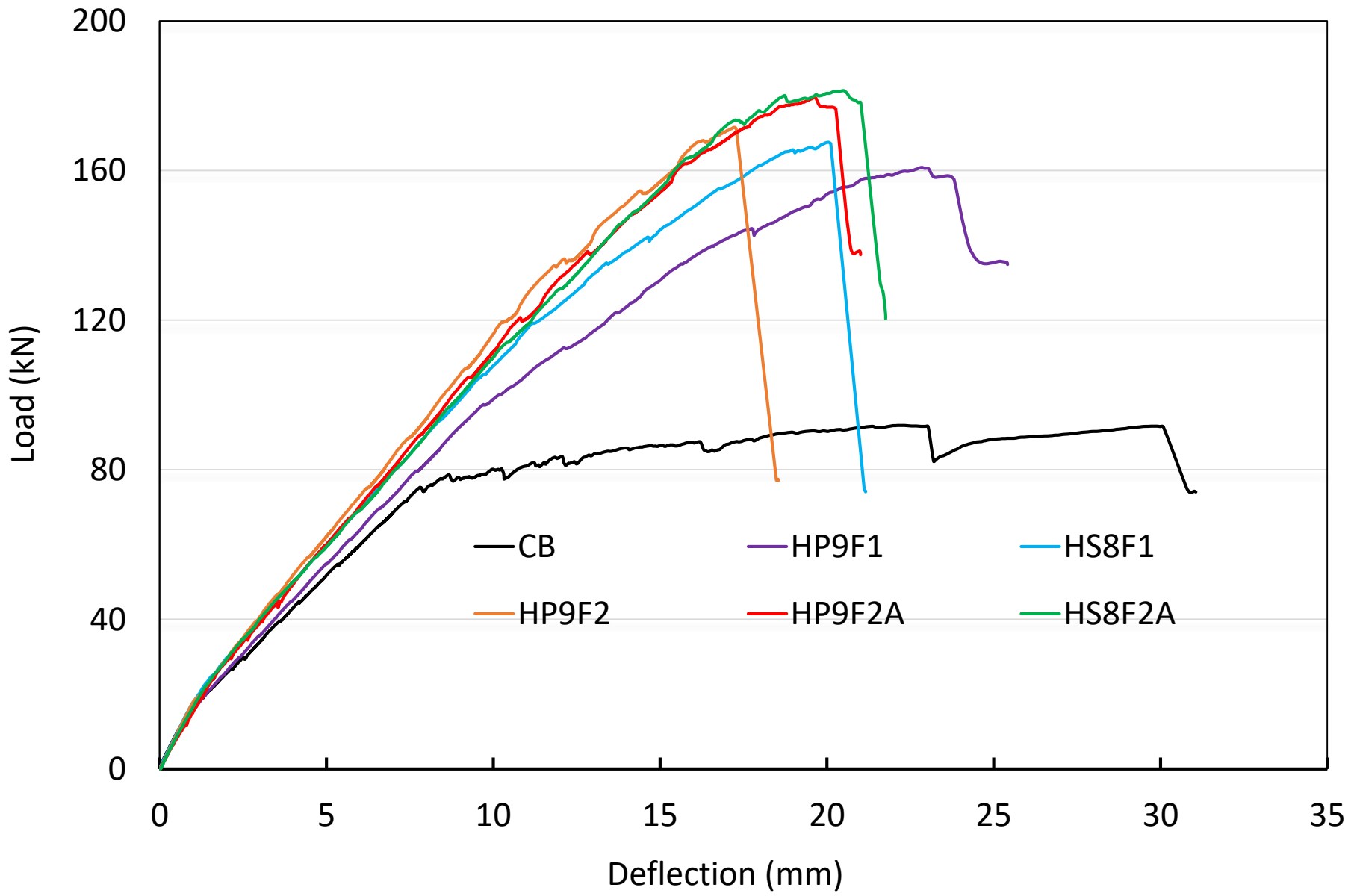
| Beam ID | $P_{cr}$ (kN) | $\Delta_{cr}$ (mm) | $P_y$ (kN) | $\Delta_y$ (mm) | $P_u$ (kN) | $\Delta_u$ (mm) | Failure modes |
|---|---|---|---|---|---|---|---|
| CB | 21 | 1.15 | 74 | 7.67 | 92 | 22.33 | FFC |
| HP9F1 | 30 | 2.42 | 97 | 9.71 | 161 | 22.86 | FFC |
| HS8F1 | 35 | 2.52 | 104 | 9.58 | 168 | 20.06 | CS |
| HP9F2 | 47 | 3.60 | 120 | 10.49 | 172 | 17.26 | CS |
| HP9F2A | 60 | 5.00 | 121 | 11.00 | 180 | 19.63 | CS |
| HS8F2A | 37 | 2.75 | 112 | 10.19 | 181 | 20.52 | CS |

$P_{cr}$ = first crack load; $\Delta_{cr}$ = deflection at first crack; $P_y$ = yield load; $\Delta_y$ = deflection at yield of steel; $P_u$ = ultimate load; $\Delta_u$ = mid-span deflection at failure load; FFC = flexural failure (concrete crushing after steel yielding); CS = concrete cover separation

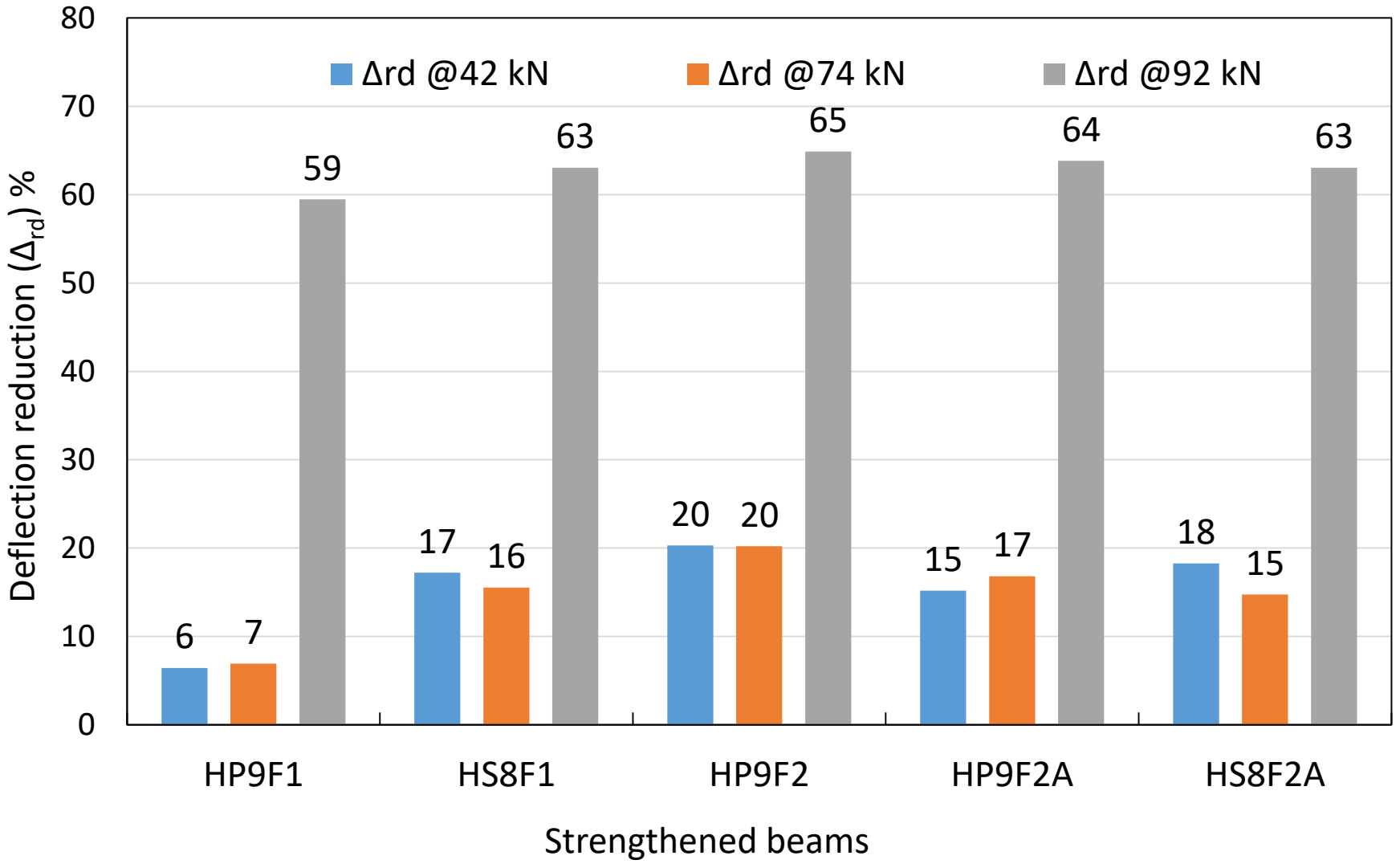
# Percentage Load Increment compared with Control Beam



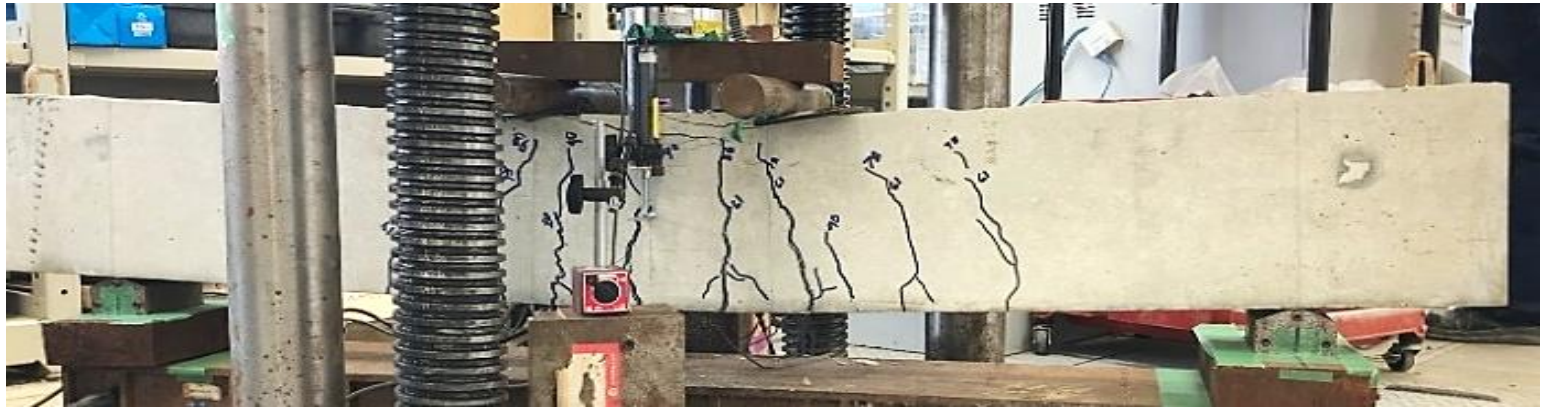
# Load-deflection behavior



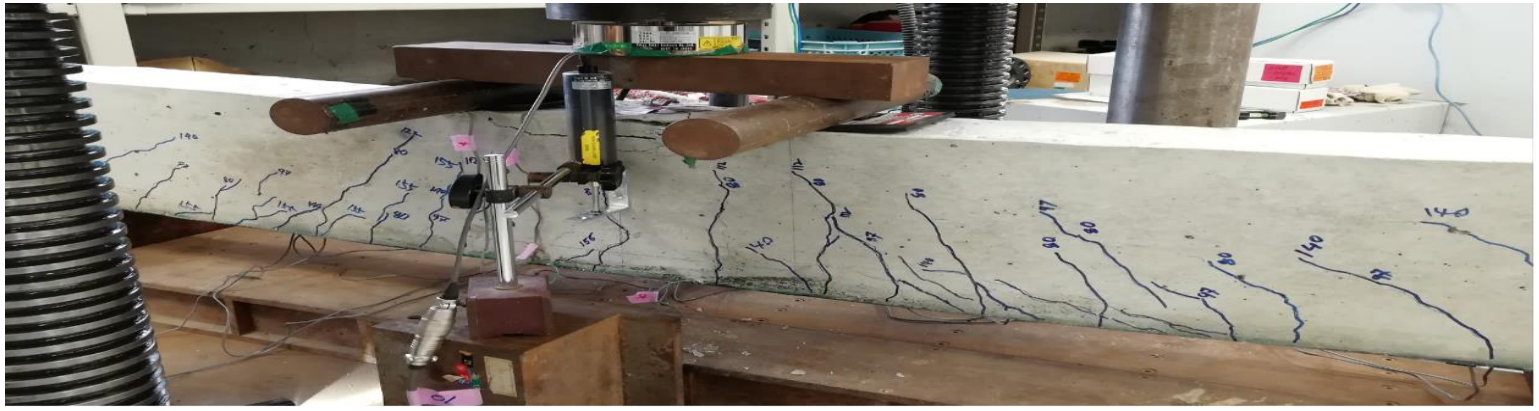
# Deflection reduction compared with Control Beam



# Failure modes



**CB**
**Failure modes=FFC**
**Crack nos. = 10**



**HP9F1**
**Failure modes=FFC**
**Crack nos. = 27**

**HS8F1**
**Failure modes=CS**
**Crack nos.= 22**

# Failure modes

**HP9F2**
**Failure modes=CS**
**Crack nos. =24**

**HP9F2A**
**Failure modes=CS**
**Crack nos. =22**

**HS8F2A**
**Failure modes=CS**
**Crack nos. =25**

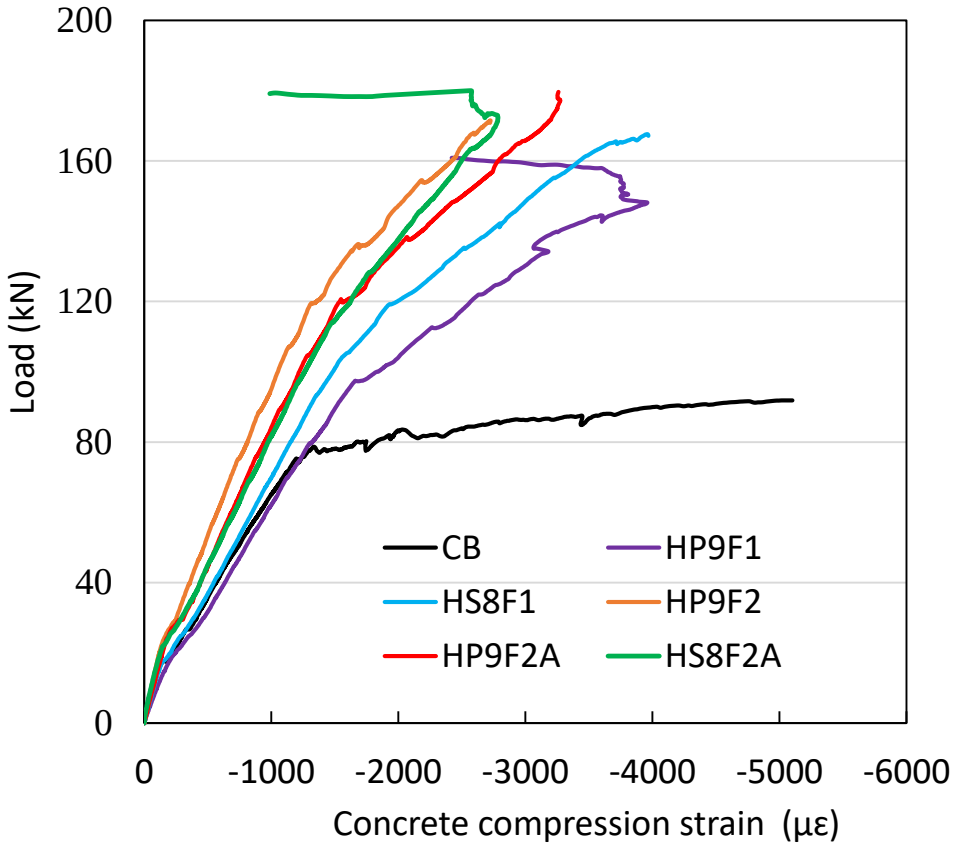
# Cracking characteristics

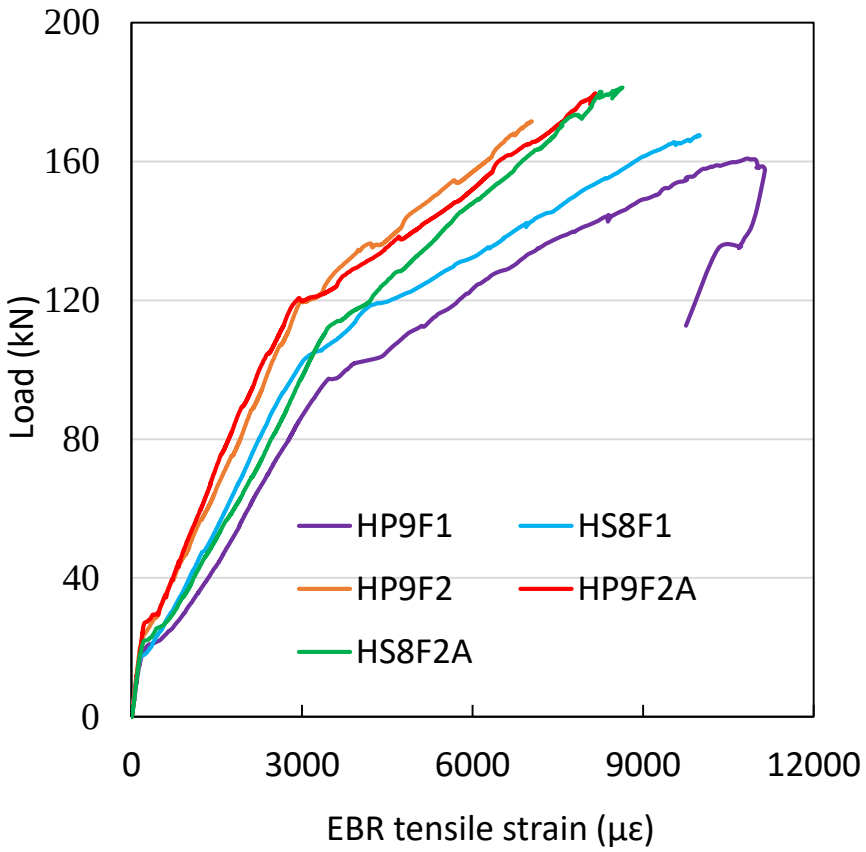
| Beam ID | $S_{r.max}$ (mm) | $S_{r.min}$ (mm) | $S_{r.mean}$ (mm) | No. cracks |
|---|---|---|---|---|
| CB | 172 | 48 | 93 | 10 |
| HP9F1 | 117 | 13 | 48 | 27 |
| HS8F1 | 125 | 10 | 53 | 22 |
| HP9F2 | 171 | 15 | 54 | 24 |
| HP9F2A | 82 | 12 | 48 | 22 |
| HS8F2A | 78 | 16 | 39 | 25 |

Better Energy Dissipation

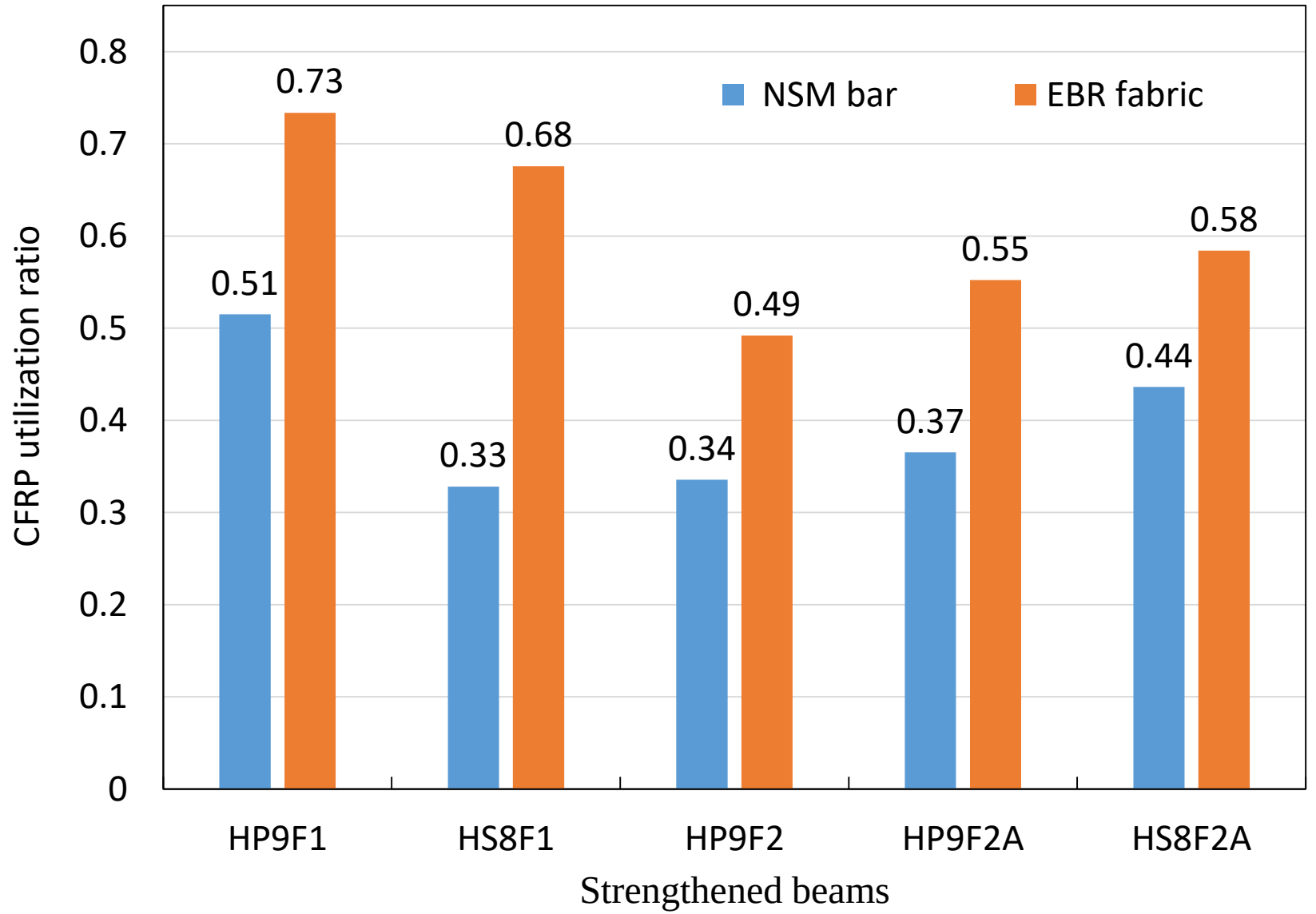
$S_{r.max}$ = Maximum crack spacing; $S_{r.min}$ = Minimum crack spacing;
$S_{r.mean}$ = Average crack spacing

# CFRP tensile strain

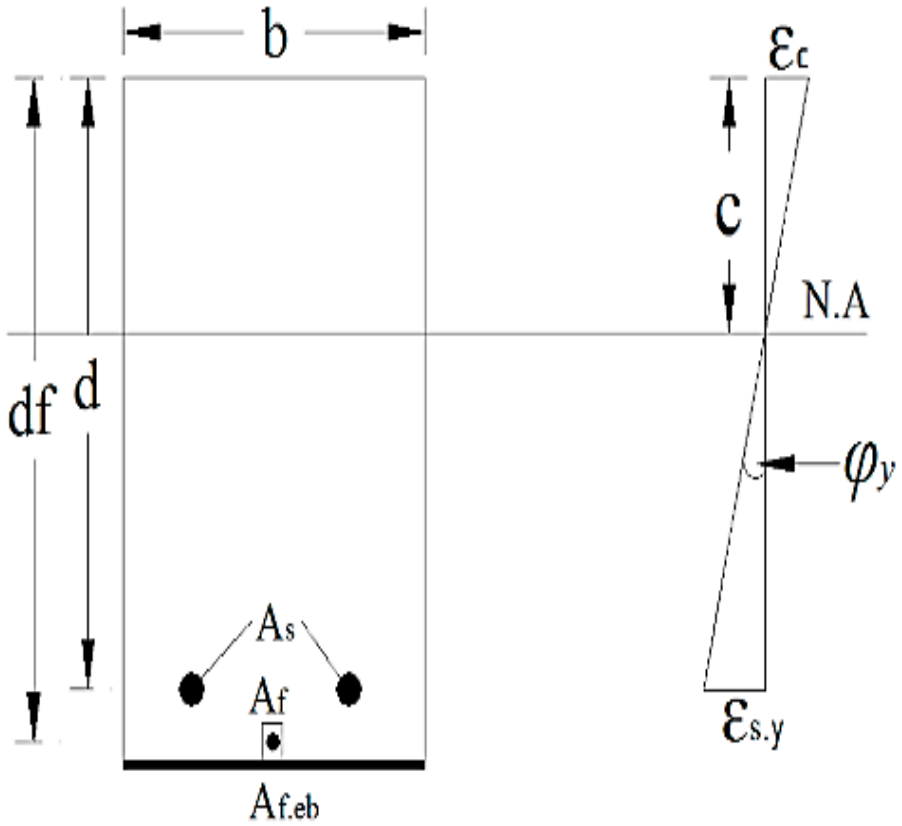


# CFRP utilization ratio



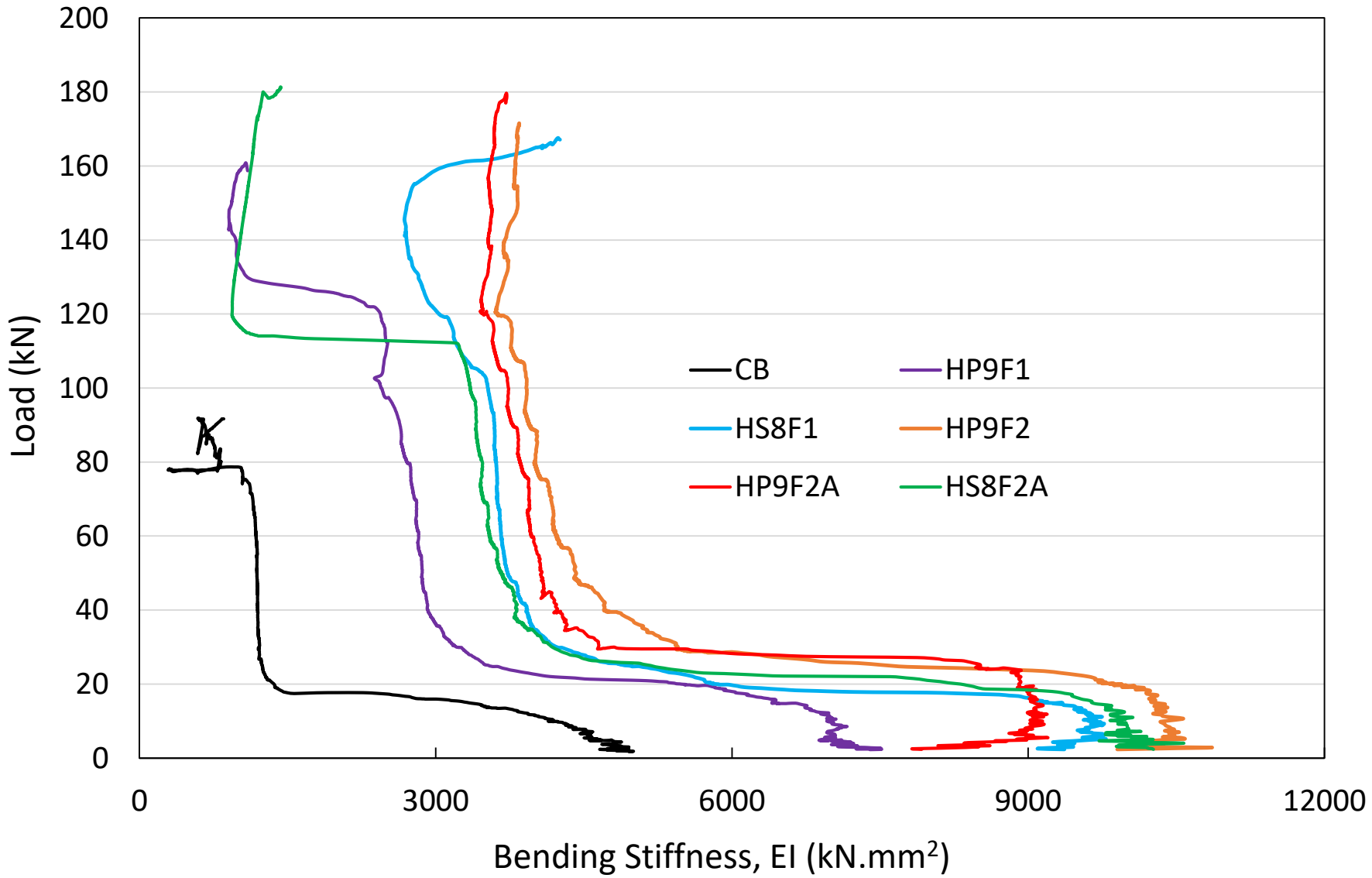
# Bending Stiffness




$$(EI)_{\exp} = \frac{M}{\varphi}$$

$$\varphi = \frac{\varepsilon_c + \varepsilon_s}{d}$$

# Load *Vs.* Bending Stiffness



# Conclusion

- A considerable deflection decrease of the strengthened beams observed at ultimate load point of the control beam. End Anchorage has little contribution to increase of load of strengthened of hybrid beam( when a/d ratio is small)
- The first crack load, yield load, and ultimate load of the hybrid-strengthened beams significantly increased compared with the control beam.
- All strengthened beams showed concrete cover separation, except the HP9F1 strengthened beam. However, concrete cover separation (HP9F2A, HS8F2A) was not eliminated by using U-wrap anchorage.
- Increased total crack numbers and decreased crack spacing compared with the control beam ensured the enhanced energy dissipation of the hybrid strengthened beams using thermoplastic CFRP.

# Conclusion

- Strain value of concrete, NSM bar, and EBR fabric for the strengthened beams was less than the control beam. HP9F1 demonstrated the highest CFRP strain utilization ratio which indicated the optimum use of CFRP strengthening materials.
- The bending stiffness of the strengthened beam specimen significantly increased at all load levels compared with that of the control beam.
- Hybrid bonding method could be applied in beam specimens where the shear span to depth ratio is comparatively shorter.
- The thermoplastic CFRP strand rod could be applied to the RC beam using a hybrid bonding method.

# Thank You
# for listening ...


Gifu University
Faculty of Engineering

# *Corrosion Classification of Weathering Steel by Deep Learning method*

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*Supervisor* *Koji KINOSHITA*

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Mongolia

Affiliation：Ministry of Road and Transport of Mongolia
University：Gifu University(M.D)
Duration： 2019.3 -2021.3

Akashi Kaikyō Bridge
Total length -3911 m

Oda Nobunaga- the first "Great Unifier" of Japan

**Reason for Applying (Background)**

- Graduated from the University of Science and Technology of Mongolia.
- After graduation, worked as a material engineer in road/bridge construction projects.
- Since 2012: An officer of the Ministry of Road and Transport Development of Mongolia.

The Government Action Plan /2012/ aiming to connect all provinces with the capital city by paved road is approaching completion. The next challenge is how to keep the network in good condition.

Road sector management in Mongolia is in the process of switching its focus from new construction to maintenance of the existing structure. ⇒ Road Asset Management

**Research**

“Corrosion Classification of Weathering Steel by Deep Learning method”

Road Asset Management is a systematic and permanent process. Regular bridge inspection helps to make better decisions based on informed understanding of the current actual condition of the bridge. Briefly, regular inspection is the first step to the Strategic Asset management system and helps the road administrator to discharge their responsibilities effectively by data-driven systematic maintenance management.

-Using advanced technologies, such as UAV and robotic cameras, the images of bridge components can be obtained. Based on the images, we can evaluate the defects and understand the condition of the bridges.

-Various images of rust on specimens’ surfaces (exterior appearance) are obtained to create training datasets to making classification models of corroded weathering steel. Based on those datasets using image processing technologies the deterioration can be classified and assessment of soundness class of the bridge can be evaluated.

**Prospect**

I will use my new knowledge to extend operational life and reduce the life cycle cost of roads and bridges in Mongolia. I will advocate and convince the Road Asset Management concepts to the decision-making procedure. Undertaking the Master’s program I will gain knowledge to become able to give a professional consultancy in the elaboration of policy in the Ministry.

**Daily life**

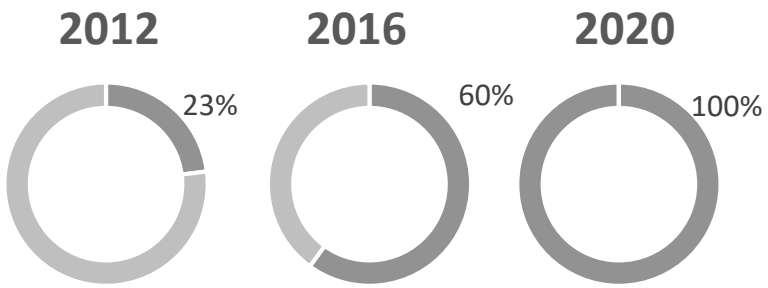
I like to go short trips in Japan to sightseeing and participating in short-term trainings. Last year, I traveled to Kyoto, Kobe, Nagoya, Yokohama, and Tokyo. This year, due to the pandemic disease I am minimizing the extracurricular activities. Luckily, my supervisor allowed me to travel to Ryukyu University in Okinawa last week. It was an amazing experience.

# Contents

# 1. Road network development in Mongolia

## Road network in 2012


## Road Network Development




Road sector management in Mongolia is in the process of switching its focus from new construction to maintenance of existing structure.

# What is the next challenge ?

**Road network development:**

**New construction**

**Asset Management:**

**To keep the network in good condition**

- To ensure the safety of the network
  - Strategic Asset Management-Systematic repair work
  - Regular Inspection - Data-driven management
- To keep serviceability, and operating, maintaining, upgrading the network requires
  - Financial resources
  - Human resources
  - Technical resources

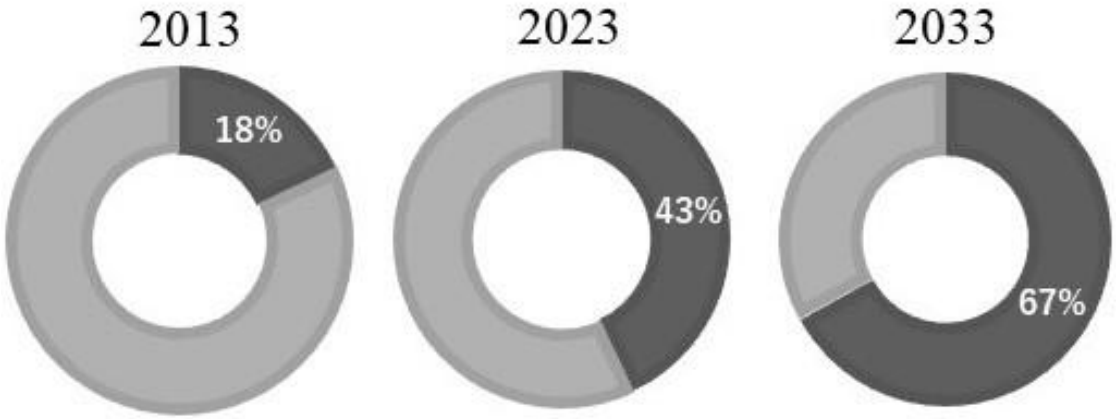
- Most roads are economically non-profitable due to sparse population but must keep serviceability and ensure traffic safety throughout the year as they are essential to service populations.
- The road network construction and maintenance works are financing by state budget ►►► Huge fiscal burden on the general Public Budget.
- Inefficient management:
    - ►►► Worst-first approach-High LCC
    - ►►► Political interfere to project prioritization
- To adapt data-driven management systematic Asset management and to reduce LCC regular inspection is important. It requires
    - **Decrease inspection cost:**
        - **Shorten inspection time and save labor-time of inspectors'**

# 2. Strategic systematic maintenance -Road Asset Management in Japan

The Ministerial Ordinance: the Infrastructure Maintenance Era which includes the periodic inspection plan started in 2014.

- **Once-in-five-years close visual inspection** of tunnels, bridges, and other structures, and defines four categories of soundness of structures.

Percentage of bridges older than 50 years




- Regular inspection is most important to understand bridge conditions.
- Data-driven systematic preventive maintenance
- As modern bridge designs become more complex and complicated, it is more difficult to conduct inspections.
- More technologically efficient way to do it to make it safer, easier and faster ▸▸▸ Advanced technologies

# 3. Advanced technologies in Bridge inspection

The capabilities of unmanned aerial systems (UAS) in bridge inspection have improved exponentially over the past few years due to its excellent capacity. Compared with traditional inspection methods, UAS has the potential to

- shortening of inspection time;
- relatively cheaper- by saving inspection time ▸ lower overall inspection costs
- facilitate the inspection work by reducing risk of inspectors to hard-to-reach or challenging areas
- improve inspection quality- detailed, reliable, more flexible data acquisition
- less disruptive to traffic flow

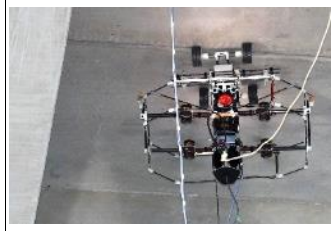
# Bridge inspection

## a) Conventional method

Rope access

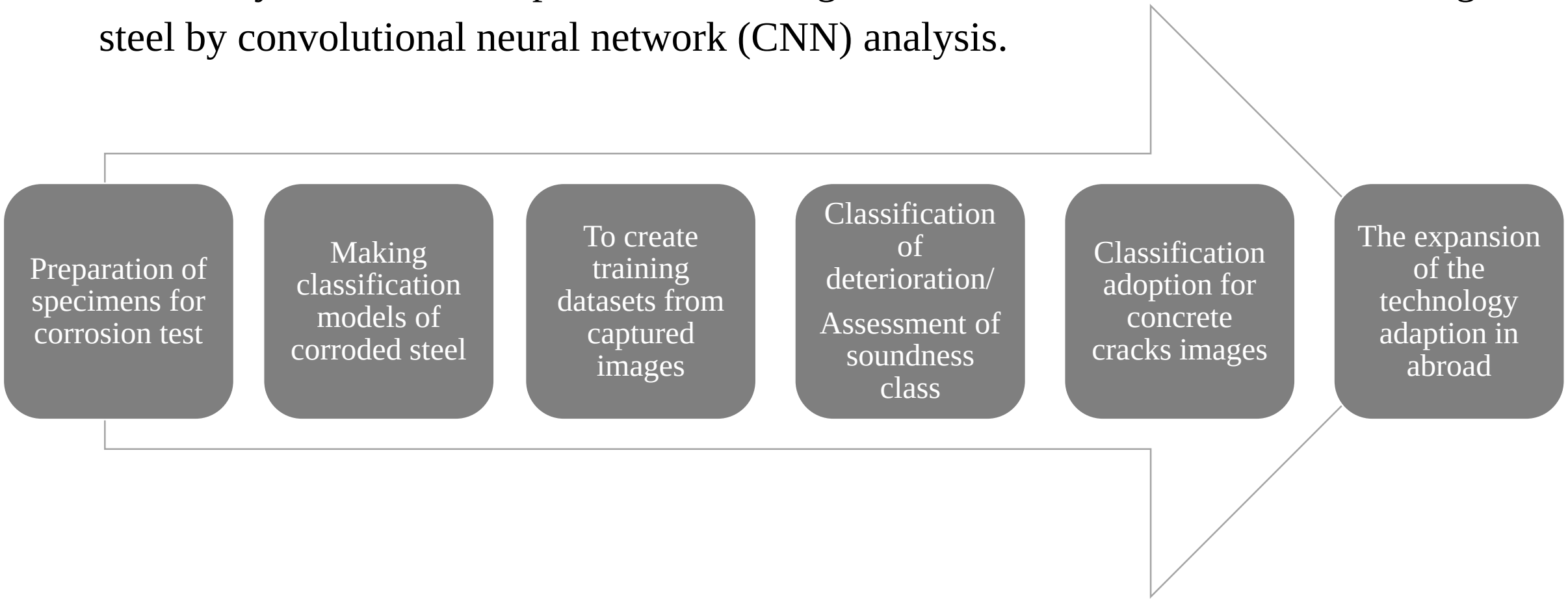
Large-scale inspection vehicle

## b) Advanced technology

| Type | Name of technology | Working | Name of technology | Working |
|---|---|---|---|---|
| UAV/UAS, Drone | (1) Two-wheeled UAV with camera |  | (2) Small-sized Two-wheeled UAV with camera |  |
| | (3) UAV with a passive rotating spherical shell |  | (4) Drone with controllable pitch propellers |  |
| Robotic Camera | (5) Robotic camera indicating crack scale |   | (6) Camera system |  |
| Hammering Robot | (7) Drone with wheels for visual observation and hammering tests |  | (8) Drone with hammering test equipment |  |

# 4. Research objectives and workflow

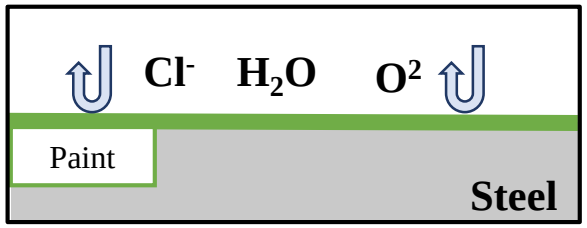
This study aims to develop an efficient diagnosis method for corroded weathering steel by convolutional neural network (CNN) analysis.



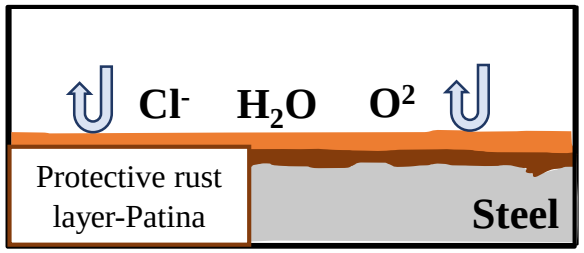
# Weathering steel characteristics

In Japan, the use ratio of weathering steels in steel bridges has increased rapidly, approximately tripling in the last 10 years, and now exceeds 15%.

Ordinally steel




Weathering steel




Attractiveness:

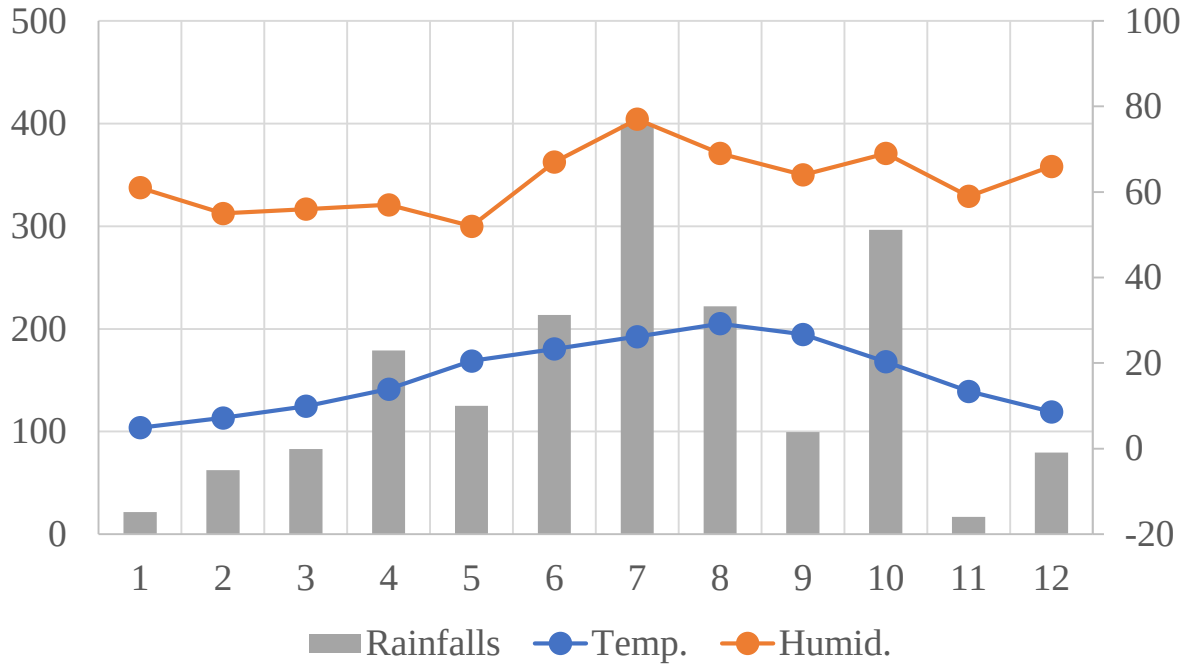
- Paint is not required. Enhanced resistance to rusting compared with ordinary carbon manganese steels.
- Initial and maintenance cost is lower: elimination of the additional painting material cost and labor time .
- The environmental problems such as Volatile Organic Compound (VOC) emissions from paint coatings can be avoided.
- Suitable in most locations ($Cl < 300mg/m^2/day$).
- Attractive appearance

Issues:

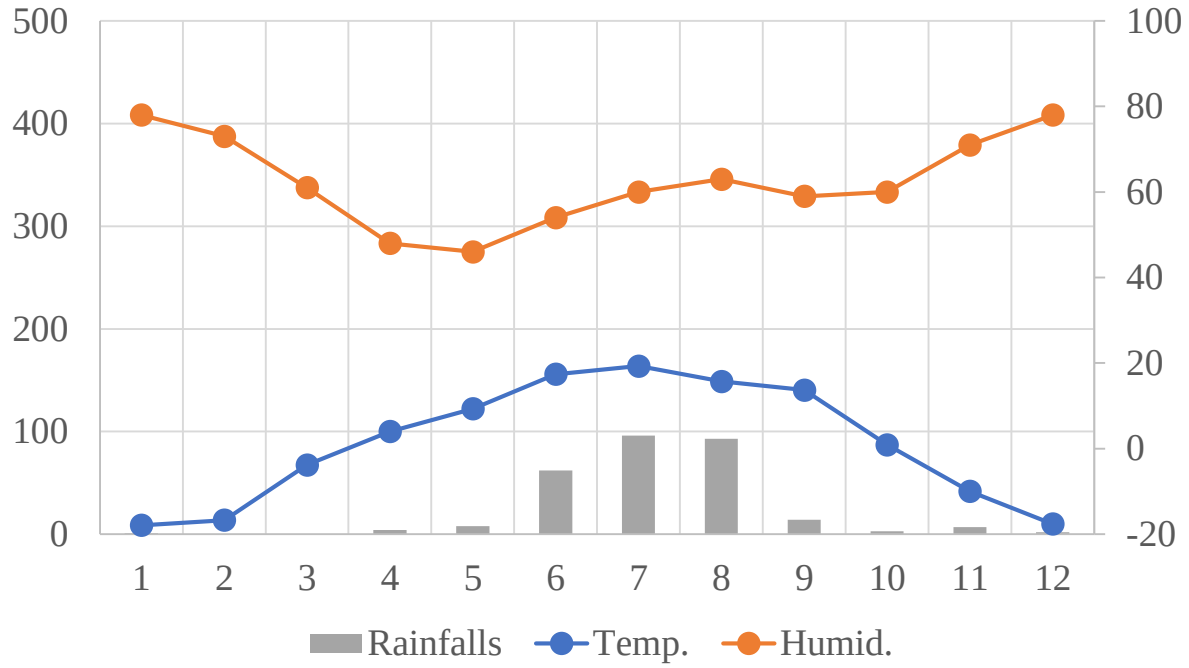
- Consideration to environment high concentration airborne salt, high humidity etc., the protective rust cannot be produced.
- When abnormal corrosion occurred, to remove and repair it are difficult.
- The weak point of weathering steel bridge is the end of girder: due to high humidity, accumulating salt etc. Carefully inspecting for the end of girder is important.

# Applicability of weathering steel

Gifu in 2019




Ulan Bator in 2019



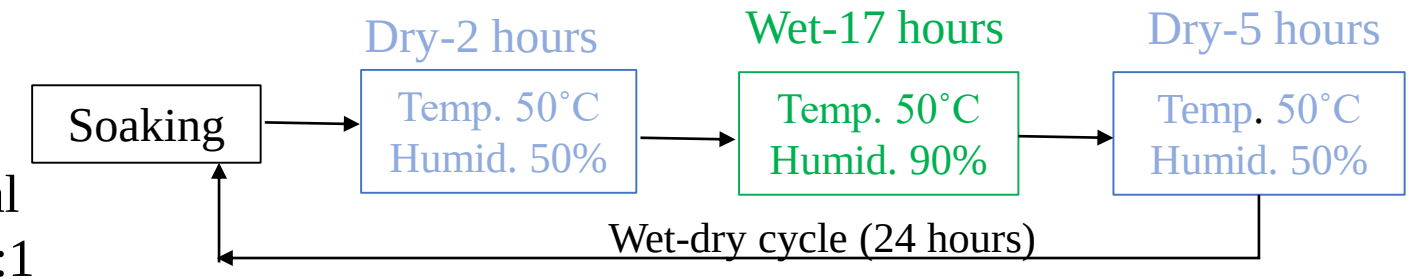

- Mongolia has good environment to weathering steel.
- Maintenance cost is lower: Reduce the LCC by eliminating of the additional painting material cost and labor time
- Enables rapid construction

# a. Preparation of specimens for corrosion test

The weathering steel (SMA) with dimensions of 50 mm × 50 mm × 8 mm was used.

- To making classification models of corroded steel, eight corroding specimens were produced by eight different types of anti-freezing materials:

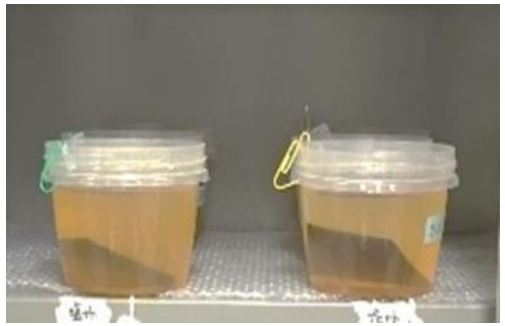
1.chloride based anti-freezing material
2.with 0.25% inhibitor
3.with 0.5% inhibitor
4.with 2.5% inhibitor
5.non-chloride anti-freezing material
6.chloride/ non-chloride mixed as 9:1
7.mixed as 5:5
8.mixed as 1:9




The wet-dry cycle test was conducted for boost the corrosion process and the specimens were soaked into each solution and exposed the environment. One cycle takes 24 hours.

# b. Making classification models of corroded steel

- Various images of rust on specimens' surfaces (exterior appearance) are obtained to create training datasets to making classification models of corroded steel.
- Those images are taken twice per week, and the gained weight due to corrosion is measured.



Corrosion test cycle-Soaking

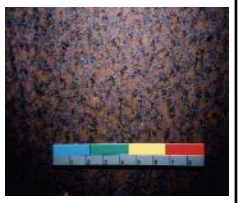
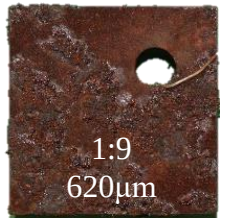
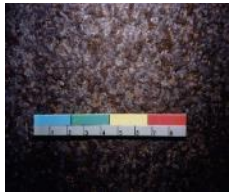
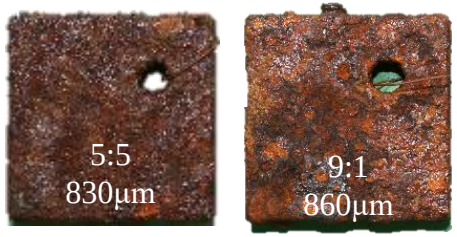
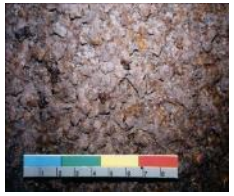
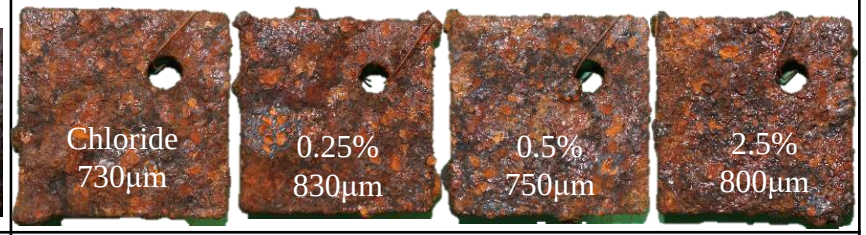
Corrosion test cycle-Exposing

The weathering steel specimens' surfaces after 250 cycles

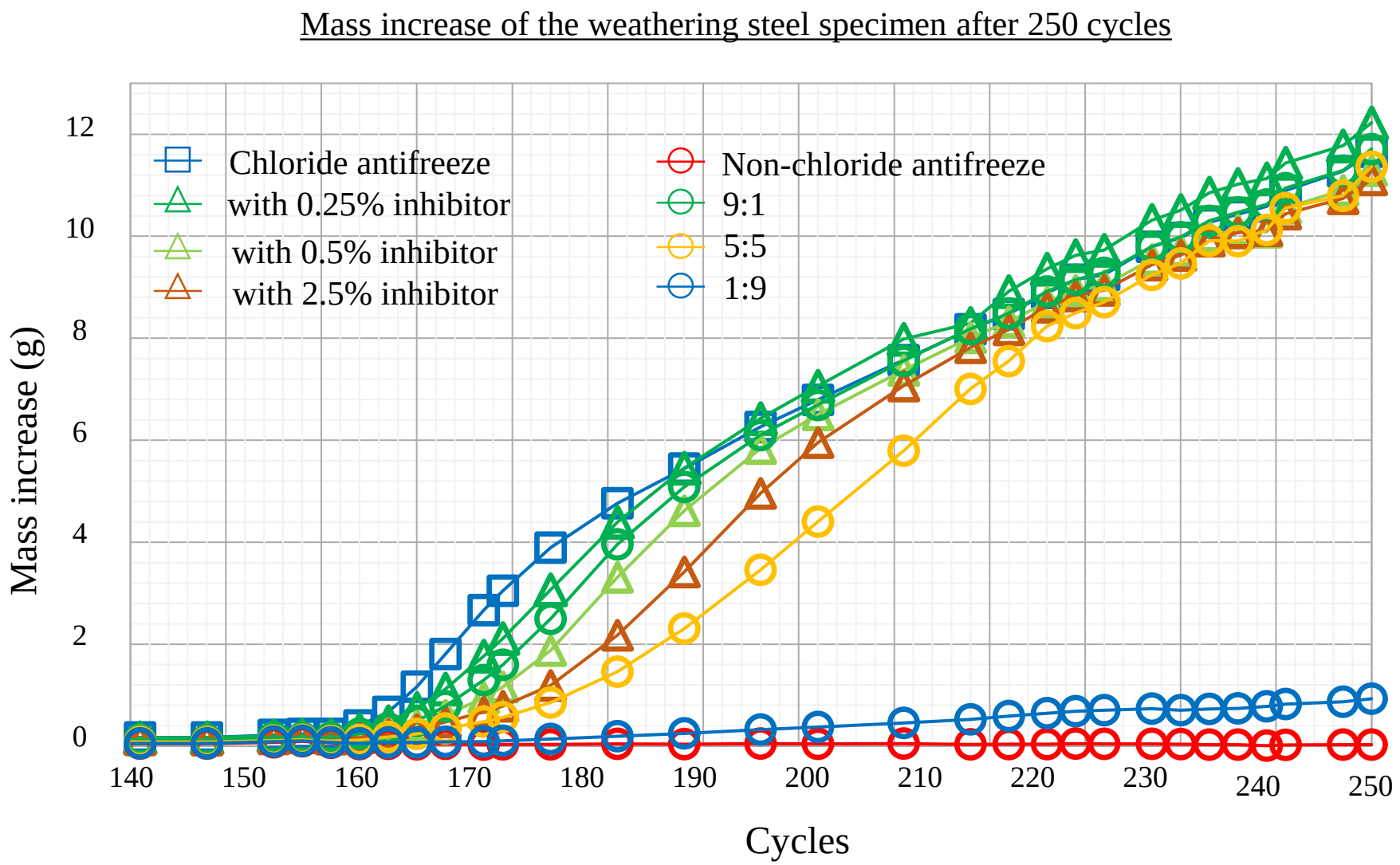
(a) Chloride (b) 0.25% inhibitor (c) 0.5% inhibitor (d) 2.5% inhibitor

(e) Non-chloride (f)mixed as 9:1 (g) mixed as 5:5 (h) mixed as 1:9

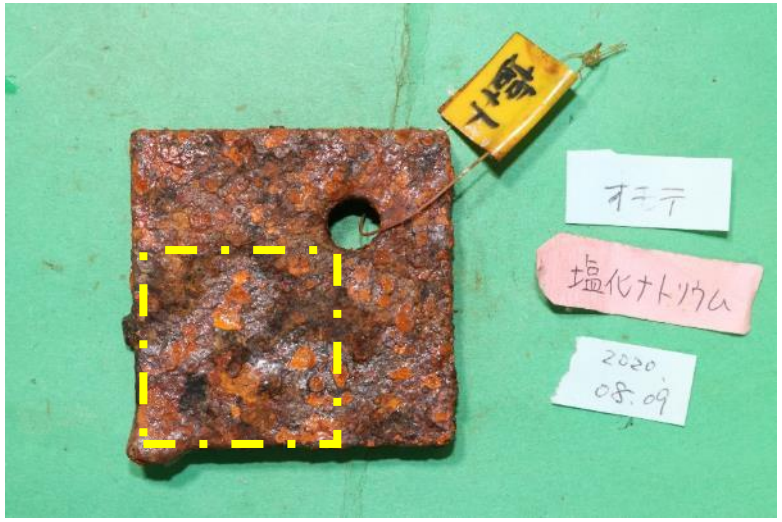
# Comparison of rust appearance rating criteria for weathering steel

| State | Level | Rust condition | Rust thickness | Exterior appearance | Test results（250 cycles later) |
|---|---|---|---|---|---|
| Normal | 5 | 1) The color is generally bright tan and mottled.<br>2) Almost no unevenness, fine rust particles<br>3) The amount of rust is small, and the maximum particle size is about 1 mm or less. | Less than 200μm |  |  |
| | 4 | 1) The color is dark brown and there is no uneven color.<br>2) There is almost no unevenness, and the rust particles are fine and uniform.<br>3) The amount of rust is rather large, and the maximum particle size is about 1 mm or less. | Less than 400μm |  |  |
| | 3 | 1) Color tone is dark brown to brown with no uneven color<br>2) Slightly uneven, rust particles are coarse and non-uniform<br>3) The amount of rust is large, and the maximum particle size is about 1 to 5 mm. | |  |  |
| Observation required | 2 | 1) The color tone is dark brown to brown with some unevenness.<br>2) Large irregularities, rust particles are coarse and scaly<br>3) The amount of rust is large, and the maximum particle size is about 5 to 25 mm. | Less than 800μm |  |  |
| Abnormal | 1 | 1) There are various color tones (severe color unevenness) locally.<br>2) There are large irregularities and layered peeling (traces) | More than 800μm |  | |

The gained weight of the specimens due to corrosion is measured.



# c. To create training datasets from captured images




Before trimming
1560 × 1560 pixel

After trimming
128 × 128 pixel





Data augmentation techniques to enhance the dataset size.

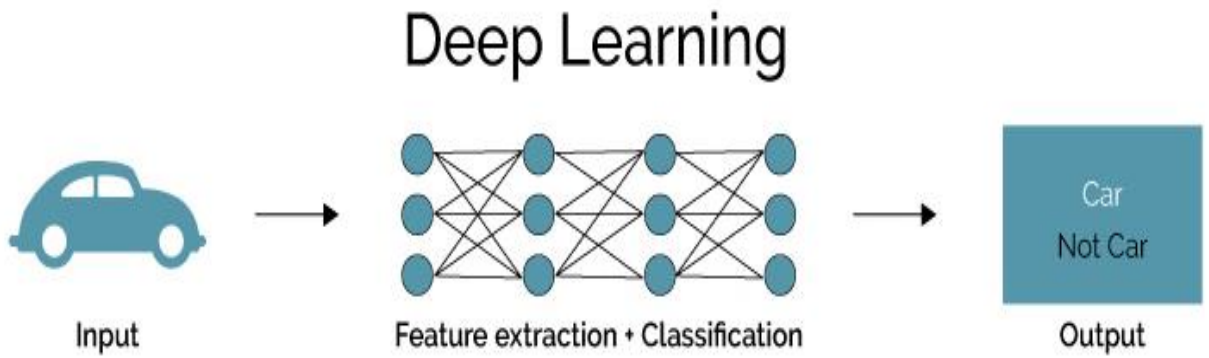
# 5. Image processing by Deep Learning method

The deep learning algorithm-the convolutional neural network (CNN) is the most popular neural network model being used for image classification problem.

• Making classification models of corroded steel: By using CNN, an innovative deep learning classifier that identify corrosion level will be executed and the input image will be classified based on its level of corrosion.

- Based on those classifiers the deterioration can be classified and assessment of soundness class can be determined.

Deep Learning method for image classification



# 6. Future works

**a.** Based on the training datasets, innovative classifiers will be created and will be classified based on its level of corrosion.

**b.** By utilizing the dataset of classification of corrosion in weathering steel, adoption for classification of concrete cracks images with the appropriate datasets can be proposed.

**c.** The expansion of the technology adaption in abroad (Zambia, Mongolia) will be considered and is continuing to verify.

# Analysis of problems for improving the actual condition and capacity of bridge maintenance in developing countries

Graduate School of Engineering, Nagasaki University
Social Environmental Design Engineering Course
Civil Engineering Laboratory

Long-term Trainees: Mr. SOUMPHONPHAKDY Bounthipphasert

2020 September 29

Mr. Bounthipphasert Soumphonphakdy

Laos

Affiliation：Ministry of Public Works and Transport
University：Nagasaki University (Ph.D)
Duration：2017.10 - 2021.3

I am a member of Freestyle badminton club, and I very enjoy playing it in my free time.

I really enjoyed visiting the site of road rehabilitation because I was able to improve my knowledge and it was very helpful in my work and research.

## Reason for Applying

My desire to apply this program is to contribute to roads and bridges maintenance and management systems in Laos.

## Research

My research objective is to analyze the risks of managing roads in Laos to look for the best ways to improve them in tight budgets for maximum benefit and maximum efficiency.

## Prospect

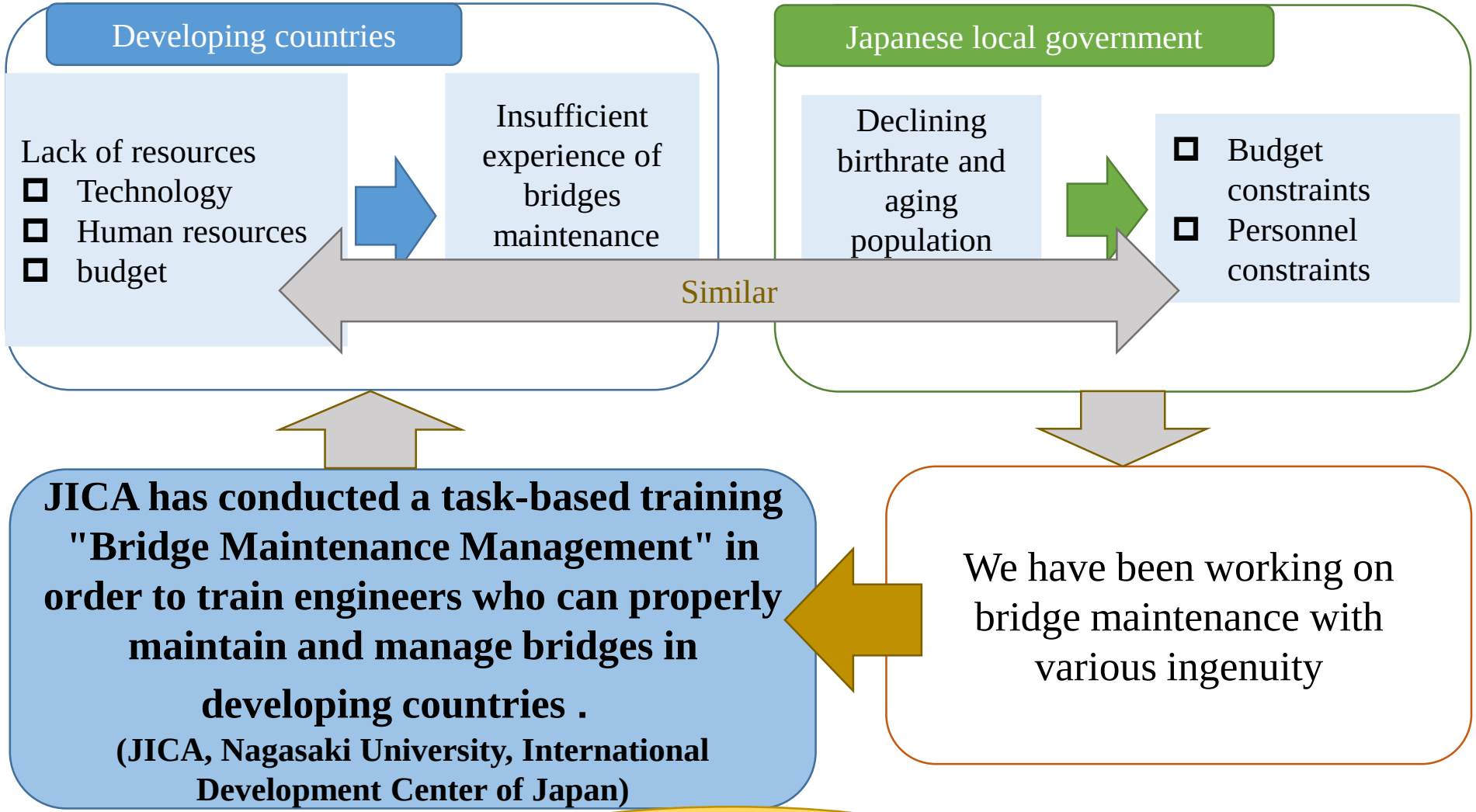
After I graduate from Nagasaki University, I will use the knowledge I have studied in Japan to improve the roads management systems in Laos.

## Daily life

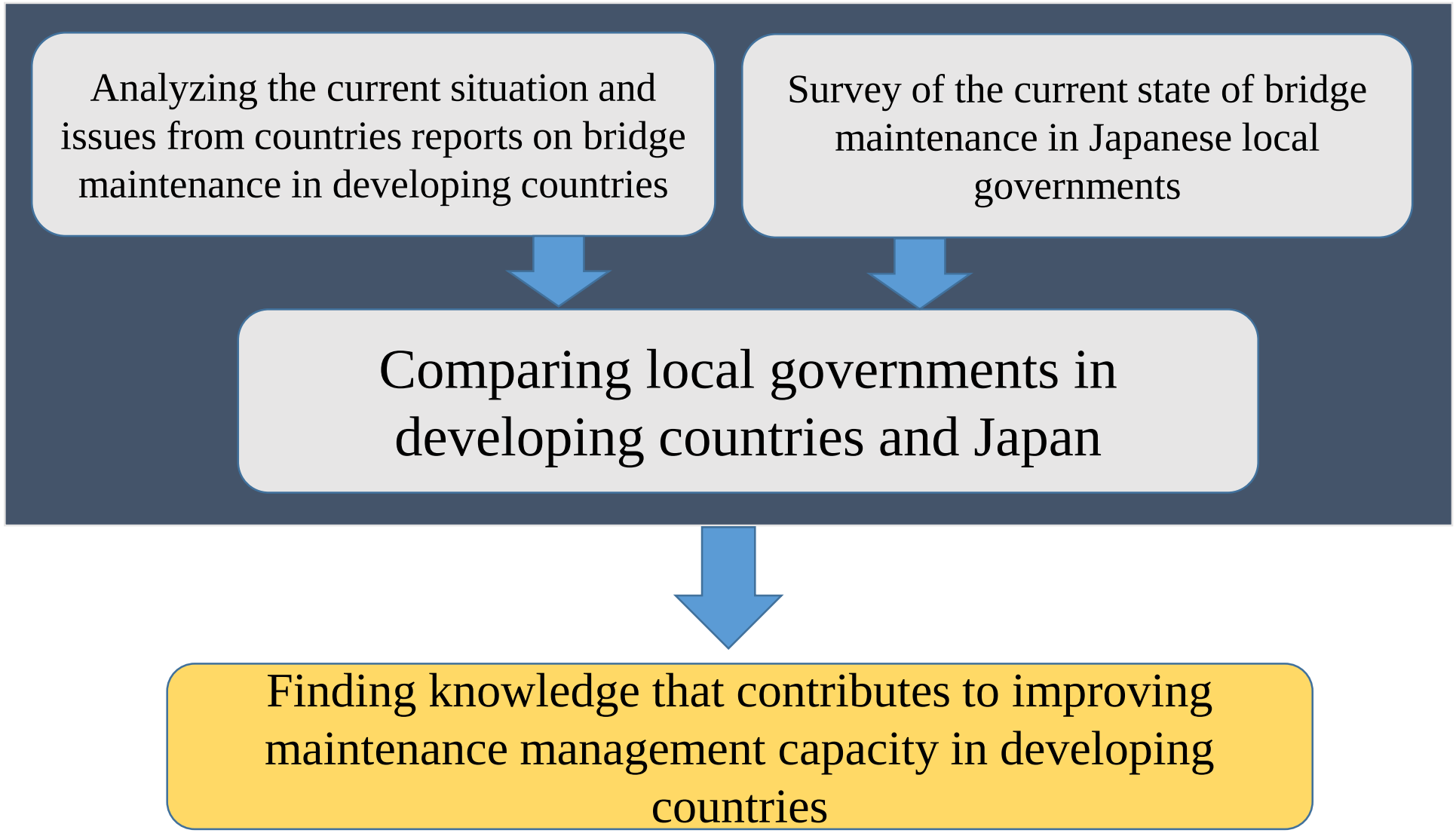
I have been to many famous places with my friends and enjoy staying in Nagasaki.

During march to may in this year, I cannot go to my university because of COVID-19, so during that time it was quite difficult to research.

# Research background



# Training method and purpose



# Method of analyzing the current state of bridge maintenance in developing countries

## What is a countries report?

- A report summarizing the issues of the training participants in their own country
- Format to fill in the answers to the specified questions (infrastructure budget, inspection / evaluation, human resources, etc. )

## Country report analysis method

- Training data for the past 3 years (2016-2018)
- Answers are roughly classified into the following 6

| | |
|---|---|
| budget | Human resources |
| Inspection / evaluation | Maintenance plan |
| BMS | Other |

- Summarize the contents of similar answers from 3 or more countries

| Area | Number of participating countries |
|---|---|
| Southeast Asia | 5 countries |
| South Asia | 5 countries |
| Oceania | 5 countries |
| East Africa | 4 countries |
| South Africa | 4 countries |
| North Africa | 3 countries |
| West Africa | 3 countries |
| Latin America | 3 countries |
| Central Africa | **33 countries in total** |

# Main status of bridge maintenance management in developing countries (1/2)

| | Main Current Status |
|---|---|
| Budget | ・Insufficient maintenance budget.<br>・Bridges cannot be prioritized and the budget cannot be used efficiently. |
| Human resources | ・The number of people in the workplace is small (insufficient manpower)<br>・Insufficient experienced and excellent technicians.<br>・There is no minimum training program. |
| Inspection / evaluation | ・Cannot procure equipment required for inspection (The accuracy of the equipment required for inspection is low).<br>・Don't know how to evaluate<br>(Repair begins only after serious damage to the bridge appears). |

# Main status of bridge maintenance management in developing countries (2/2)

| | Main Current Status |
|---|---|
| Maintenance plan | ・There is no inventory of bridges and it is not possible to make a plan.<br>・Don't know how to do it because no experience in maintenance planning. |
| BMS (Bridge maintenance system) | ・Data is not unified by region.<br>・Cannot utilize BMS sustainably<br>(BMS itself has not been developed). |
| Other | ・The security of the country is bad.<br>・Standards for maintenance are not unified nationwide. |

# Local government bridge maintenance method

## Nagasaki Prefecture Bridge Maintenance Method

Conducting bridge inspections is the most important for planning and execution

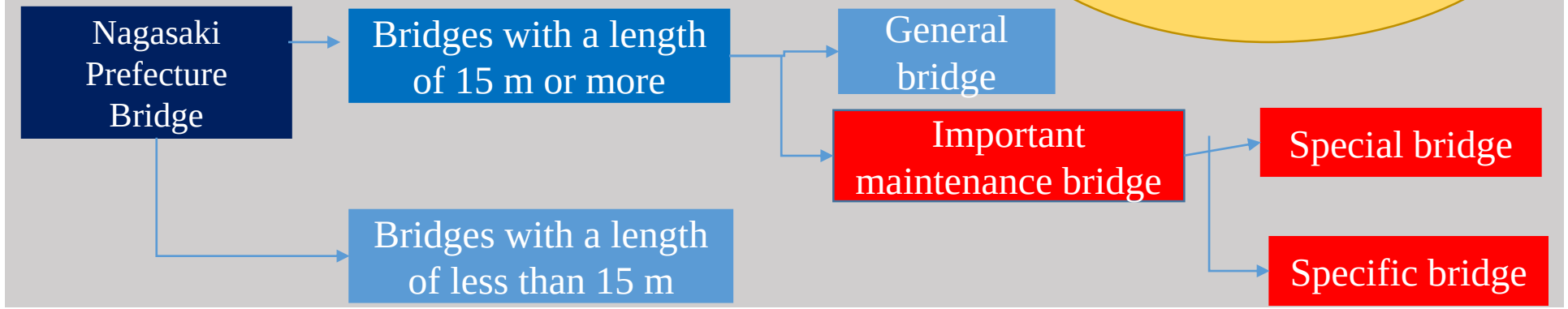
Insufficient prefectural staff to inspect bridges

Cooperation of prefectural alumni and certified road guards

- know the construction method at the time of bridge construction.
- Transfer knowledge of old construction methods
- Inspection advice, etc.

Focus on maintenance to distinguish it from general bridges

## Distinguishing bridges



# Local government bridge maintenance method

## Gifu Prefecture Bridge Maintenance Method

The purpose is to produce human resources who can contribute to regional revitalization by learning the planning, design, and construction techniques for maintenance of infrastructure facilities.

→ Training of social infrastructure maintenance experts (ME)

## Niigata Prefecture Bridge Maintenance Method

Maintenance bridges are classified according to road network characteristics (road priority, daily traffic volume) and bridge characteristics (special bridges, salt-damaged area bridges)

→ Set different maintenance levels for each bridge

↓

We carry out well-balanced maintenance under budget constraints.

## Comparison of local governments in developing countries and Japan

| Item | Developing countries | Japanese local government |
|---|---|---|
| Budget | ・Budget is not allocated properly | ・Prioritizing social security, no planned budgetary measures have been taken. |
| Human resources | ・There is no experienced technician | ・Insufficient number of people to carry out bridge inspection. |
| Technical capabilities | ・There is no data for existing bridges.<br>・There is no clear maintenance standard.<br>・It does not have the ability to construct bridges or repair individual bridges. | ・There are OBs who have the ability to construct bridges and repair individual bridges.<br>・Engineers also exist in consulting companies. |

# Experience of Japanese local governments that contribute to improving maintenance capacity in developing countries

| | |
|---|---|
| Budget | ➢ Set maintenance level for each bridge and allocate budget according to importance |
| Human resources | ➢ Build human resources training and qualification systems such as “Michimori" and "ME" |
| Technical capabilities | ➢ Create a manual by conducting questionnaires and workshops<br>➢ Training how to use while revising the manual |

# Summary

## Even in developing countries

Maintenance by classifying bridges according to road network characteristics and bridge characteristics, etc. Set different maintenance levels for each bridge according to weight and bridge type

- It is thought that the budget can be used more efficiently

Build human resources training and qualification systems such as " Michimori " and "ME"

- It is possible to increase the number of human resources with maintenance skills

It is thought that it is possible to unify the entire country and aim to improve bridge maintenance technology

Thanks for your kind attentions!
ご静聴ありがとうございました

# Development of Lifetime Extending Maintenance Model(LEM). “The case study of Bailey bridge in Laos”.

**By Thavone KHOUSIDA**

Structural Engineering Laboratory

Graduate School of Engineering

Nagasaki University

Adviser: Assoc. Prf. Dr. Takafumi NISHIKAWA

Co-adviser: Prf. Dr. Shozo NAKAMURA

Khounsida Thavone

Laos

Affiliation：Ministry of Public Work and Transport 2014-2017

University：Nagasaki University
Duration：2017.10-2021.3

I love to play football and enjoy playing at the weekend with International friends in my university. I also go fishing around Nagasaki city frequently with my family.

For my academic life, I love to spend time researching and participating in many joyful seminars, training, and get much experience of traveling all over Japan after each seminars.

**Reason for Applying**

I work on road and bridge training for many years, and I found that a lot of improvements are needed for road and bridge management in my country as well as developing countries around the world.

**Research**

My research objective is to develop a Lifetime Extending Maintenance Model for the steel bridge( The case study for the Bailey bridge in Laos).

**Prospect**

After I graduate from Nagasaki University, I will back to my country and contribute to developing for my beloved country.

**Daily life**

I spend more time researching, enjoy tasting Japanese food, culture, and enjoy visiting many places around Nagasaki city. During the COVID-19 pandemic, it is a little tricky situation and challenging for daily life. Fortunately, we can use the internet and media for sharing and learning instead.

# Contents

Background and Objectives

Field testing and data collection

Partial research finding

# 1 Background & Objectives

The Bailey bridges were initially invented for temporary military use since WWII.

Due to many advantages of the structure: lightweight structure, flexible form, easy and short time for recovery from failure, required for no heavy equipment in site fabricating, and low construction cost.

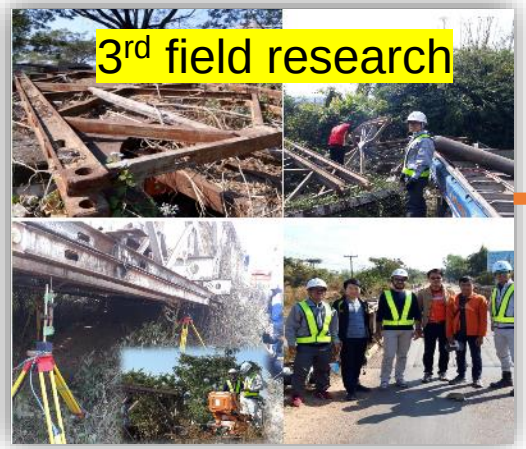
The bridges have been adapting for civil works in developing counties, especially rural area for a long-term service.




Some data and previous surveys revealed that such bridges are aging deteriorations without proper maintenance and management. Moreover, a few research and reference are available.

# Research road map and progress



| Data collection and Experiment | Structure Analysis and Model validation | Research Presentation and publication |
|---|---|---|
|  1st field research | Linear Analysis: Model validation Static and Dynamic behavior | ASEM19 The 2019 World Congress on Advances in Structural Engineering and Mechanics ICC Jeju, Jeju Island, Korea September 17 - 21, 2019 Techno-Press Journals<br>Published conference paper: Static and Dynamic behavior of Bailey birdge<br>Journal version of this title is under progress |
|  2nd field research | 1st Exp. and Analysis result discussion and planning for next experiment: | |
|  3rd field research | 1. Linear Analysis(1 st phase data quality improving and model validity) | 「Steel Construction Symposium2020」Academic Session 28th JSSC Proceedings of Constructional Steel<br>Accepted paper: Experimental and analytical study on the dynamic behavior of the deteriorated Bailey bridge |
| | 2.Nonlinear Analysis and Model validation Static and Dynamic behavior | Under progress: Mechanical properties investigation of Bailey bridge material and Nonlinear Analysis |

# Other Presentations

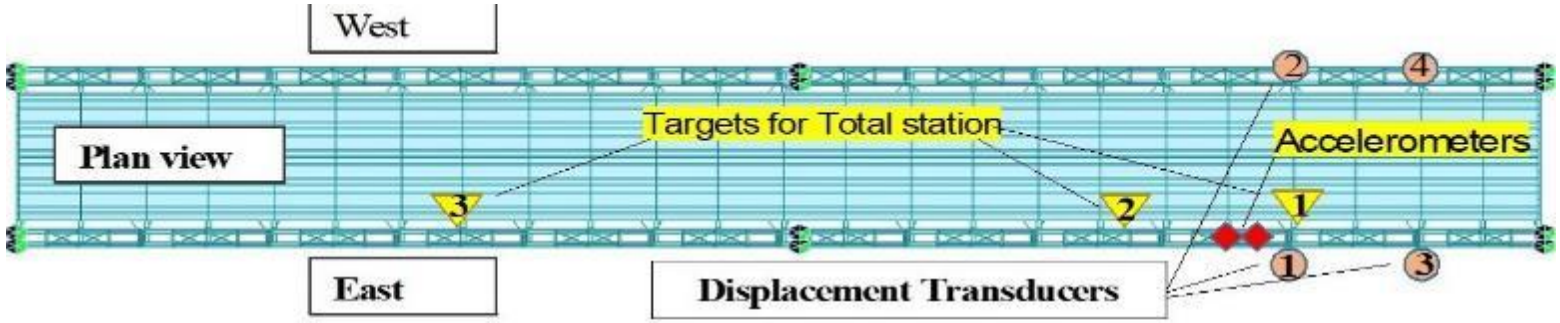
| Type of Conference | Topic/Description | Place |
|---|---|---|
| **Regional symposium** | **Paper on Current Situation and Key Issues on Bridge and Road Management in Laos at 6th Kyushu Association for Bridge and Structural Engineering (KABSE) Symposium,** | **Fukuoka, 14 Dec 2018.** |
| **International symposium** | **Paper on Experimental and Analytical study on Load-Carrying Behavior of Bailey bridge 21st JSCE International symposium** | **Kagawa, Sep 2019,** |
| **Others/Meeting** | **Share the research finding on JICA Project meeting for** The Project for Capacity Development on Bridge Maintenance and Management (For Lao P.D.R) JICA Headquarter,JICA Okinawa, JICA Laos, Ministry of Public Works and Transport(Laos) and National University of Laos | At JICA Headquarter 23 Mar 2020 |

# Graduation

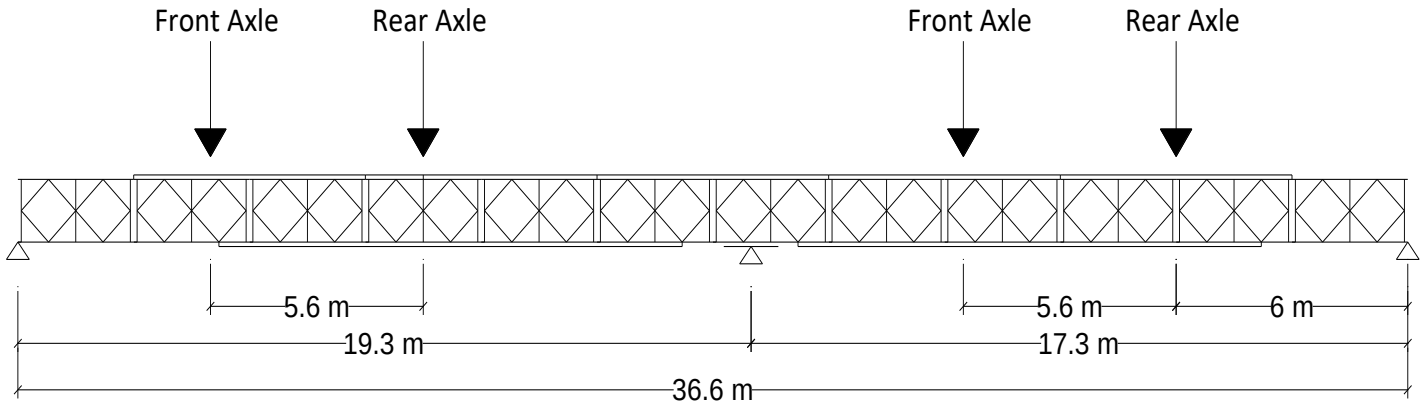
| Type of research paper | Topic/Description | Start | Expected to submit |
|---|---|---|---|
| Doctoral Thesis | Development of Life-time Extending maintenance of steel bridge structure | Oct 2020 | Preliminary end of Oct 2020<br>Final Dec 2020 |
| Graduation |  | Hopefully Expected: Marc 2021 | |

# 2 Field testing and Data collection

# Field Measurement







# Overview of testing activities

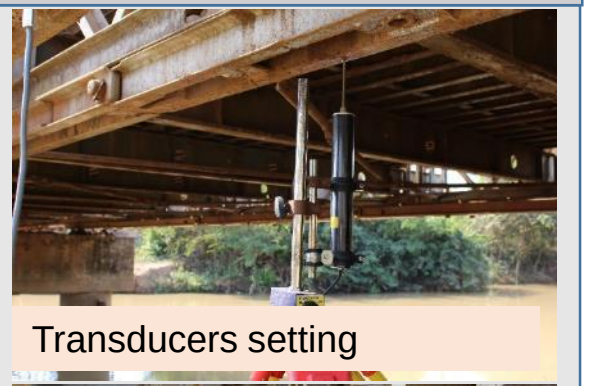
## Planning and Inspection

Meeting with Professors of the National University of Laos

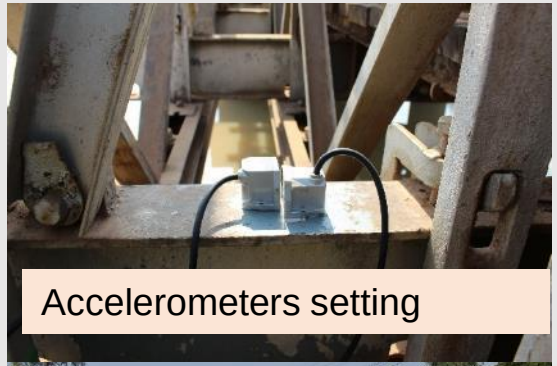
Preparing testing equipment

Site visit and inspection

## Marking and setting



Transducers setting

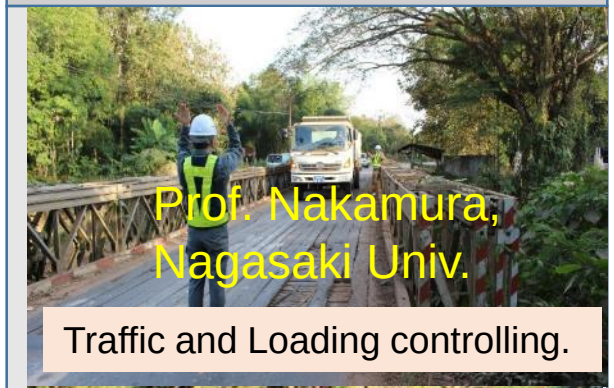


Accelerometers setting

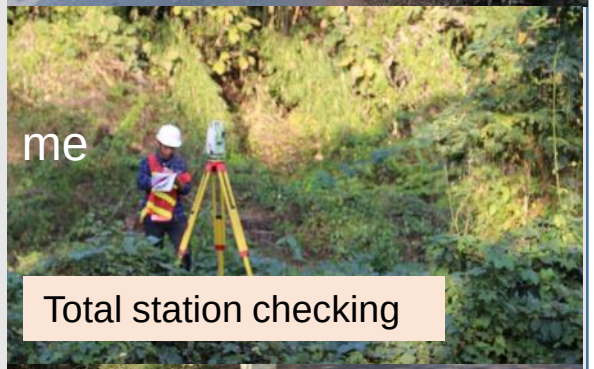
Total station targets setting

Point load marking

## Testing




Traffic and Loading controlling.




Total station checking


Testing data recording

# 3 Research Finding

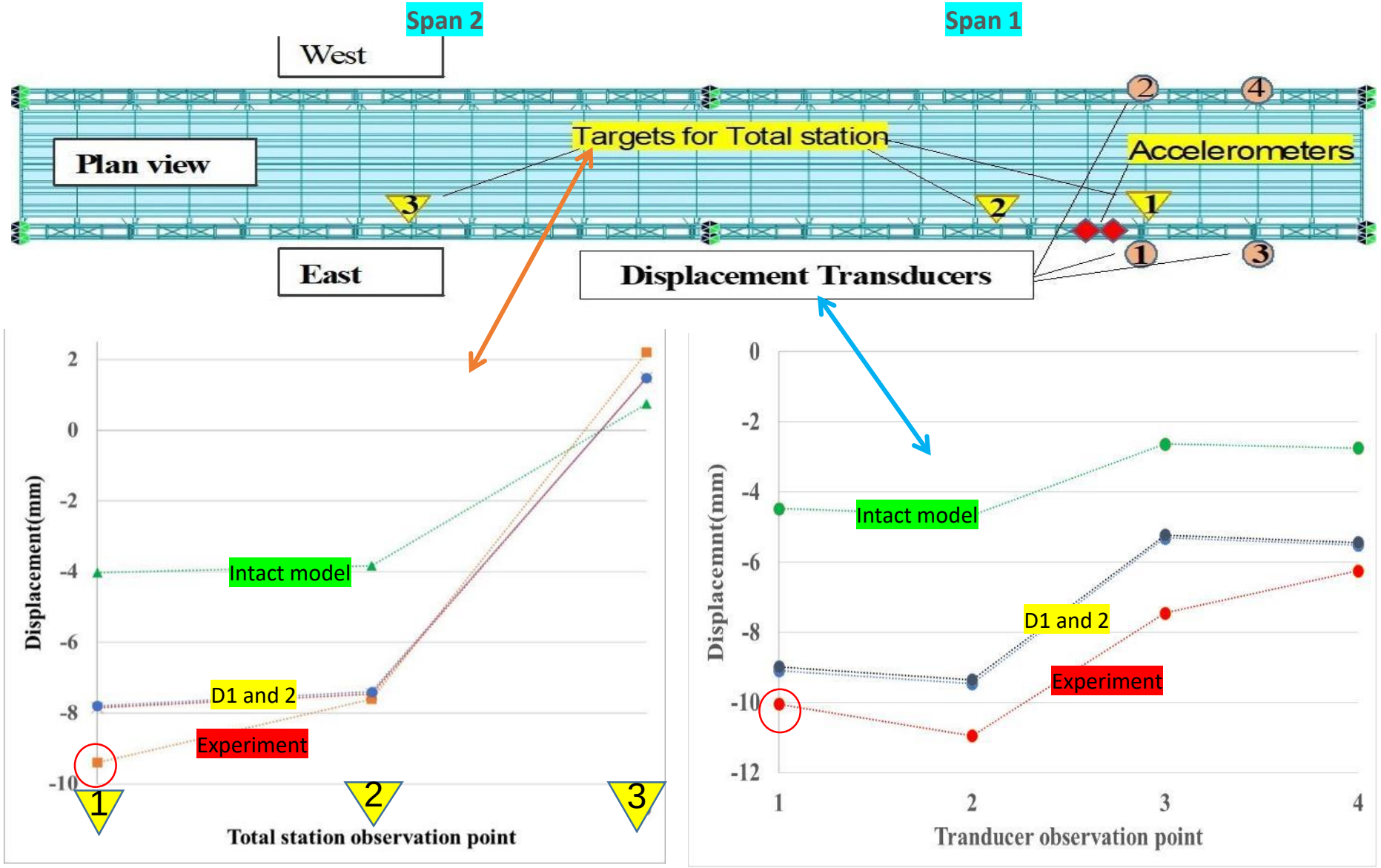
# Static and Dynamic behavior FEA approach

# Static behavior

Structure condition for each analysis model

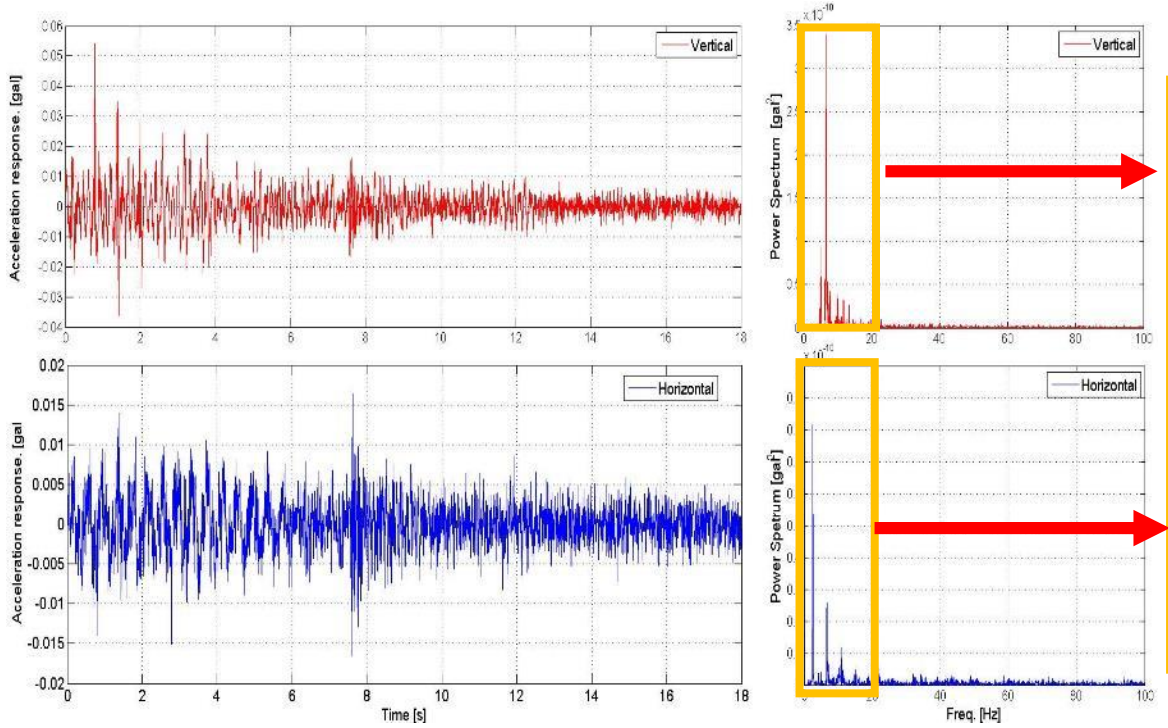
| Model code | Status | Damage | | |
|---|---|---|---|---|
| | | Panel and reinforcement | Desk | Sway bracing |
| Intact | Rigid | Intact | Including wooden desk | Intact |
| D1 | Defected | Reduced 50% member thickness, | No desk | Reduced 100% of the thickness |
| D2 | Defected | Reduced 50% member thickness, | No desk | Reduced 50% of the thickness |

# Static Deflection

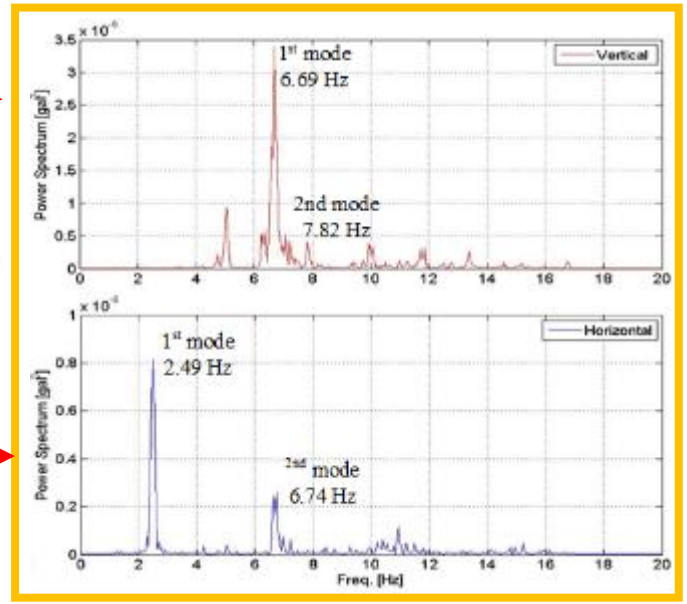


# Dynamic behavior

Noisy signal in time domain and frequency domain

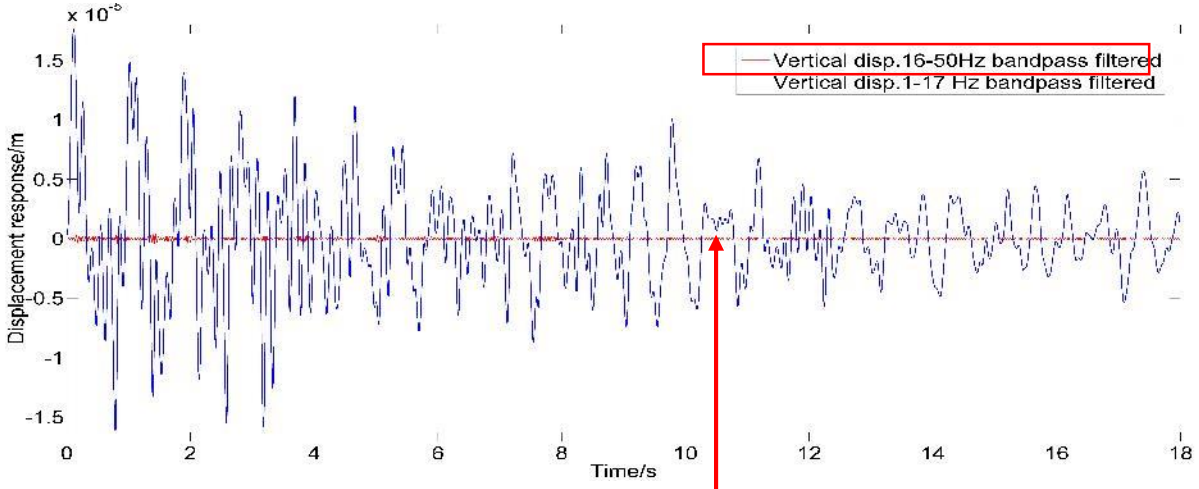



Frequency domain after filtering

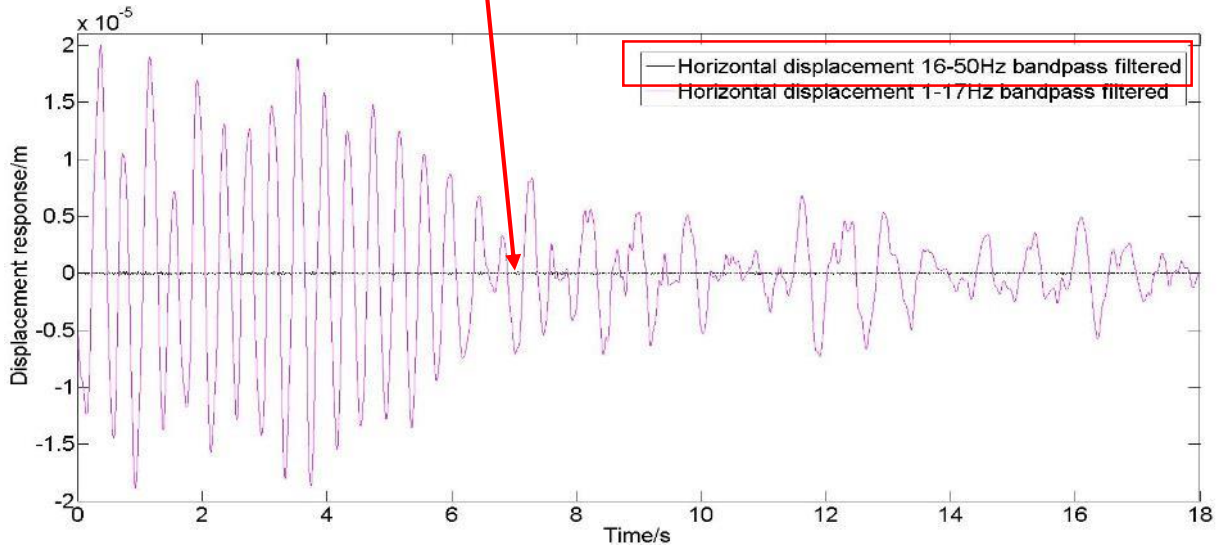


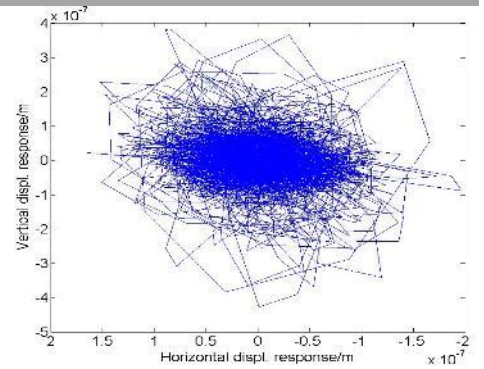

Data acquiring by ambient traffic condition

# Displacement response by acceleration data

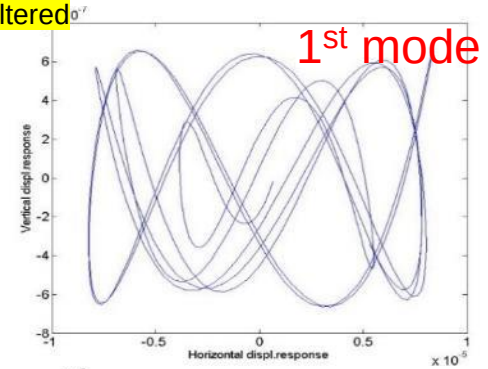


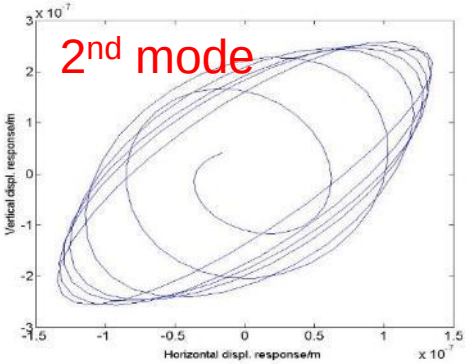

By time domain displacement response, noisy frequency range are flat amplitude



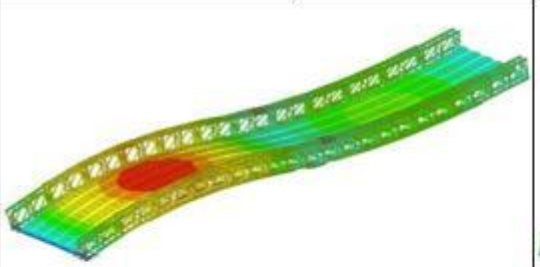
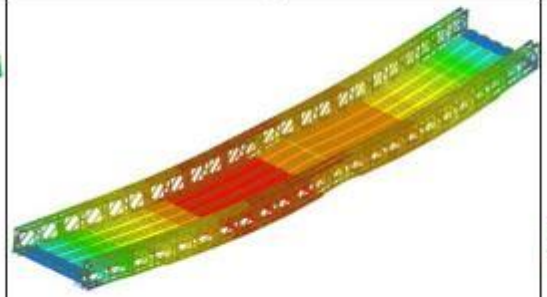
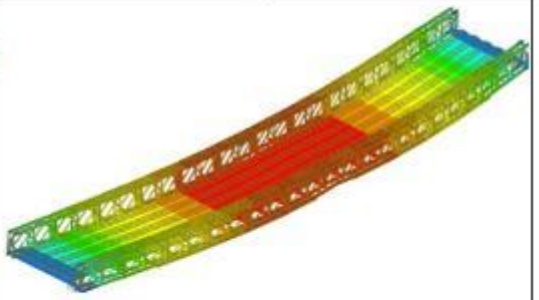
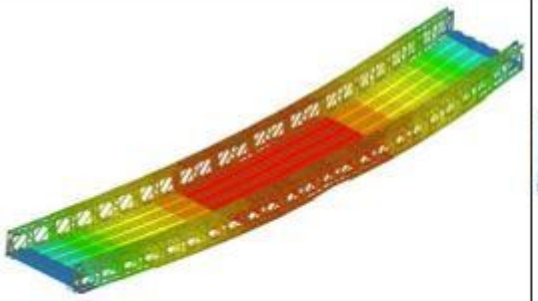
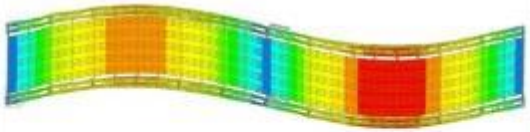
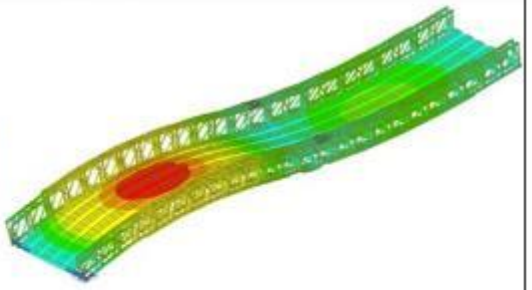
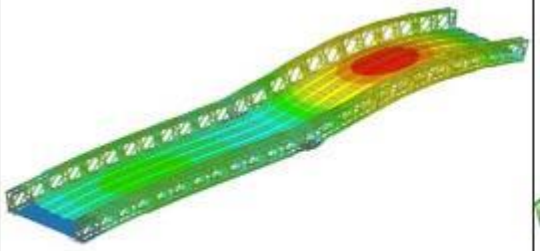
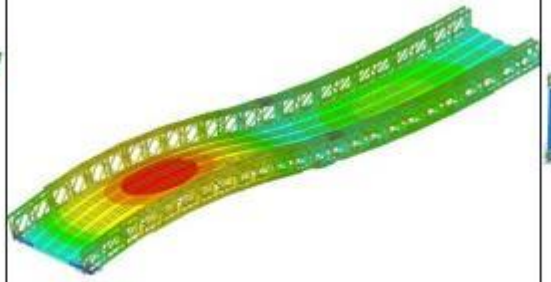
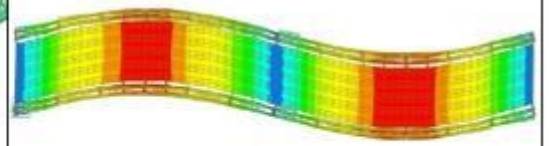

Lissajous pattern of 16 Hz high pass filtered




Lissajous pattern of structure vibration

# Vibration mode shape by eigen-analysis

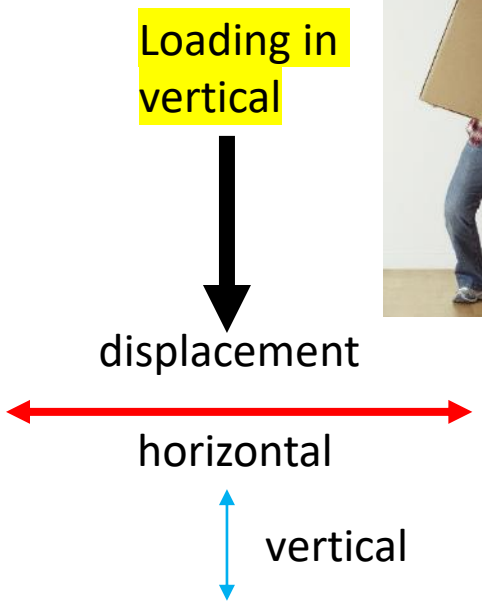
| Mode | Vibration shape | | | | | |
|---|---|---|---|---|---|---|
| | Intact | | D1 | | D2 | |
| | Span 2 | Span 1 | Span 2 | Span 1 | Span 2 | Span 1 |
| 1 |  | |  | |  | |
| 2 |  | |  | |  | |
| 3 |  | |  | |  | |

# Comparison of experimental data and structural analysis

| Mode No. | Experimental (Hz) | | Structure Analysis (Hz) | | |
|---|---|---|---|---|---|
| | V | H | Intact | D1 | D2 |
| 1 | 6.7 | 2.5 | 16.7(V) | 5.5(H) | 7.3(H) |
| 2 | 7.8 | 6.7 | 20.2(H) | 8.3(H) | 11.5(V) |
| 3 | 9.9 | 10.9 | 20.5(V) | 11.4(V) | 12.6(H) |
| 4 | 11.9 | 15.2 | 30.6(V) | 13.3(H) | 13.9(V) |
| 5 | 13.4 | N/A | 34.1(V) | 17.2(V) | 18.1(V) |
| 6 | 16.8 | N/A | 35.2(V) | 18.0(H) | 19.5(H) |

*H=Horizontal, V=Vertical

# Conclussion Dynamic Behavior



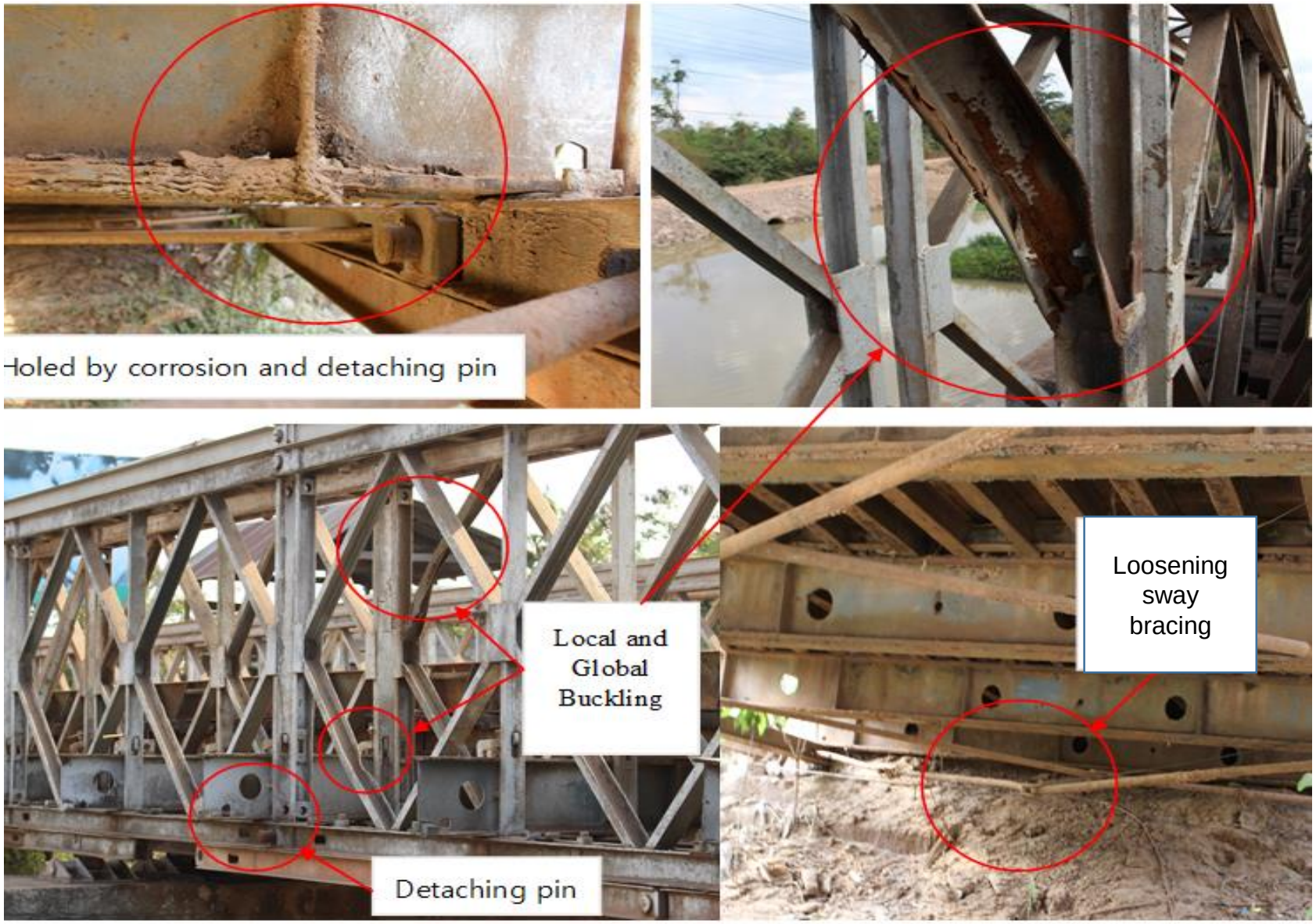

1. The analytical data were confirmed and validated:

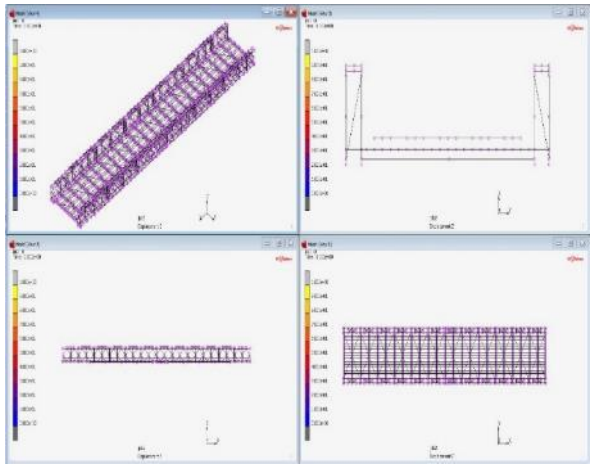
#Combined vibration is existing in case of severe damage.

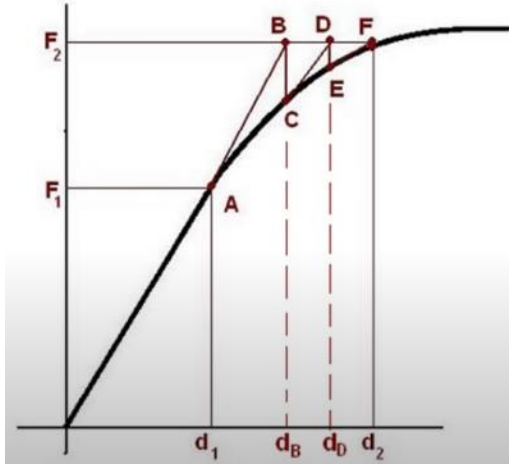
# Timber deck and sways bracing damage are directly affected the whole structure stiffness.

2. The horizontal vibration frequencies were lower than the vertical. Conversely, horizontal displacement was higher than the vertical.

# Some critical structure condition







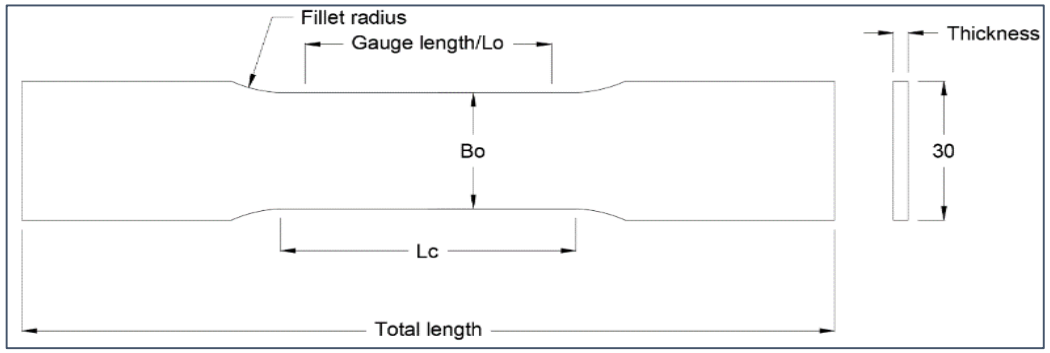

# Material properties investigation and Nonlinear Analysis

# Material properties

Sample collected from the site at Sungthong district Vientiane Capital

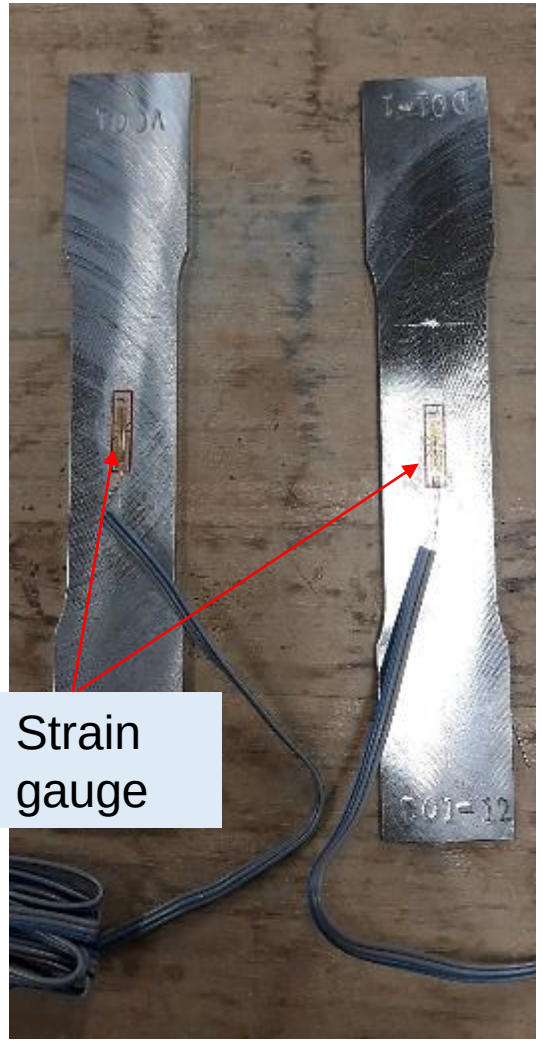

| No. | Code | Description | Illustration |
|---|---|---|---|
| 1 | BC 01 to 02 (Channel section) | Cut off from the panel that placed at the northern side of OPWT building (Panel 1) | |
| 2 | BT 01 to 02 (Channel section) | Cut off the from panel that placed southern of OPWT building (Panel 2) | |
| 3 | N01 and N02 (Channel section) | Cut off from the panel that placed at southern of OPWT building (Panel 3) | |
| 4 | B01 to B04 (I section) | Randomly picked of Stored of Raker | (DS) |
| 5 | VC 01 *(I section) | Cut off from the vertical chord of panel 4 | |
| 6 | D01 to D02 (Channel section) | Cut off from the vertical chord of panel 1 | |

# Testing specimen preparation




Specimen and testing procedure are based on JIS Z2241

Gauge length/Lo 50 mm, ±1% or 0.5 mm,
Lc= 60 mm
Fillet radius 25 mm,
width/Bo is 25 mm,
thickness is 3 mm,
Total length is approximately 165 mm.



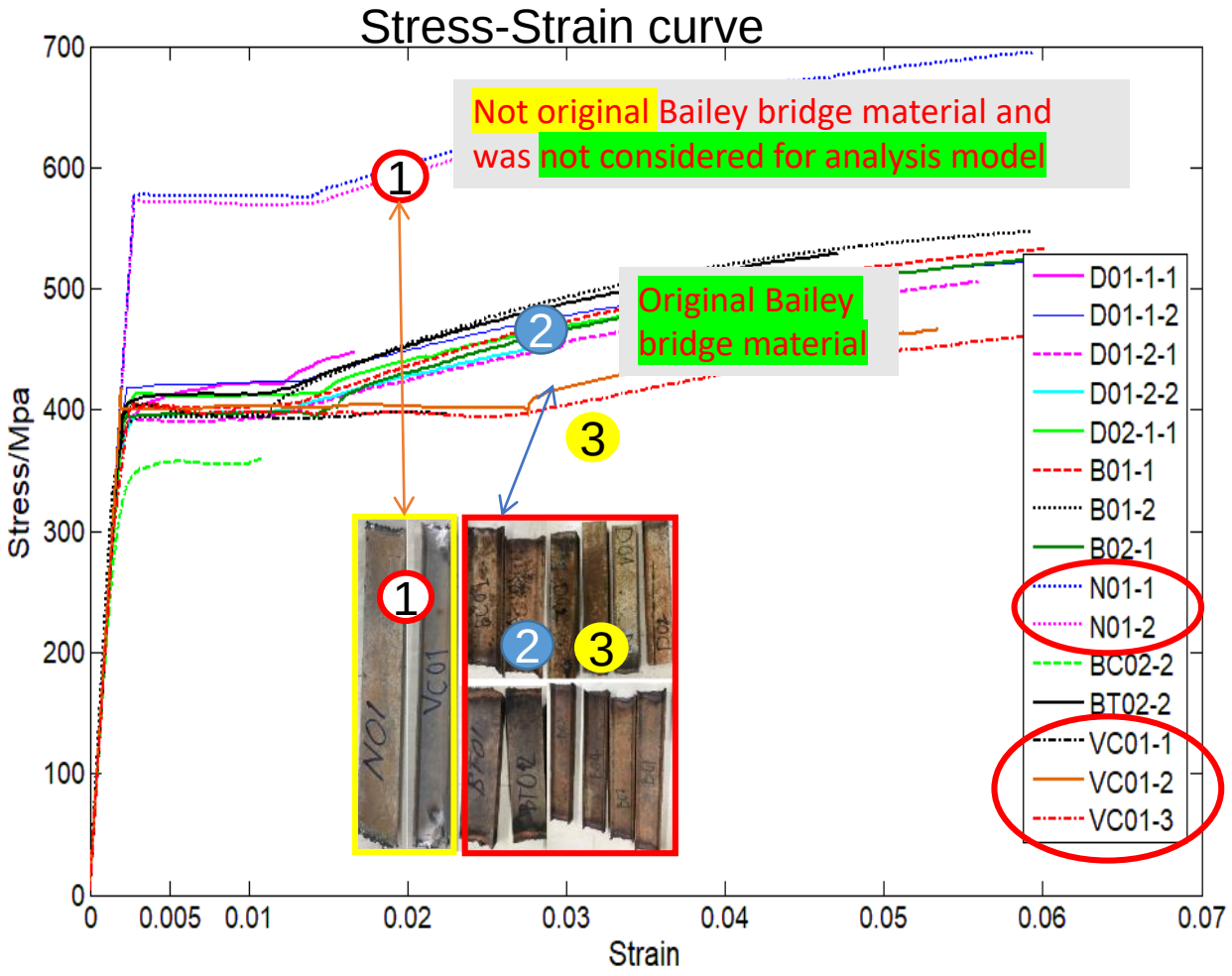
# Testing machine

Hydraulic Universal Testing Machines UH-F100kNX.

Tuning function and high precision of stress and strain controlling, the tester is compliant with the

International standards of ISO 6892-2009 and the JIS Z2241.

# Testing result




Three difference kind of material were found

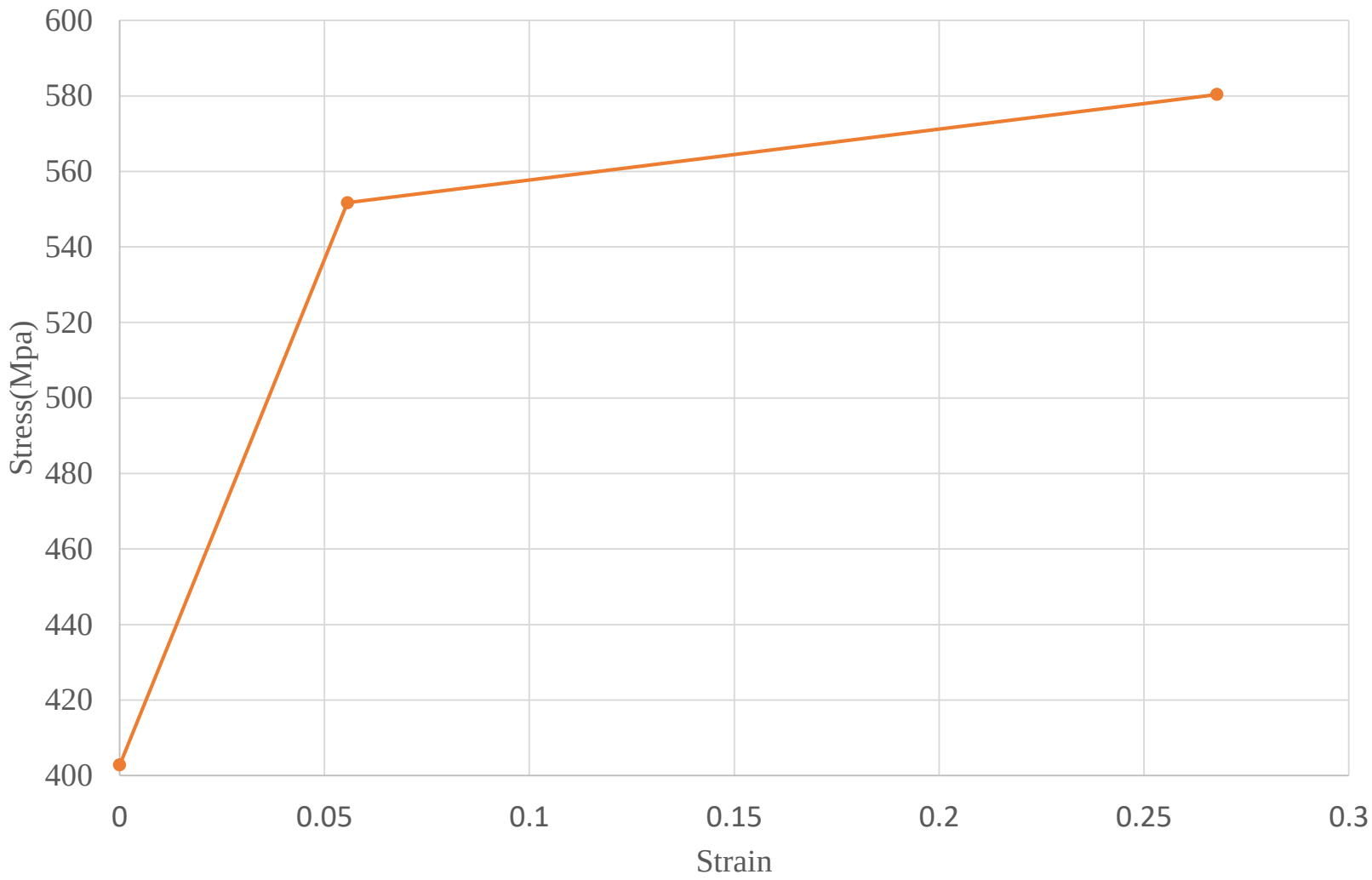
1. N01-N02 Higher yield strength*
2. Common yield strength
3. Common yield strength, higher ductile(VC01-1 to 3).

*Related to Weathering steel

N01-N02 related to Steels for Bridge High Performance Structures
JIS SBHS500 and SBHS500W

# Plastic properties

True stress-strain curve

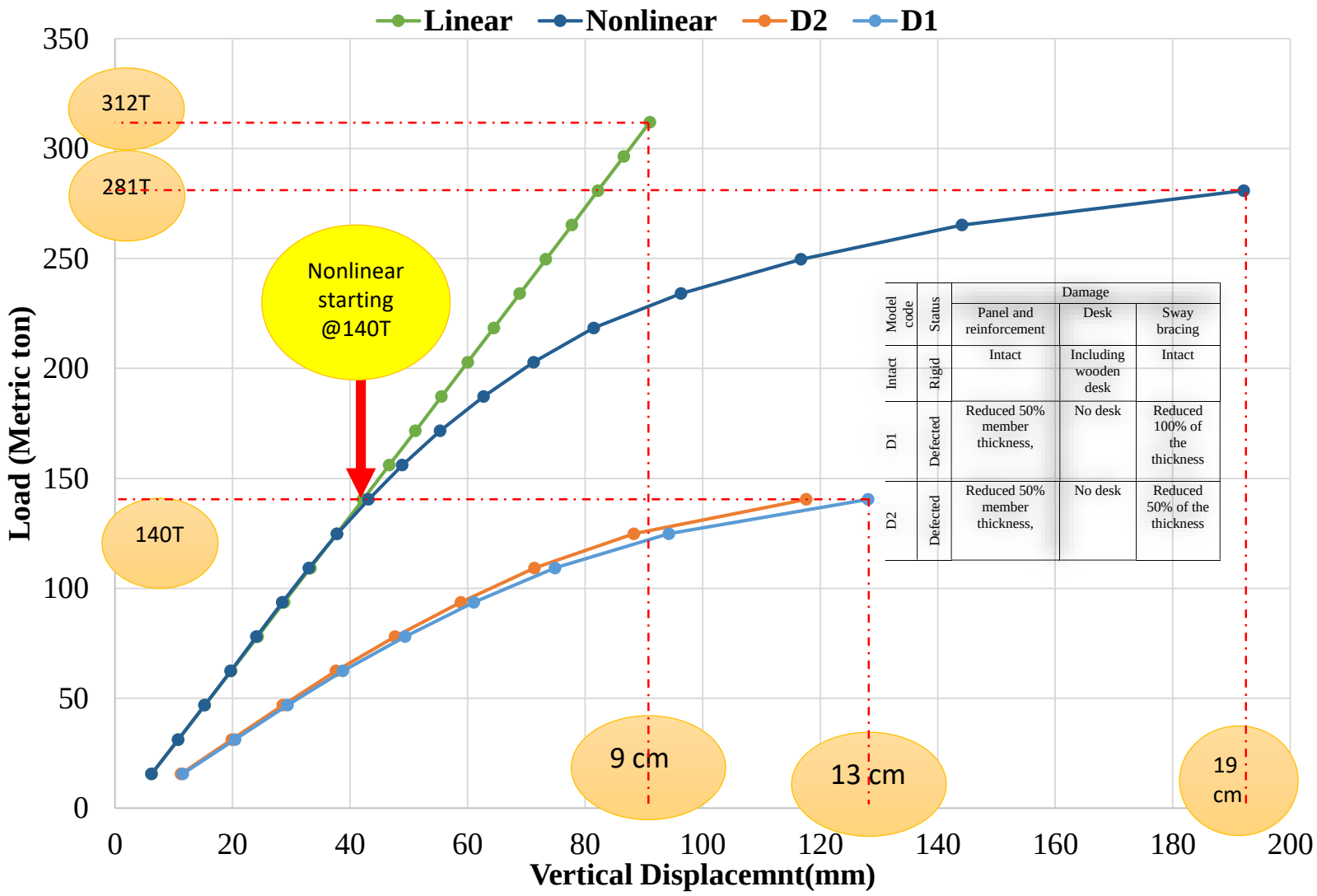


# Material properties summary

| Material | Young modulus | Yield Strength | Ultimate Strength | Fracture Strength | %Elongation after fracture |
|---|---|---|---|---|---|
| Test result | 205171 | 402 | 539 | 444 | 30.7 |
| ASTM A572-07 | 195000 | 345 | 448 | N/A | |
| SM490 | N/A | 325 min | 490 to 610 | N/A | |
| (King, Wu, & Duan, 2013). | 195000 | 338-344 | N/A | N/A | |
| ASTM A242 | N/A | 330 | 490 | N/A | |
| Q345B | N/A | 345 | 470~630 | N/A | |

The testing result is closed to the SM490 when considering the Yield strength and ultimate strength (the testing result excluding N01-N02).

# Nonlinear behavior/Load Capacity




| Model code | Status | Damage | | |
|---|---|---|---|---|
| | | Panel and reinforcement | Desk | Sway bracing |
| Intact | Rigid | Intact | Including wooden desk | Intact |
| D1 | Defected | Reduced 50% member thickness, | No desk | Reduced 100% of the thickness |
| D2 | Defected | Reduced 50% member thickness, | No desk | Reduced 50% of the thickness |

Thank you so much for your kind attention

NAGASAKI UNIVERSITY

JICA

RESEARCH PROGRESS

# Development of Roughness Prediction Models for Laos's National Roads Network


By

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Under the Supervision of

Prof. Dr. Takafumi Nishikawa

Graduate School of Engineering
Department of Science and Technology
System Engineering Program


September 2020

Mohamed Saied
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サイエッド

Egypt

Affiliation：ENIT-Ministry of Transport
University：Nagasaki University
Duration：2019.4-2022.3







## Reason for Applying

I've been a teaching assistant at the Egyptian National Institute of Transport (ENIT) since 2014. My responsibilities included teaching many Courses in the Highway and Traffic Department, in addition to participating in research projects. I'm very fortunate to participate in this program, which I've learned a lot about maintaining and investigation techniques for roads and bridges.

## Research

The main objective of my research is to develop pavement deterioration models based on roughness for Laos National Roads Network, the developed models help for;

- Eliminating expenses for obtaining and analyzing field Data.
- Helping decision maker for planning, setting priorities for maintenance and rehabilitation of deterioration roads.

## Prospect

After graduation, I'll come back to Egypt and establishing a new diploma/short term training courses in ENIT about Road and bridge asset Management, as well as developing new prediction models for pavement deterioration and transferring new technologies for data collection and inspection to GARBLT.

## Daily life

I’ve visited many prefectures in japan like Tokyo, Osaka, Nagoya, and Fukuoka. Also I used to participate in many outdoor activities like swimming, fishing, jogging. I’m so happy to lose weight 12Kg.

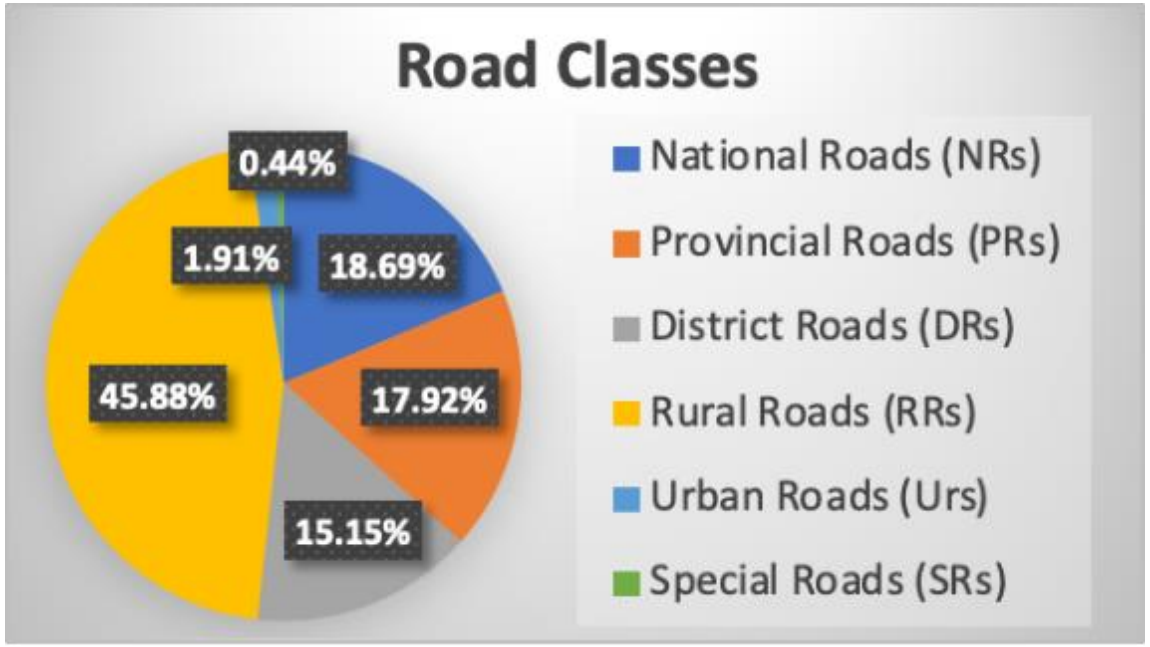
# Presentation Outlines

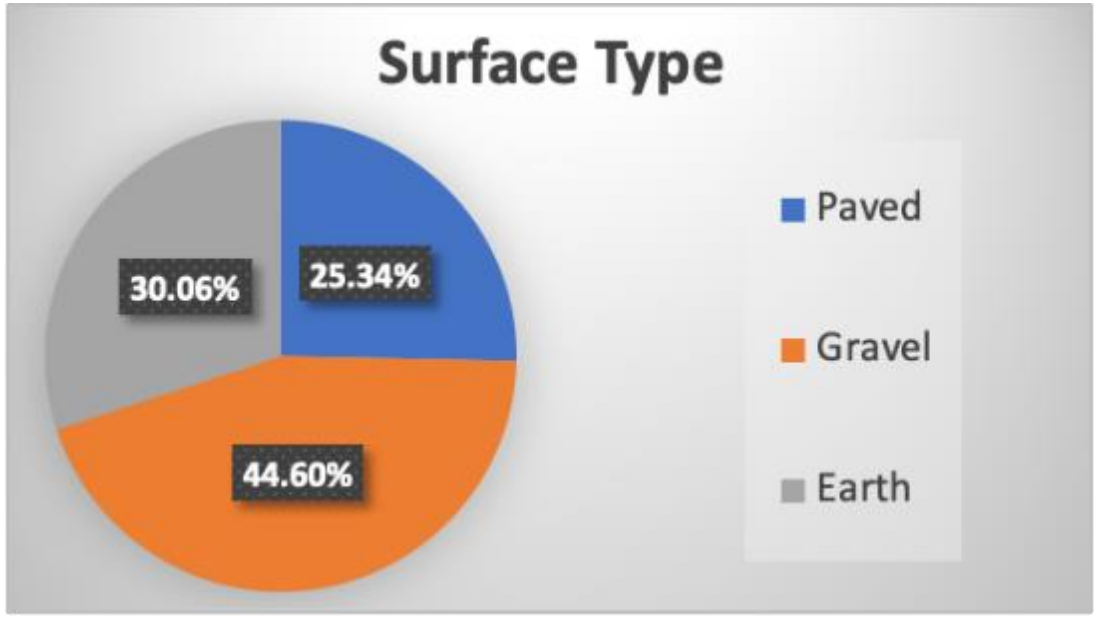
1. Introduction
2. Literature Review
3. Data Collection and Processing
4. Roughness Prediction Model
5. Model Validation
6. Sensitivity analysis of the developed Models

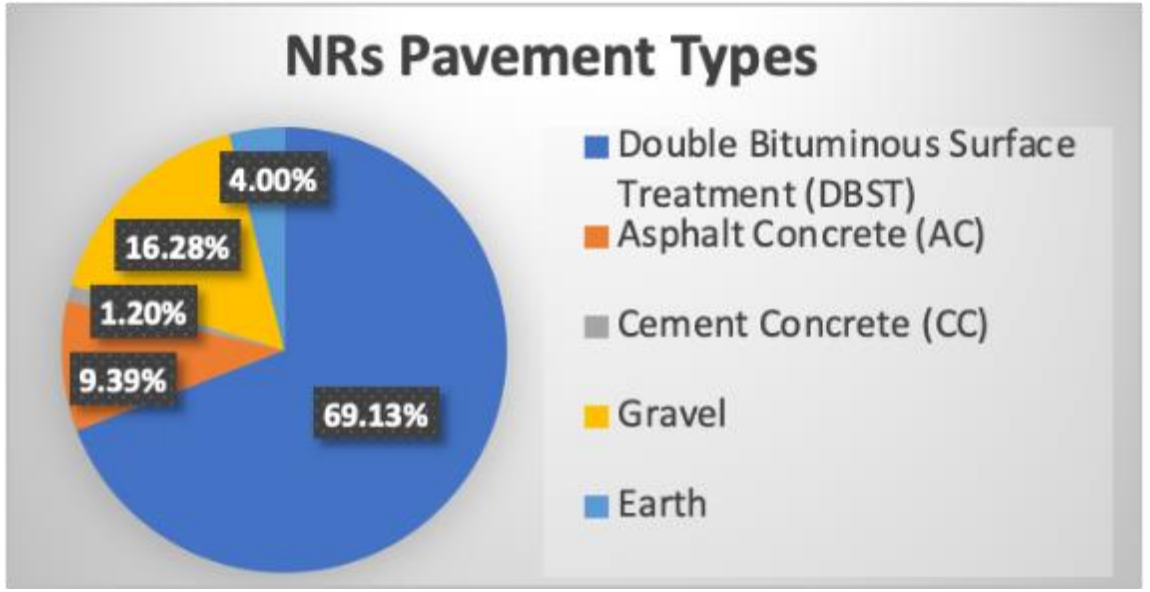
# 1- Introduction

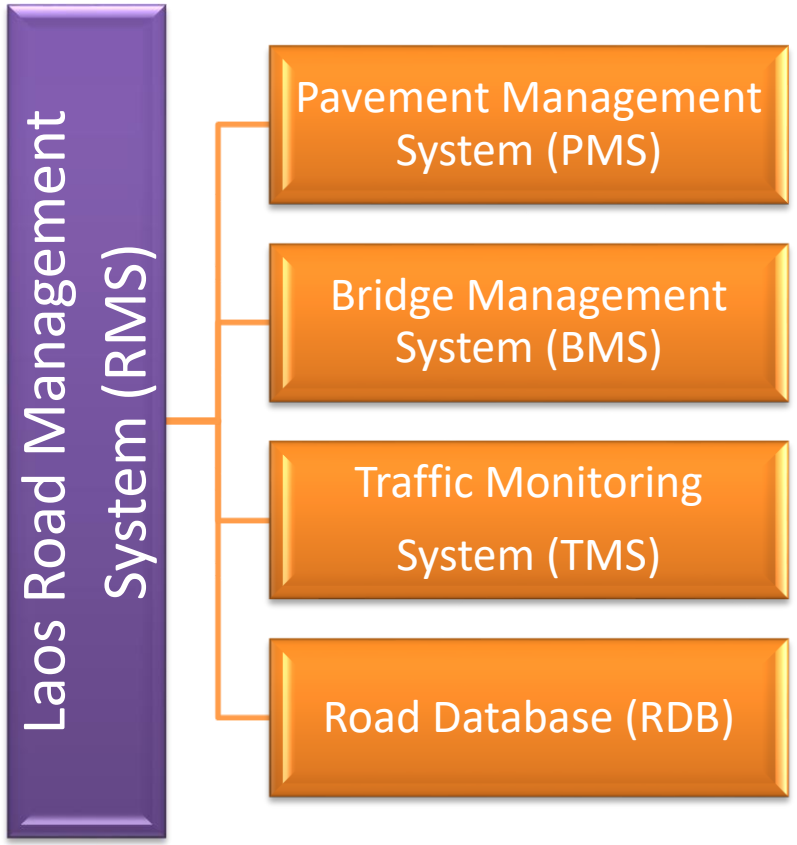
- The total length of Lao's road network is 37,552 km.

- The NRs network comprised approximately 7,019 km of roads, most of which (84%) had paved surface. While, PRs, DRs, URs, RRs, and SRs are mostly gravel or earth roads and vulnerable to heavy rains and floods.



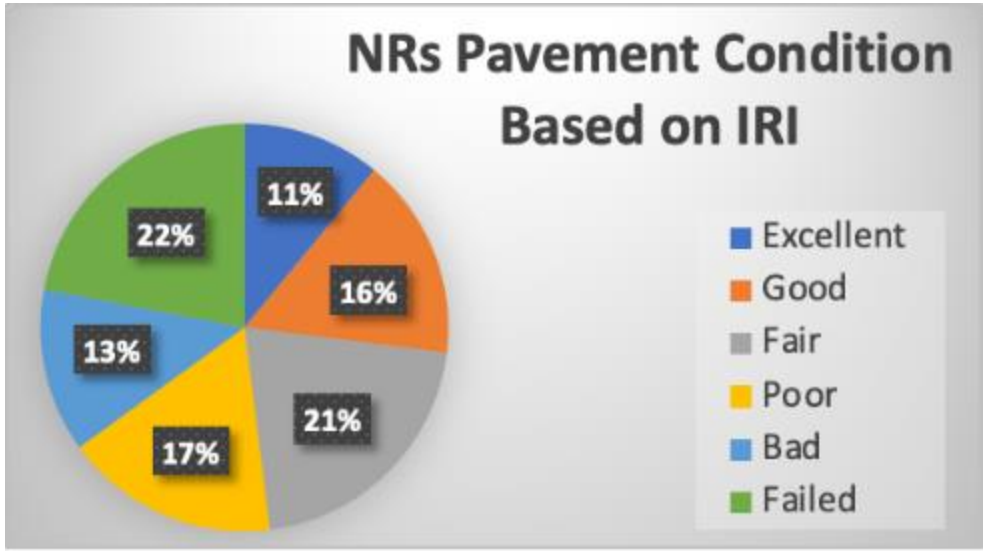


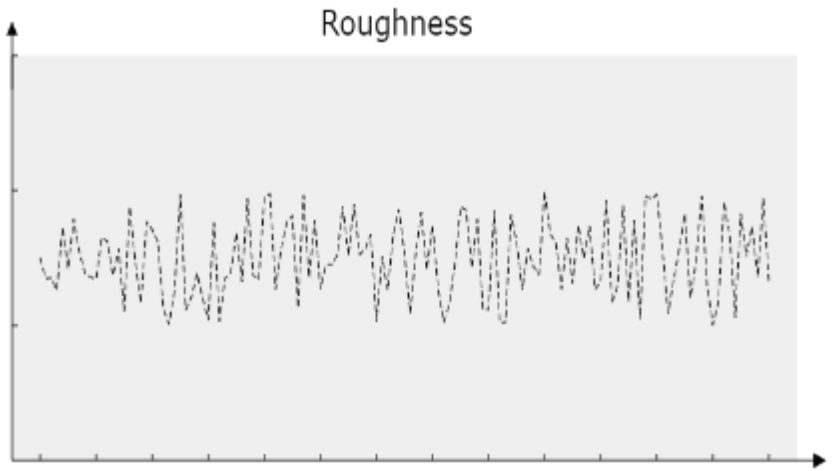

This system is used for formulating short and medium term maintenance management plans, selecting priority projects, and selecting the optimum maintenance methods.

Data for NRs are collected by Public Works and Transport Institute (PTI) while data for local roads are collected by The Department of Public Works and Transport (DPWT) in each province.

Pavement roughness describes the irregularities in the surface of the roadways which is calculated in terms of **IRI** m/km.

IRI is one of the most commonly used measures to gage road users' level of satisfaction, and provides an assessment of roadway conditions to road owners.




| Pavement Condition | IRI (m/km) |
|---|---|
| Excellent | < 3 |
| Good | 3 to 4 |
| Fair | 4 to 5 |
| Poor | 5 to 6 |
| Bad | 6 to 8 |
| Failed | > 8 |

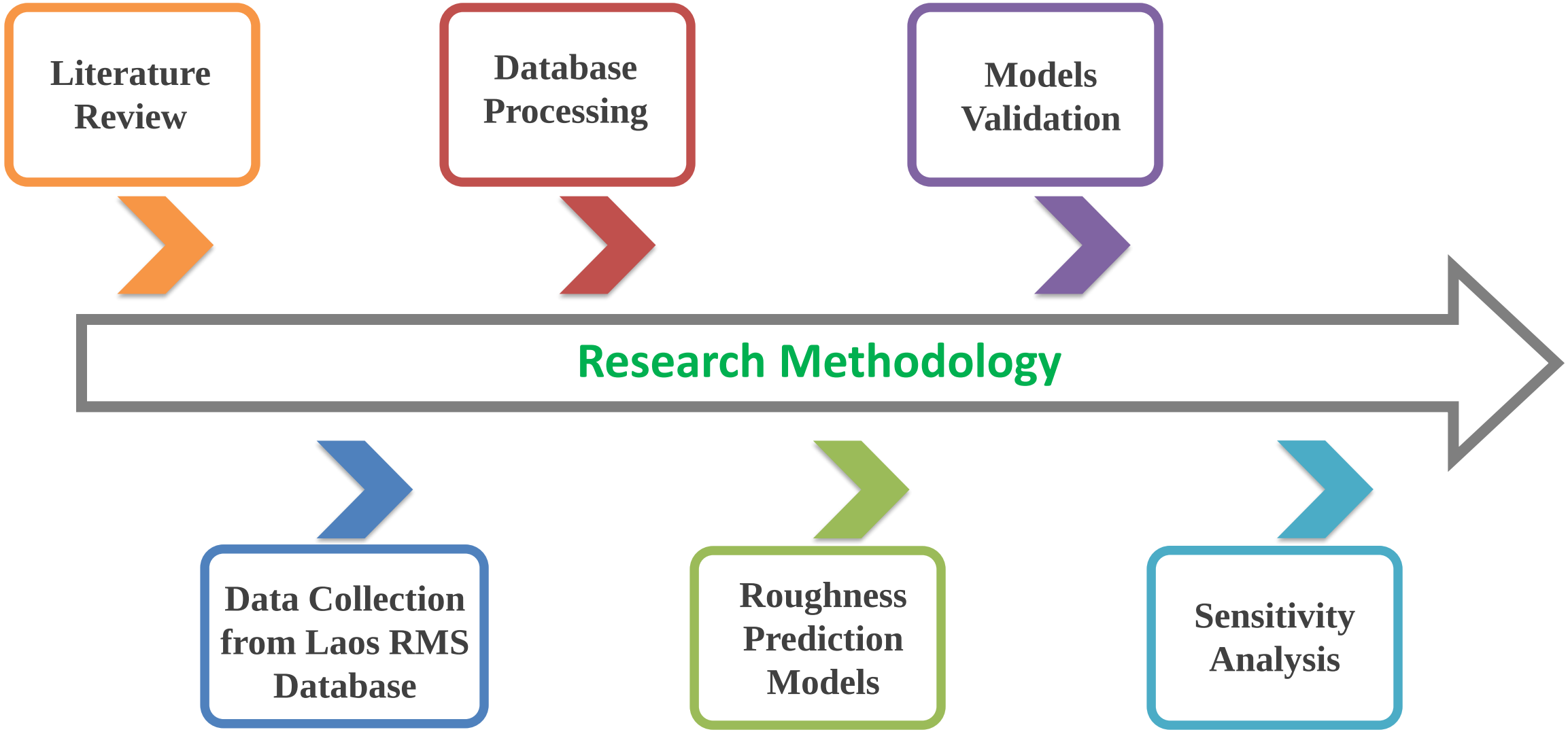
Many highway agencies, including PTI in Laos, conducted automated and regular IRI measurements (once every 3 years).

Deterioration of pavement can be attributed to various factors like age, traffic, environment, material properties, strength of pavement as well as sub-grade properties which affect the characteristics of a pavement.

Lao's RMS utilizes a **default HDM-4** IRI prediction model. However, predicted IRI values have shown the need to calibrate RMS`s default IRI prediction model or replace it with a new model based on local condition.

So, The **Main Objective** of this research is to develop pavement deterioration models based on roughness for Lao's NRs network using RMS database. The developed models help for:

- Eliminating the expenses for field data collection.
- Helping decision-makers in planning, setting priorities, and allocating funds for maintenance and rehabilitation of deteriorated pavement sections.


Literature Review
Database Processing
Models Validation
Research Methodology
Data Collection from Laos RMS Database
Roughness Prediction Models
Sensitivity Analysis

# 2- Literature Review

Over the years, research agencies and individual researchers developed several IRI prediction models. Some of these models were derived using Long-Term Pavement Performance **(LTPP),** while others were developed based on direct field measurements or the local agency database.

Based on the literature review, it's revealed that the factors such as age, traffic loading, pavement strength, pavement distresses and environmental conditions are greatly influencing the progression of the unevenness (IRI value).

The calibration and implementation of **MEPDG or HDM-4** models by highway agencies require an excessive amount of data and regular distress survey records, that are not available for Laos local conditions. Also, the IRI models available for DBST roads are very limited.

So, the indigenous IRI models for different pavement types have to be developed covering the effect of Laos's local condition which would have direct application without any correlation factors based on available data in **Laos' RMS database**.

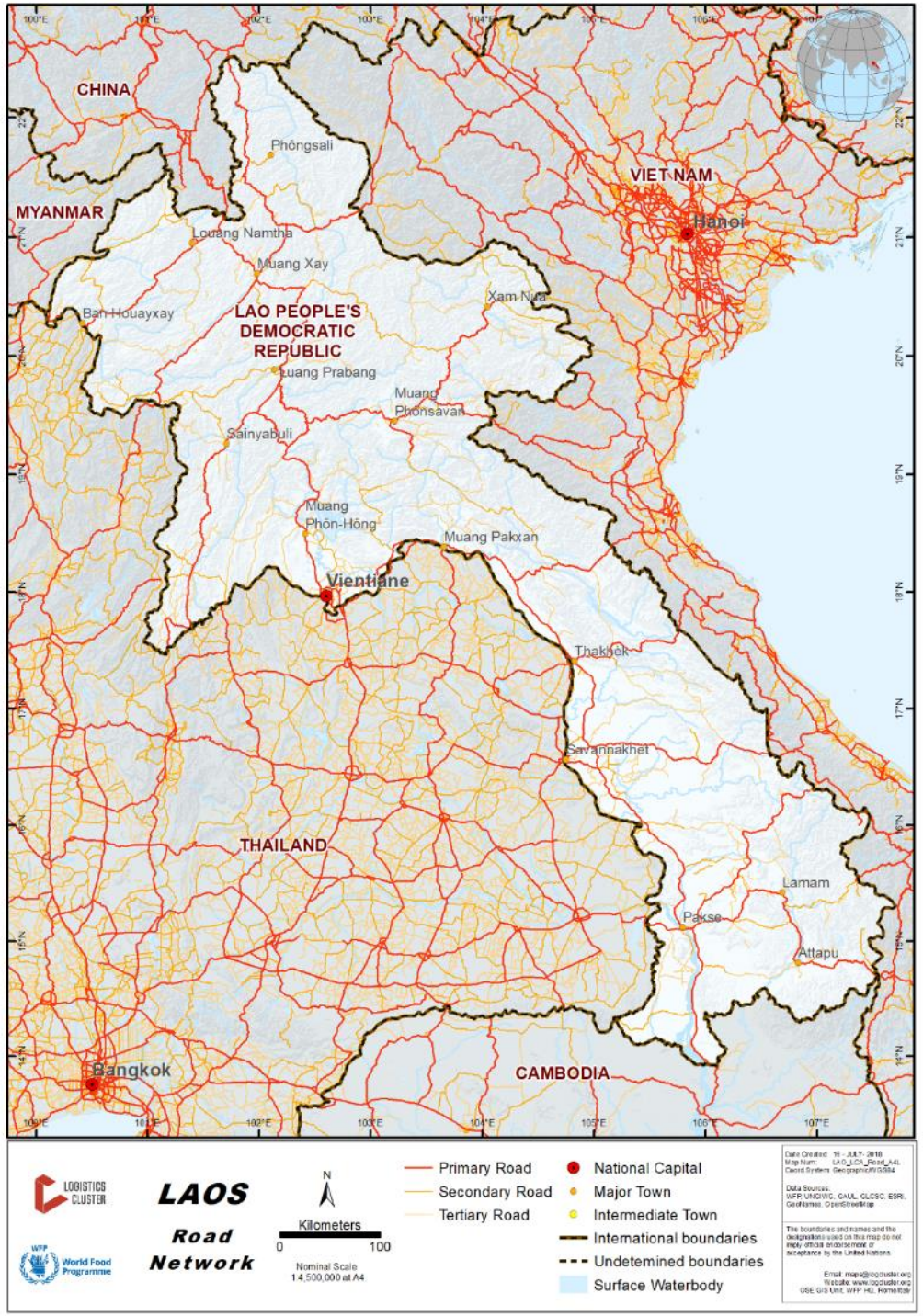
# 3- Data Collection and Processing

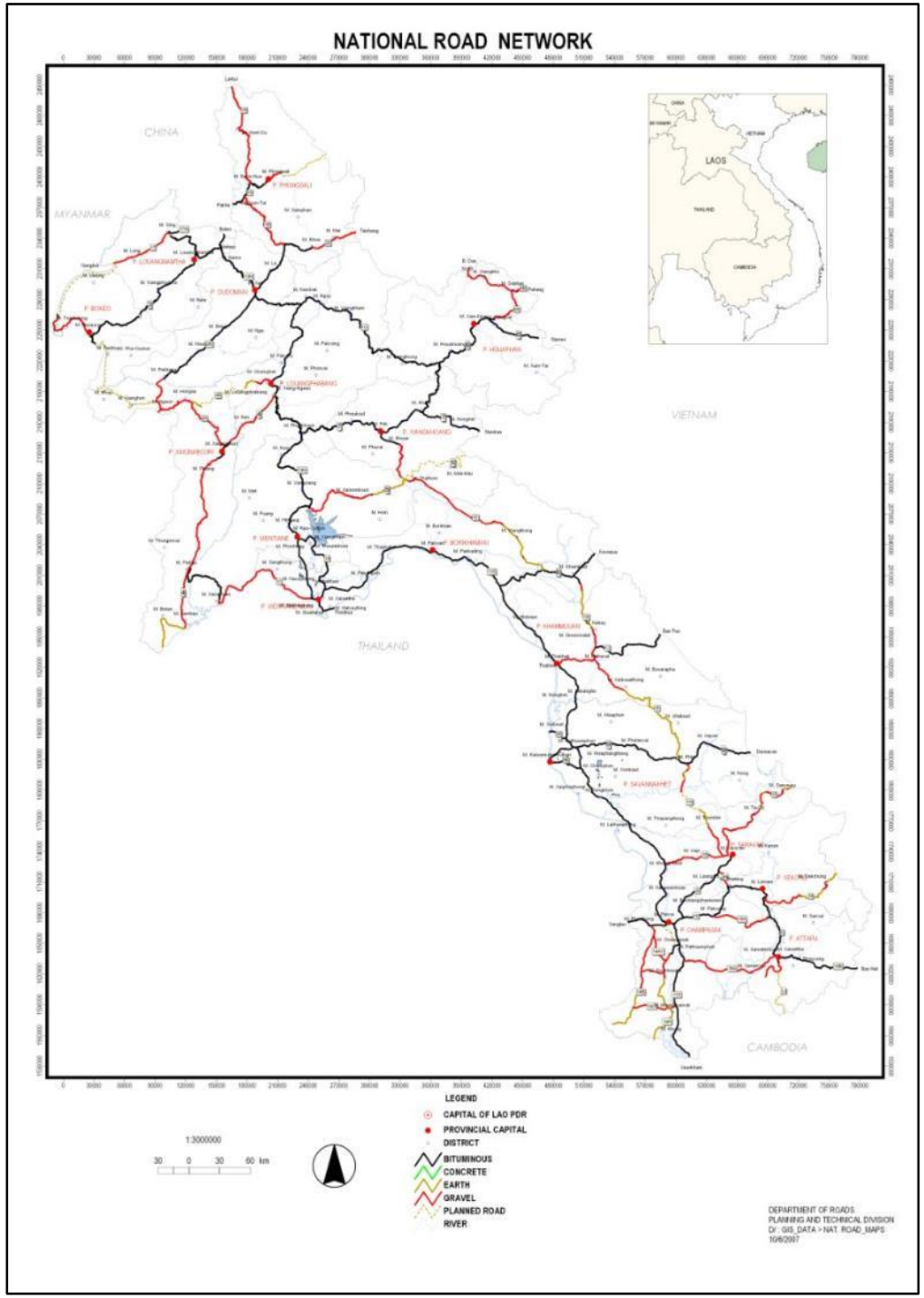
In order to establish a regression model between IRI and Independent variables, a large number of valid and precise data are needed.

I traveled with my supervisor Prof. Dr. Takafumi Nishikawa to Laos last December for data collection required for developing pavement deterioration models.

Data collected are mainly from the RMS database. The study was planned to cover a time period of 14 years, starting from 2001 to 2015 for **NRs network.**

- Road Roughness Survey (IRI)
- Traffic Condition Survey
- Road Inventory Survey
- Road Condition Survey
- Maintenance data


CHINA
Phôngsali
MYANMAR
Louang Namtha
Muang Xay
Ban Houayxay
LAO PEOPLE'S DEMOCRATIC REPUBLIC
Xam Nua
Luang Prabang
Muang Phonsavan
Sainyabuli
Muang Phôn-Hông
Muang Pakxan
Vientiane
VIET NAM
Hanoi
Thakhek
Savannakhet
THAILAND
Lamam
Pakse
Attapu
Bangkok
CAMBODIA
LOGISTICS CLUSTER
World Food Programme
LAOS
Road Network
N
Kilometers
0
100
Nominal Scale 1:4,500,000 at A4
Primary Road
Secondary Road
Tertiary Road
National Capital
Major Town
Intermediate Town
International boundaries
Undetemined boundaries
Surface Waterbody

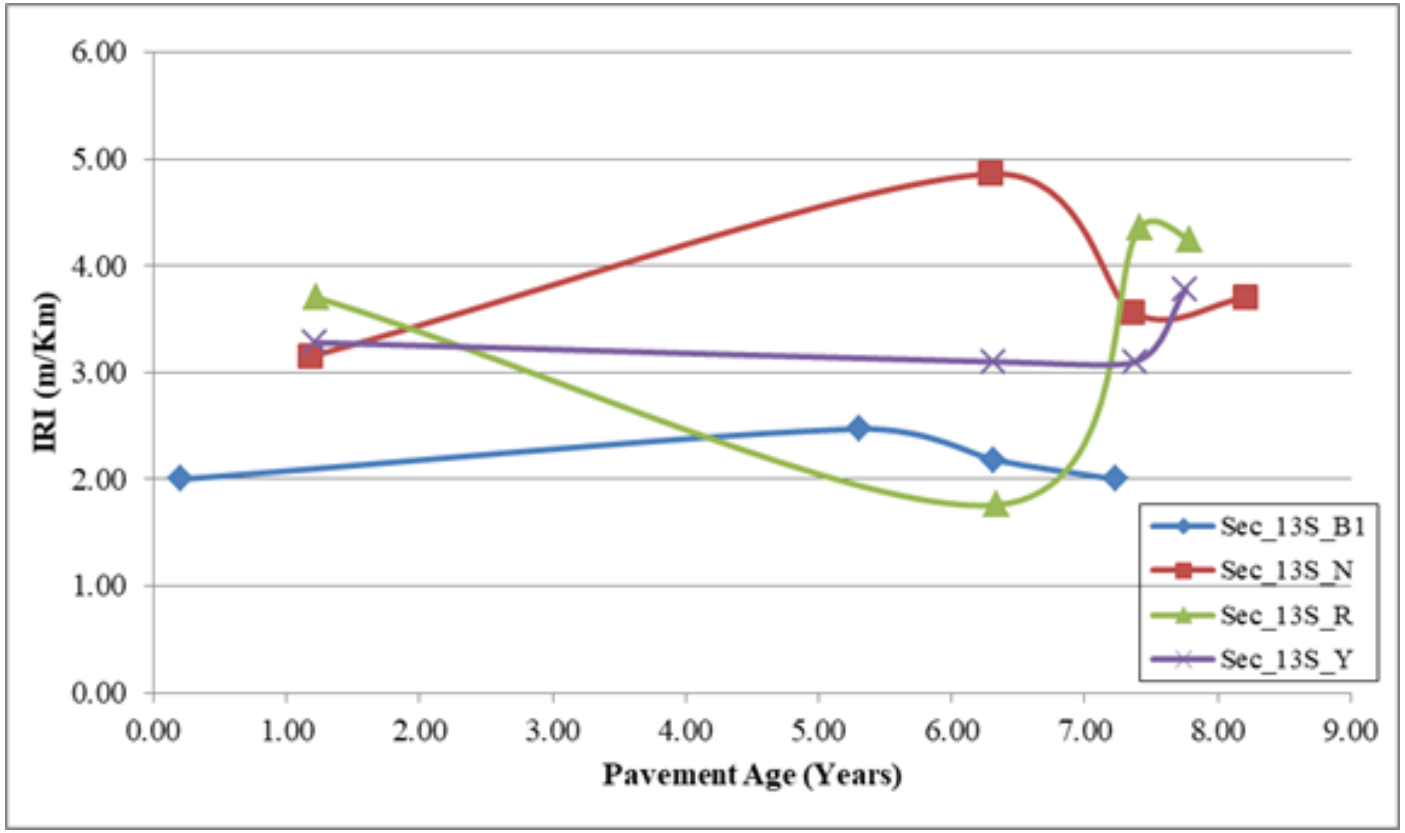

NATIONAL ROAD NETWORK
CHINA
MYANMAR
LAOS
VIETNAM
THAILAND
CAMBODIA
LEGEND
CAPITAL OF LAO PDR
PROVINCIAL CAPITAL
DISTRICT
BITUMINOUS
CONCRETE
EARTH
GRAVEL
PLANNED ROAD
RIVER
1:3000000
30 0 30 60 km
DEPARTMENT OF ROADS
PLANNING AND TECHNICAL DIVISION

For Roughness modeling, IRI was taken as the dependent variable and the calculated **Pavement Age** and Cumulative Equivalent single axle loads **(CESAL),** were considered as independent variables.

The analysis will be carried out utilizing the data available for Laos RMS, which includes **705** observations from **214** sections cover the **DBST** NRs network and **145** observations from **36** sections cover the **AC** NRs network.

Before the data could be analyzed, IRI data collected from these sections had to be checked against possible irregularities.

A linear relation between IRI and pavement age for all sections were established. The sections that displayed the negative trend (decreasing IRI value with time) were excluded from this study.



So, the valid number of observations and sections were decreased to be **269** observations from **83** sections cover **DBST** NRs network and **122** observations from **29** sections cover the **AC** NRs network.

The main issue that needs special attention while selecting variables for model development is the problem of **multicollinearity** between variables. Multicollinearity arises when independent variables that have high correlated are included in the model.

## Correlation Matrix for Study Variables

| DBST Model | | | |
|---|---|---|---|
| Variable | IRI | Age | CESAL |
| IRI | 1 | 0.85 | 0.72 |
| Age | 0.85 | 1 | **0.40** |
| CESAL | 0.72 | **0.40** | 1 |

| AC Model | | | |
|---|---|---|---|
| Variable | IRI | Age | CESAL |
| IRI | 1 | 0.82 | 0.82 |
| Age | 0.82 | 1 | **0.56** |
| CESAL | 0.82 | **0.56** | 1 |

An example is the high correlation between the age variable and the cumulative ESALs in AC modelling data. To overcome this problem the average yearly equivalent single axle loads **(YESAL)** may be used instead.

To eliminate any possible bias, the database is randomly sorted and divided into two parts; **"in-sample"** part forms the bulk of the data, about **80 %,** which will be used in developing the regression equations. The remaining **20 %** of the data, referred as the **"out-of-sample"** or **"testing data"** is used for assessing the prediction accuracy of the regression equation.

| Variable Description | Notation | Unit | Range | | Mean | Std. Deviation |
|---|---|---|---|---|---|---|
| | | | Min | Max | | |
| **DBST Model** | | | | | | |
| **Roughness** | IRI | m/km | 2.20 | 8.91 | 5.09 | 1.44 |
| **Pavement age since last overlay** | Age | Years | 0.10 | 14.10 | 6.03 | 3.73 |
| **Cumulative Equivalent single axle loads** | CESAL | 10^4 Axle/Lane | 0.02 | 130.06 | 16.08 | 20.75 |
| **AC Model** | | | | | | |
| **Roughness** | IRI | m/km | 1.47 | 5.46 | 3.54 | 1.02 |
| **Pavement age since last overlay** | Age | Years | 0.09 | 13.08 | 5.95 | 3.44 |
| **The average Yearly Equivalent single axle loads** | YESAL | 10^4 Axle/Lane | 0.03 | 27.13 | 5.72 | 4.41 |

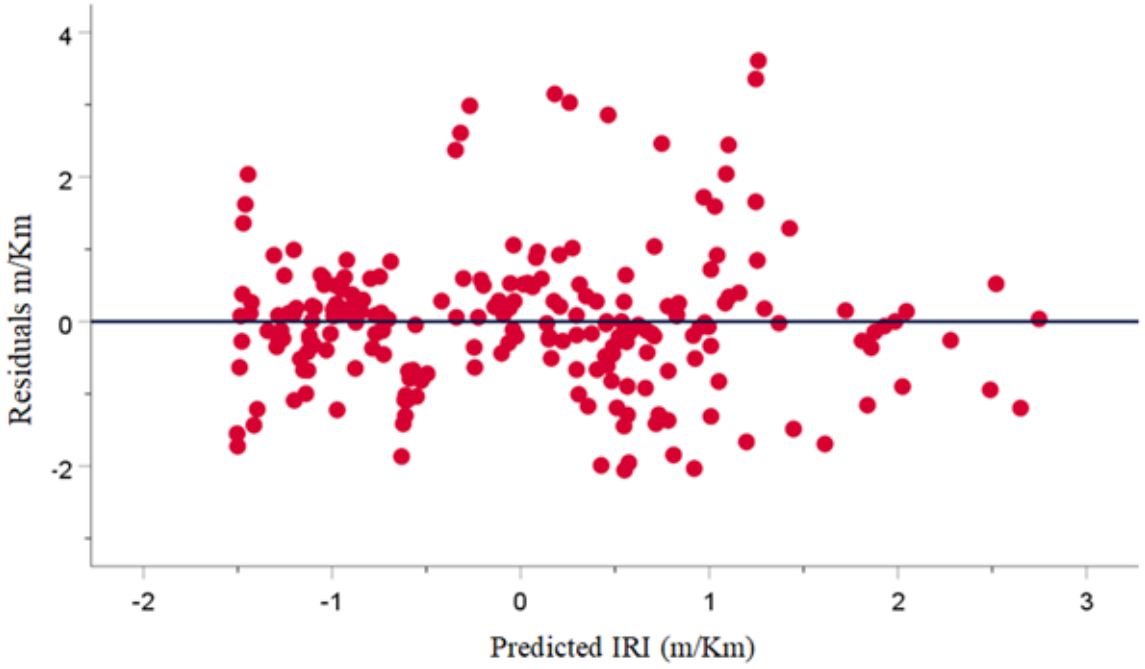
# 4- Roughness Prediction Model

The Multiple Linear Regression **(MLR)** modeling technique in SPSS was applied to develop a mathematical model to correlate IRI with the factors under the study.

**IRI Model for DBST Pavement**

**IRI = 3.001 + 0.264 Age + 0.03 CESAL**

**($R^2$=0.944, SEE=0.482 m/Km, N=215)**

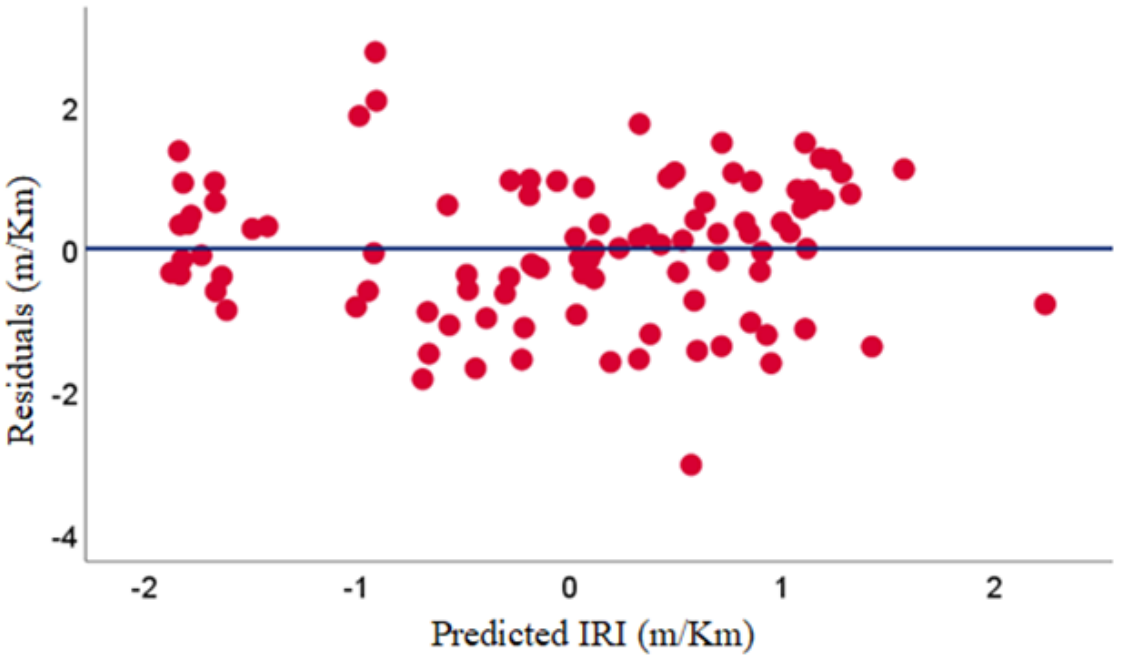



Graph of Residuals versus Predicted IRI for **DBST** Roads

**IRI Model for AC Pavement**

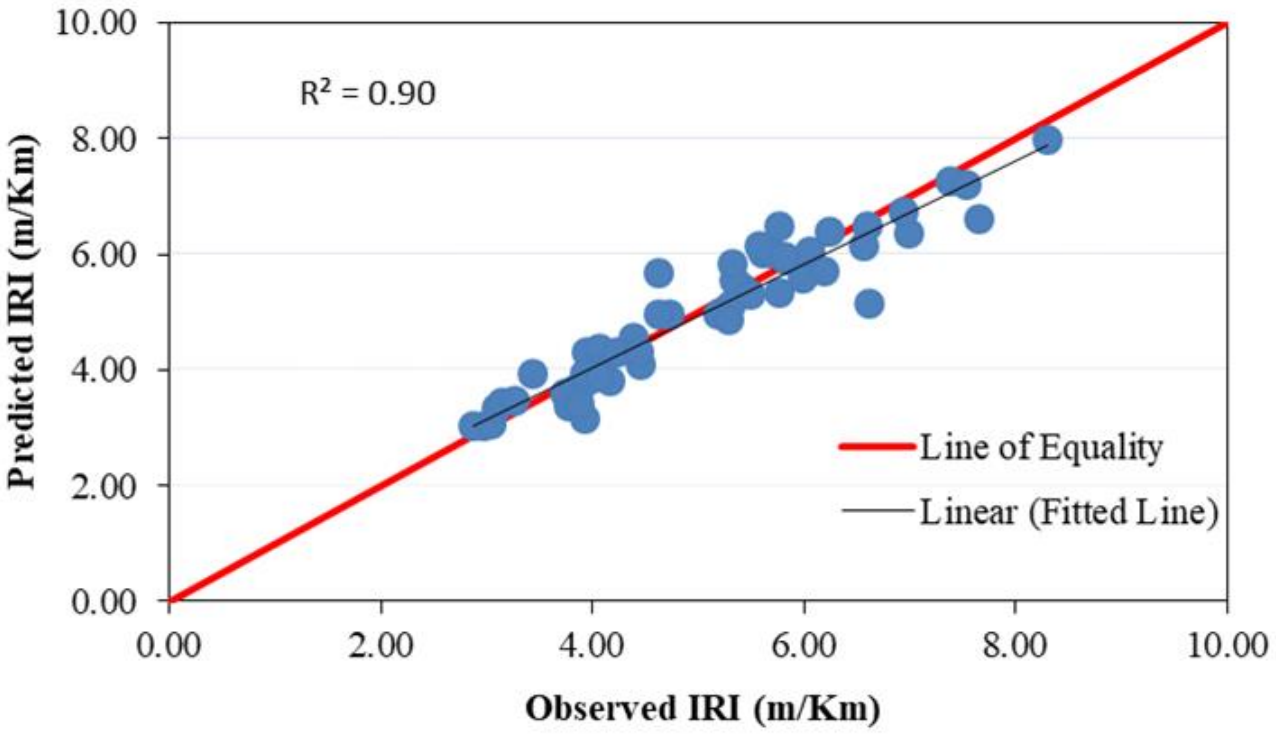
**IRI = 1.791 + 0.205 Age + 0.091 YESAL**

**($R^2$=0.918, SEE=0.402 m/Km, N=98)**

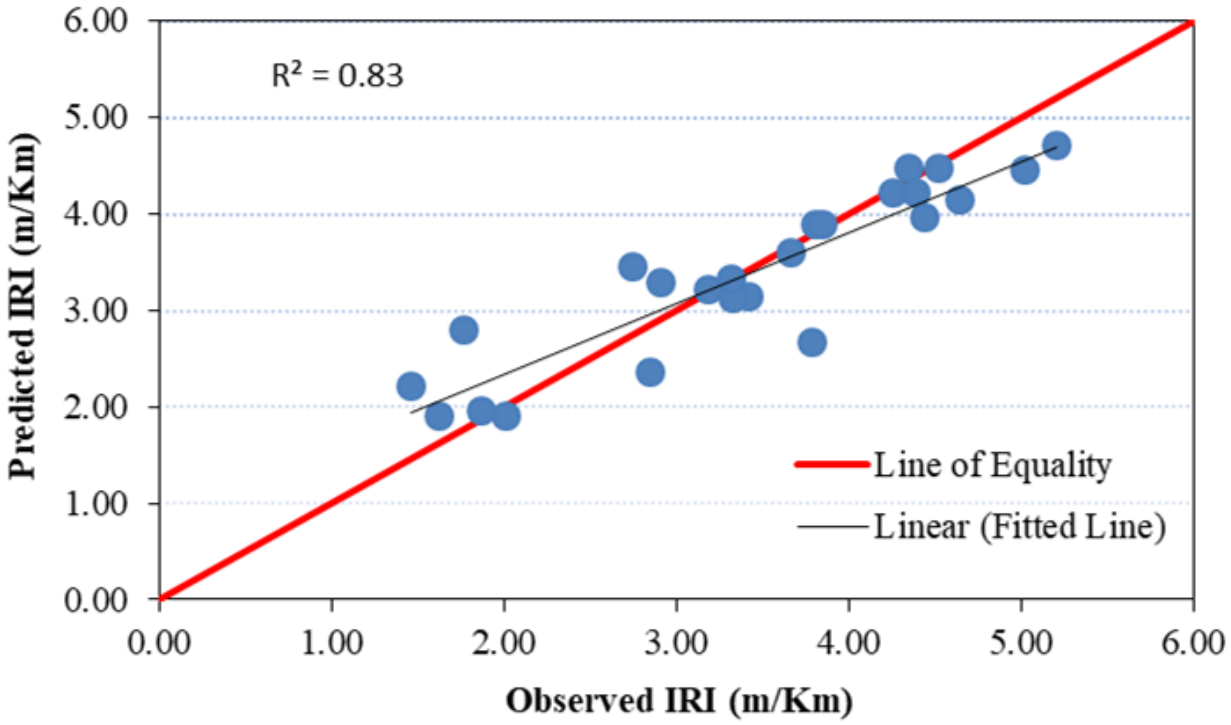



Graph of Residuals versus Predicted IRI for **AC** Roads

# 5- Models Validation




Comparison between observed and predicted IRI values for the **DBST** proposed model




Comparison between observed and predicted IRI values for the **AC** proposed model

**The alignment of plotted points along the line of equality indicates the robustness of the developed models.

## Statistics of the performance prediction models

| Independent Variable | Coefficient | Student's t | P value | VIF |
|---|---|---|---|---|
| **DBST Model** | | | | |
| Age | 0.264 | 27.232 | 3.7348E-71 | 1.188 |
| CESAL | 0.030 | 18.309 | 1.5469E-45 | 1.188 |
| **AC Model** | | | | |
| Age | 0.205 | 16.335 | 2.4503E-29 | 1.098 |
| YESAL | 0.091 | 9.902 | 2.6803E-16 | 1.098 |

The acceptable "Student's t" statistic value for 95% confidence level is 1.645.

"p values" for all independent variables in both models are less than 0.05

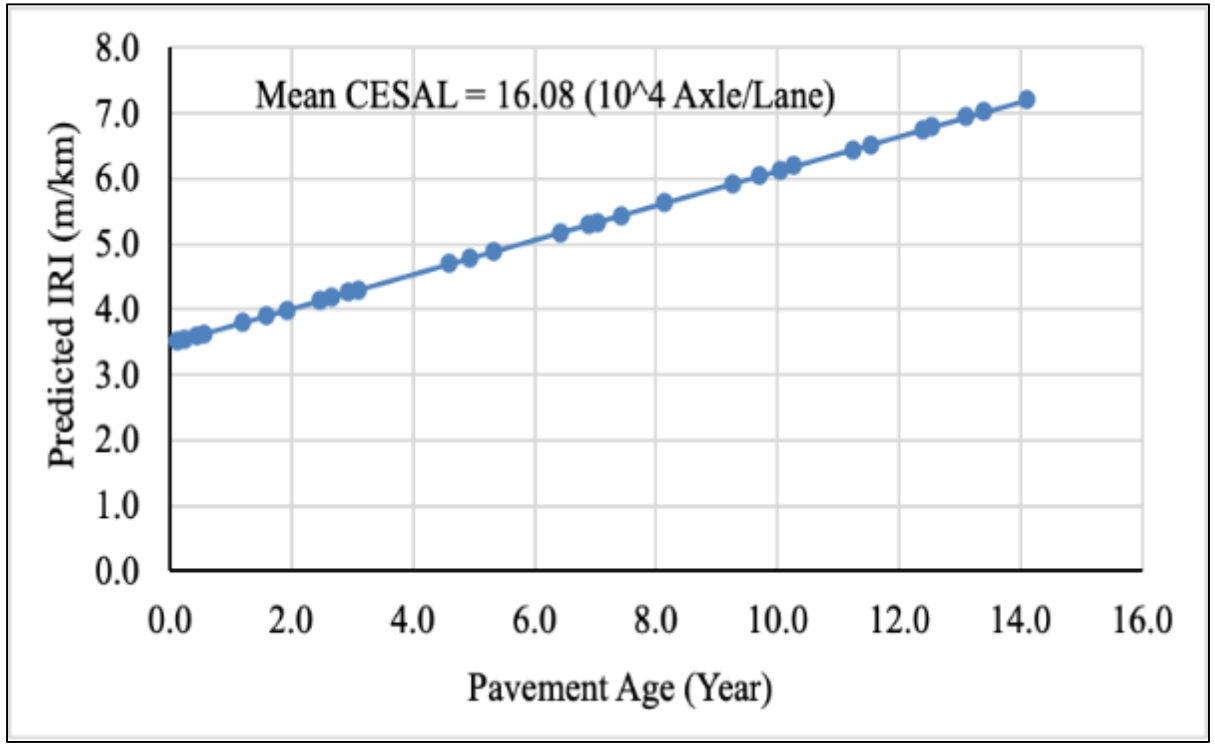
It's evident that the variance Inflation Factor (VIF) is always greater than 1

## ANOVA Results of the models

| | df | SS | MS | F | Significance F |
|---|---|---|---|---|---|
| **DBST Model** | | | | | |
| Regression | 2 | 407.057 | 203.529 | 874.978 | 3.6858 E-103 |
| Residual | 212 | 49.313 | 0.233 | | |
| Total | 214 | 456.370 | | | |
| **AC Model** | | | | | |
| Regression | 2 | 82.00 | 41.00 | 253.548 | 8.0861 E-39 |
| Residual | 95 | 15.362 | 0.162 | | |
| Total | 97 | 97.362 | | | |

The values of "Significance F" are less than 0.05 for both models, hence the developed models are significant.

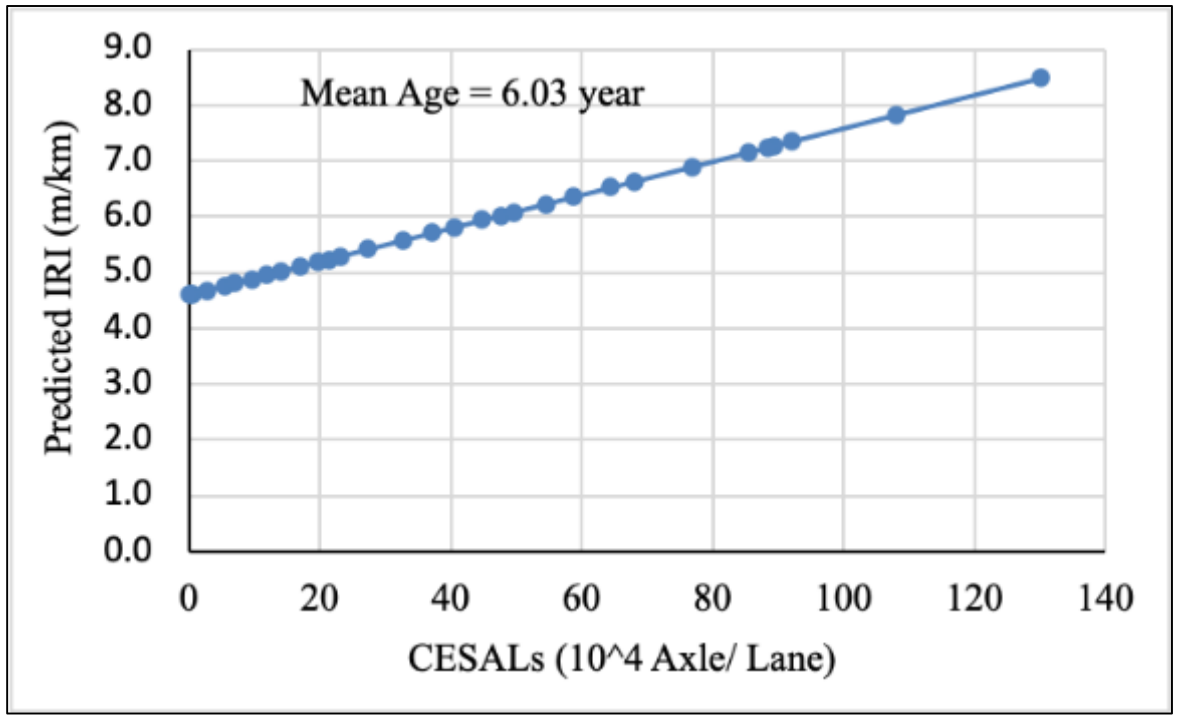
# 6- Sensitivity Analysis of IRI Models



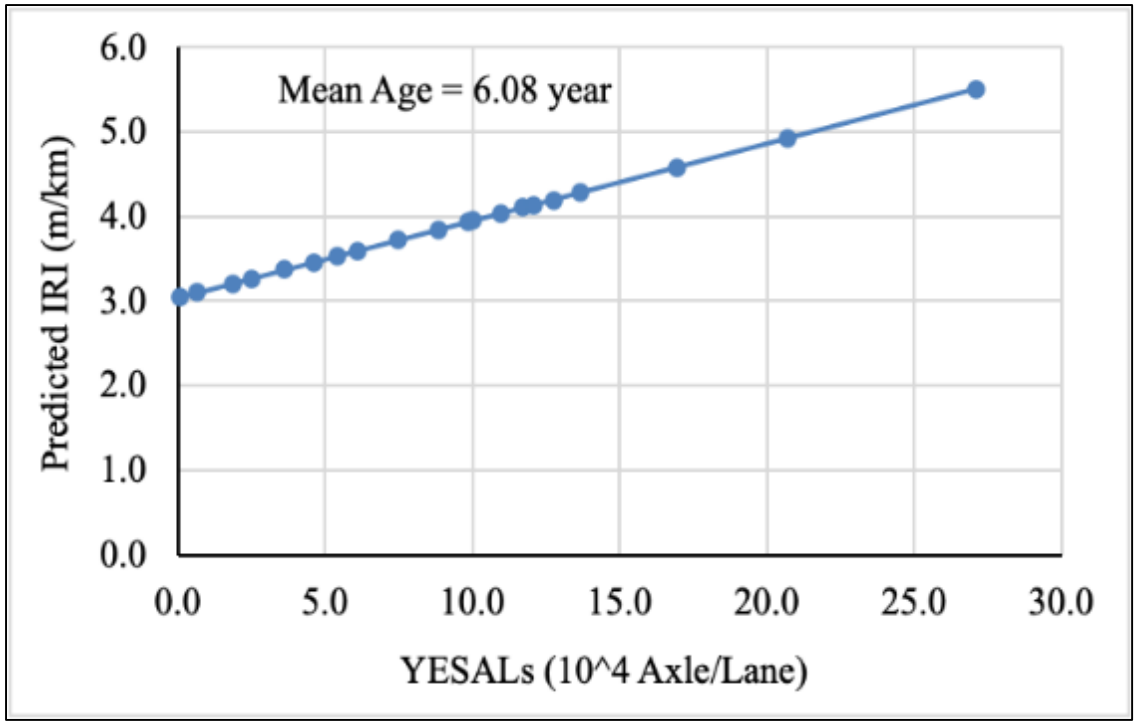

Plot of pavement age and the corresponding IRI for the **DBST** proposed model


Plot of pavement age and the corresponding IRI for the **AC** proposed model

**The steepness of the line indicates the sensitivity of the models for even a small change in pavement age value. It can be observed that IRI value in DBST model increases by 0.26 m/km and by 0.205 m/km in AC model when the age value increases by one year.**



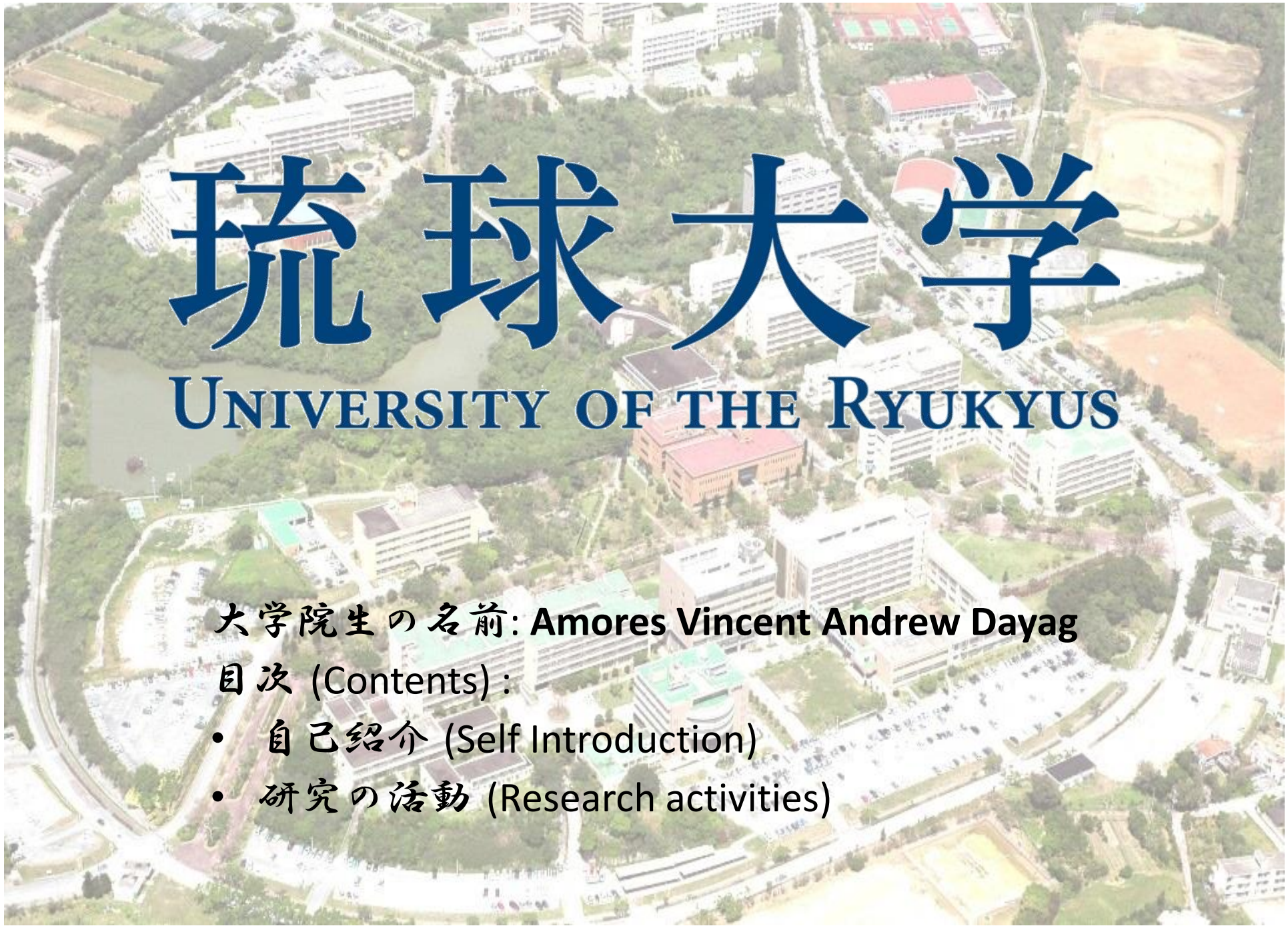

Plot of traffic loads and the corresponding IRI for the **DBST** proposed model




Plot of traffic loads and the corresponding IRI for the **AC** proposed model

**The steepness of the line indicates the sensitivity of the models for even a small change in traffic loads value. It can be observed that IRI value in DBST model increases by 0.03 m/km when the CESAL value increases by 10^4 axle/lane, and by 0.091 m/km in AC model when the YESAL value increases by 10^4 axle/lane.**


Arigato gozaimasu




大学院生の名前: **Amores Vincent Andrew Dayag**

目次 (Contents) :

- 自己紹介 (Self Introduction)
- 研究の活動 (Research activities)

Amores Vincent Andrew Dayag

Philippines

Affiliation ： Department of Public Works and Highways
University：University of the Ryukyus
Duration：2019.4-2021.3

I love exploring places with my friend. We enjoyed the snow during the warm winter last year.

The changing seasons also provide balance between research and recreation.

**Reason for applying**

Through this program, I want to learn infrastructure maintenance of Japan which can help the Philippines.

**Research**

My research focuses on steel bridges. I am studying the effect of corrosion on friction joints as well as the distribution of pressure due to wind load. Additionally, I am trying to transcribe the *Anti-corrosion Manual of Steel Bridges in Okinawa*.

**Prospect**

I plan to share the details and results of my research with my superiors and colleagues in the Philippines.

**Daily life**

For more than a year, I have been trying to learn Nihongo during rest days. しかしながら、漢字が難しいので、今でもまだあまりうまく使えません。

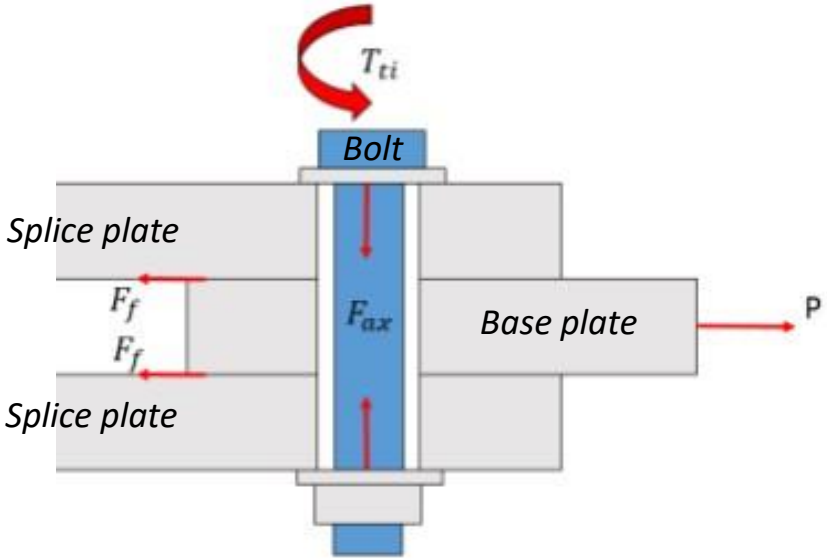
# EVALUATION OF REDUCED SLIP RESISTANCE DUE TO CORRODED SPLICE PLATE IN FRICTION JOINTS

# Background and purpose

Friction joints: vulnerable to corrosion.

*Uniform case*

*Ring case*




Corrosion of splice plate reduces slip strength.

$$F_f = \mu \cdot F_a \cdot n$$

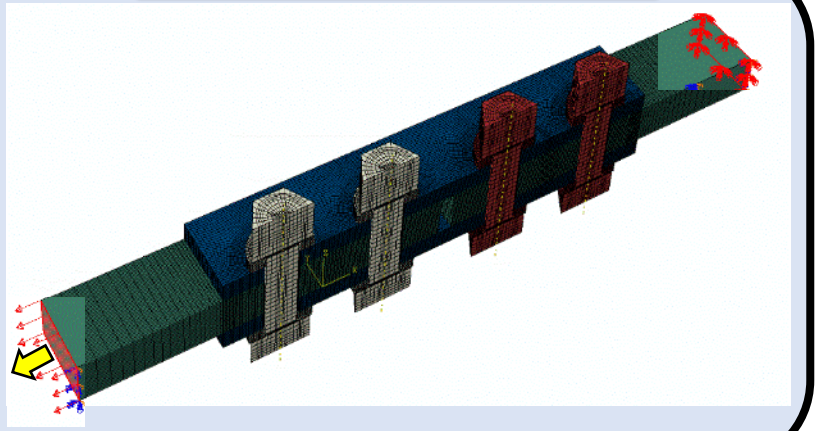
Mechanism of the reduction is not yet clear.

Study corrosion – slip strength relationship.

# Research flow

## Conduct Experiment


## FEM Analysis



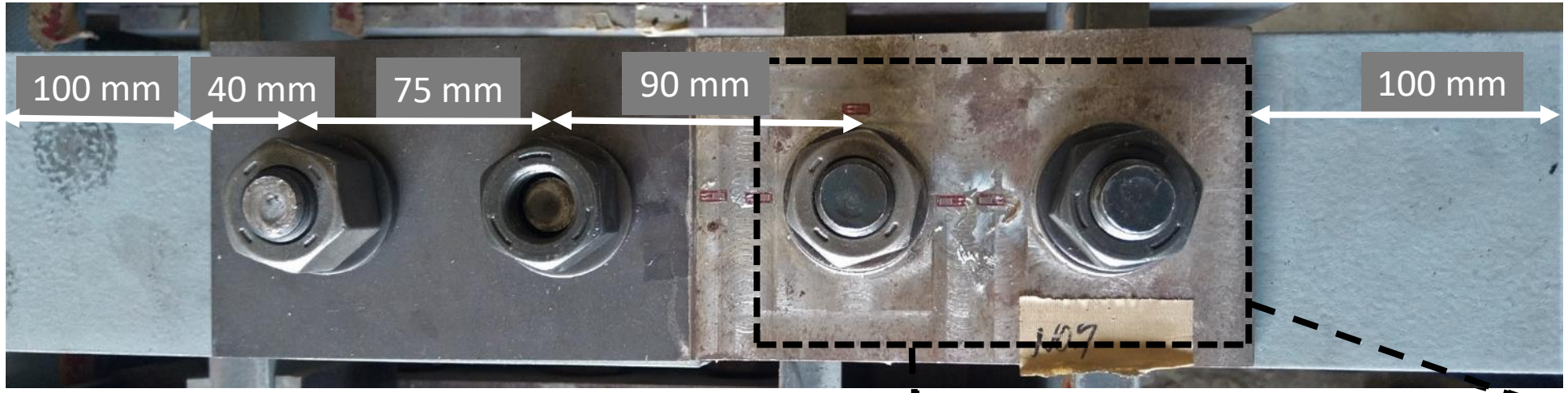
## Change Parameters

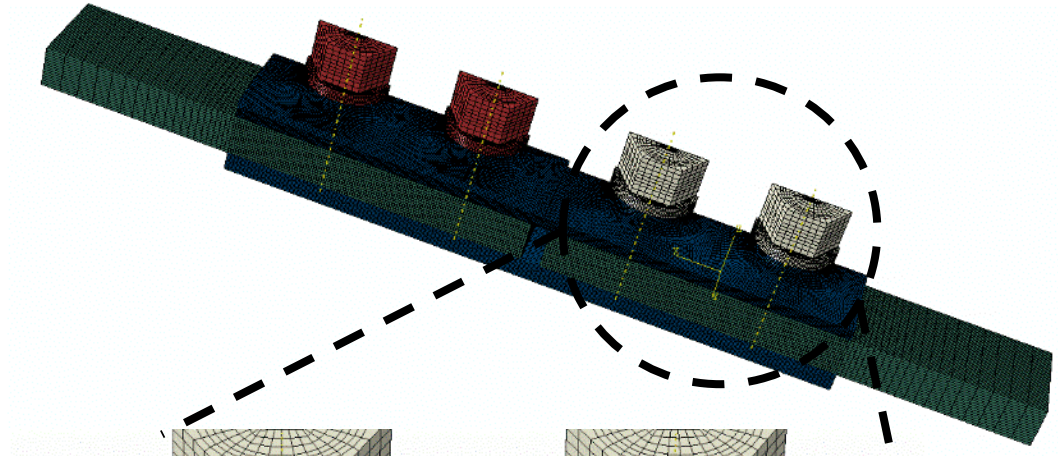
- Bolt axial force
- Corrosion depth and shape
- Coefficient of friction

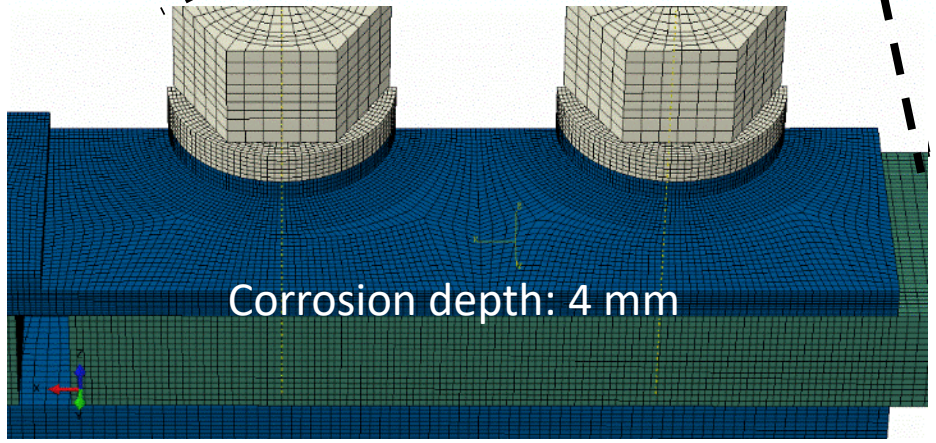
## Establish evaluation method

- Develop linear equation from results
- Introduce slip strength adjustment factor due to corrosion

# Experiment samples and analysis models



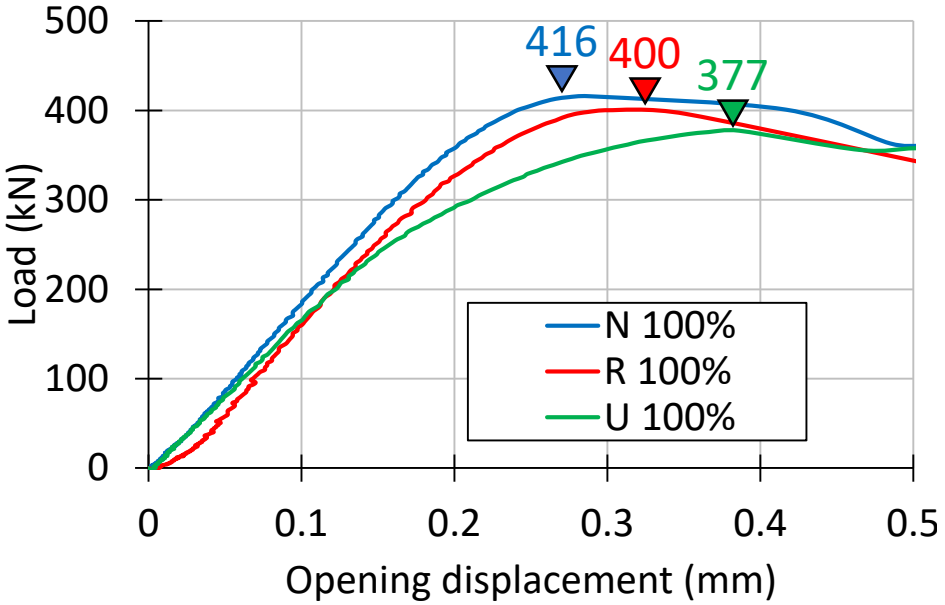



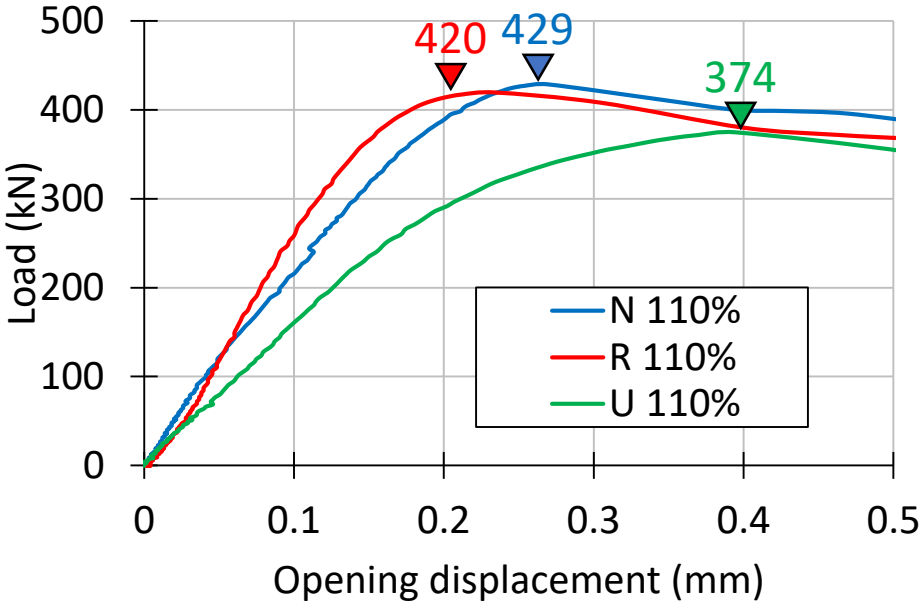


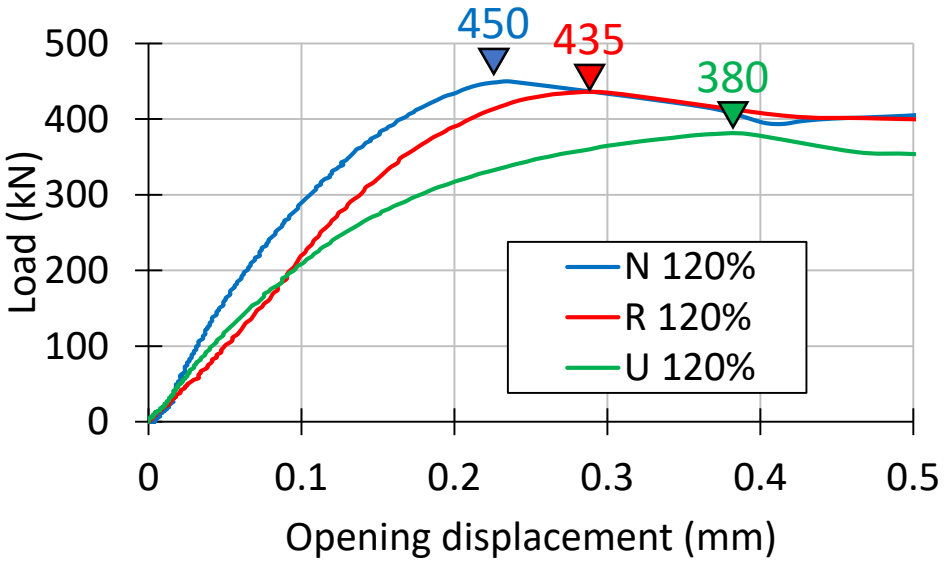

Uniform corrosion case: ***U***

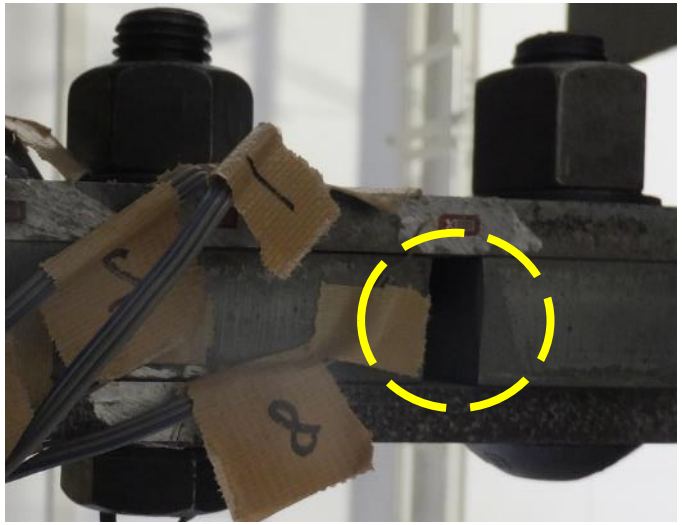
Three cases under consideration: No corrosion (**N**), Ring corrosion (**R**), and Uniform corrosion (**U**)

# Experiment results



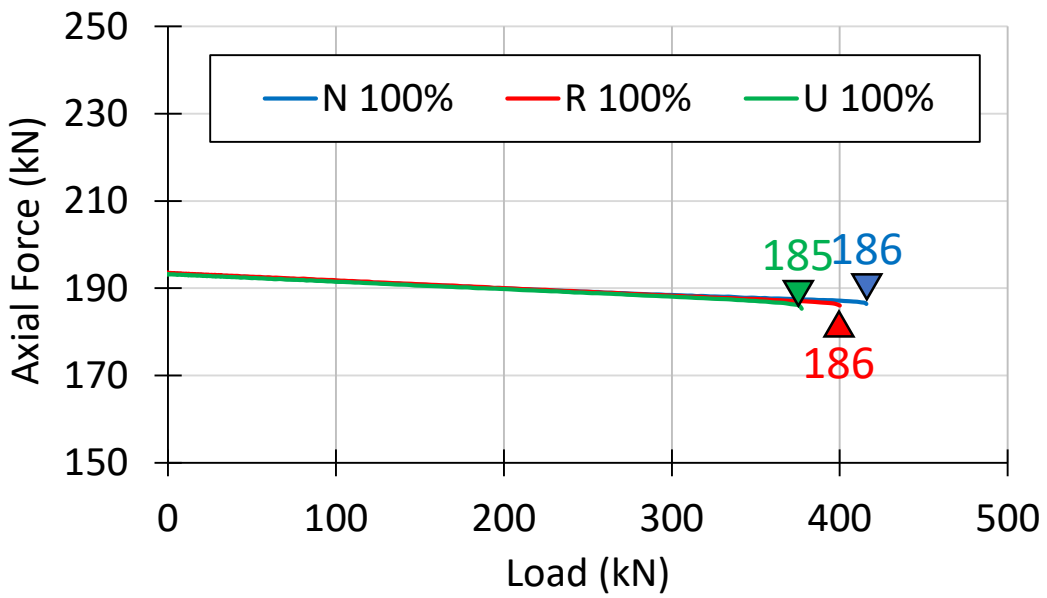



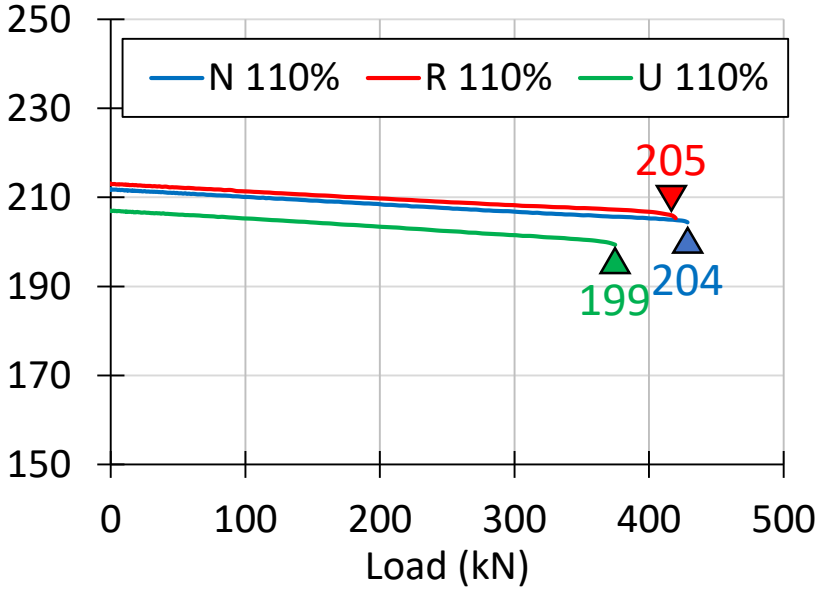



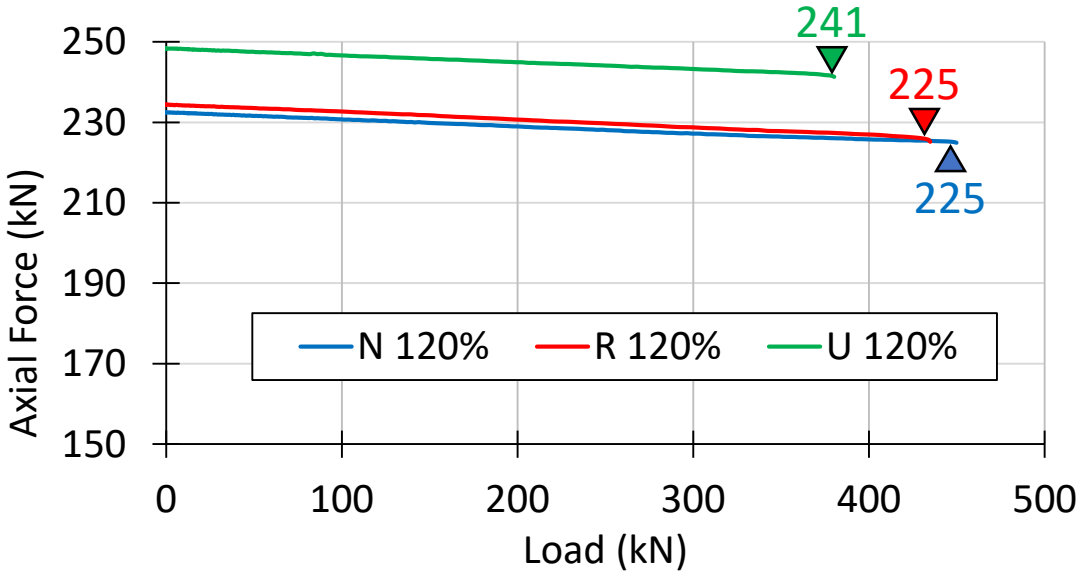



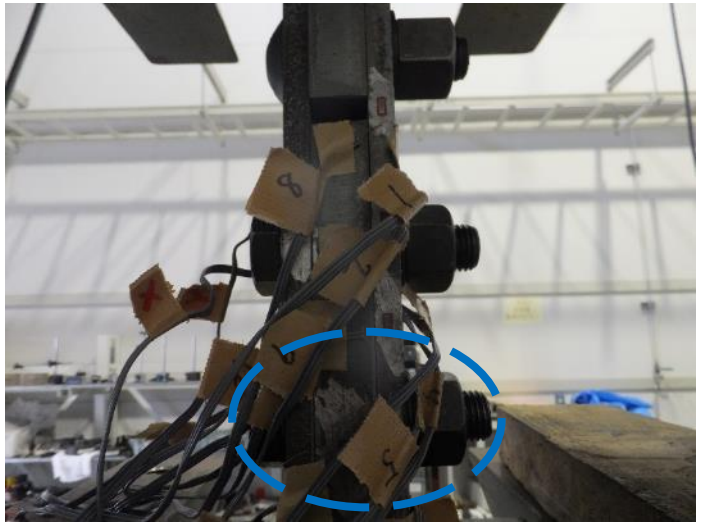
Cases with corrosion have larger opening displacements.

# Axial force (outside bolt)



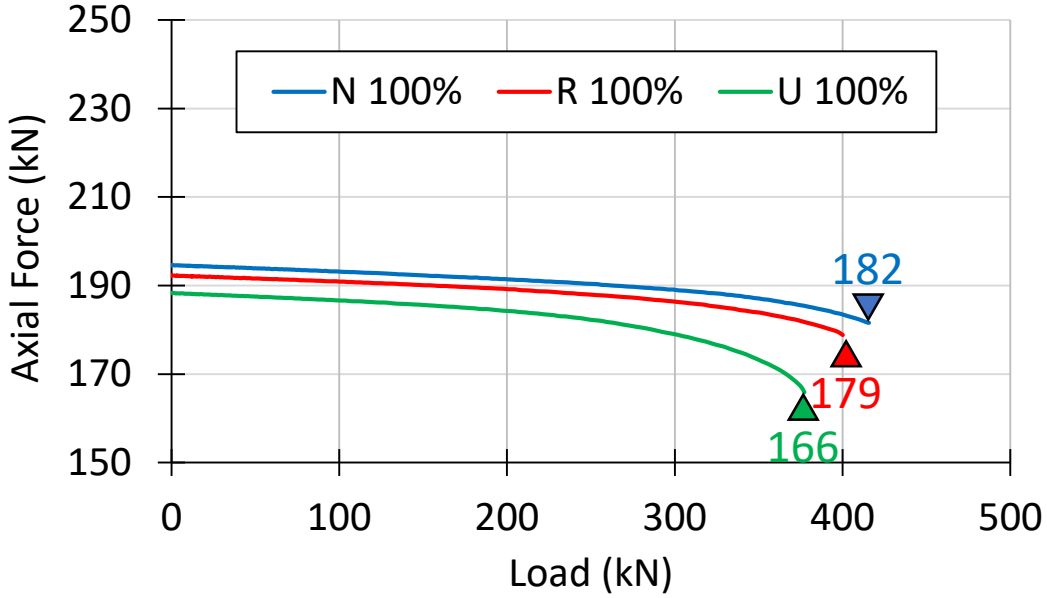



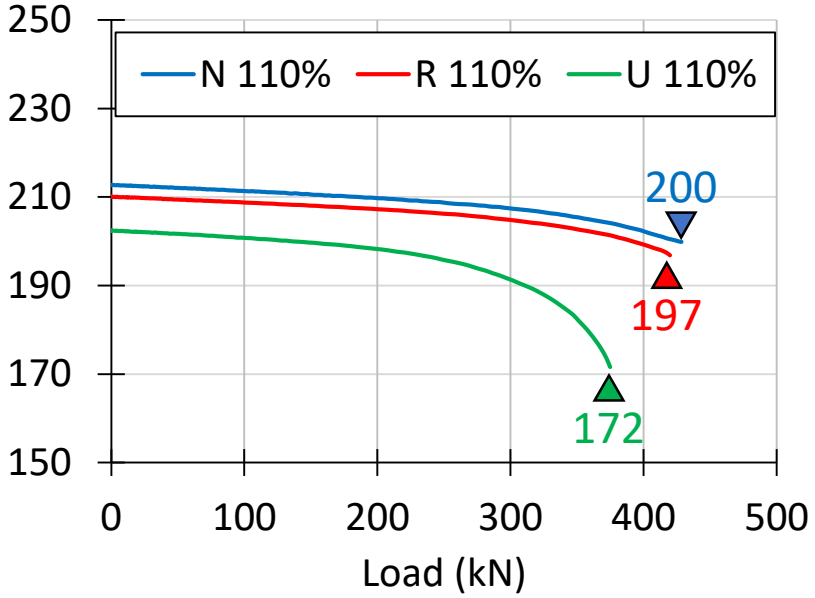



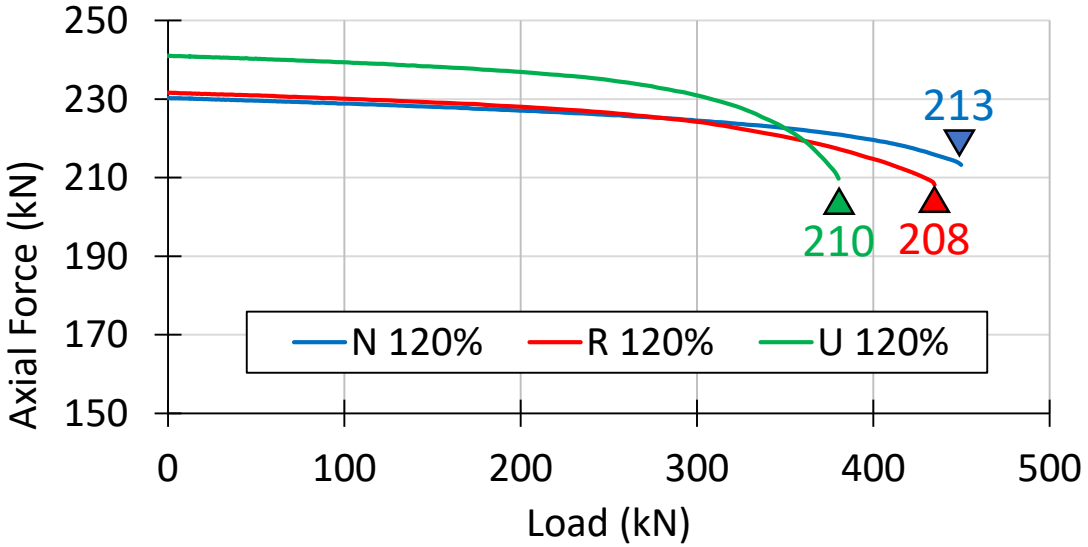



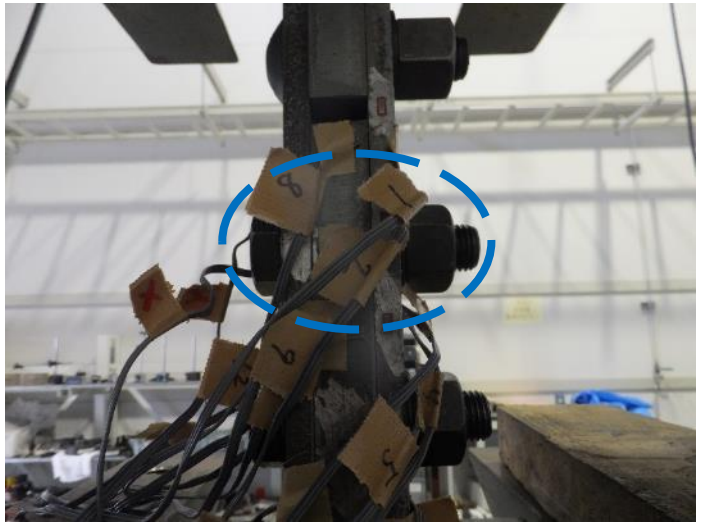
All cases have almost the same reduction.

# Axial force (inside bolt)



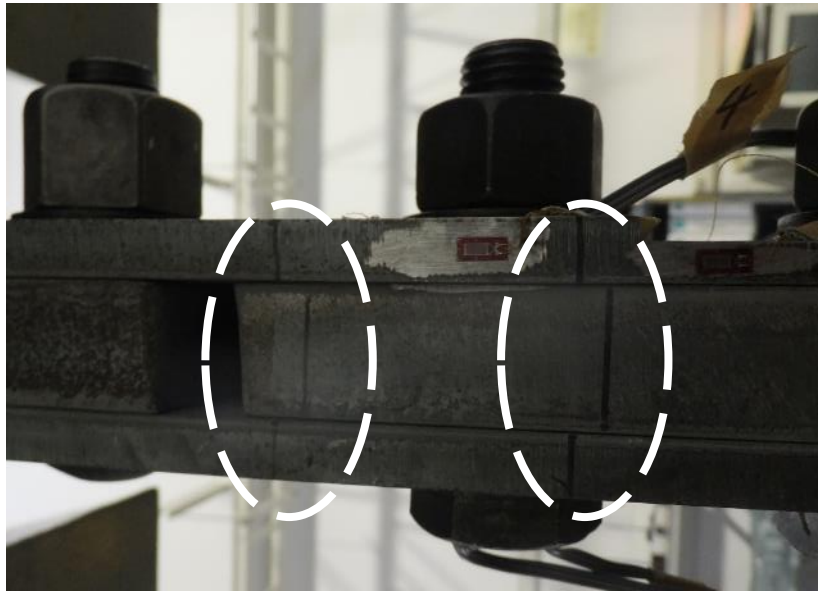



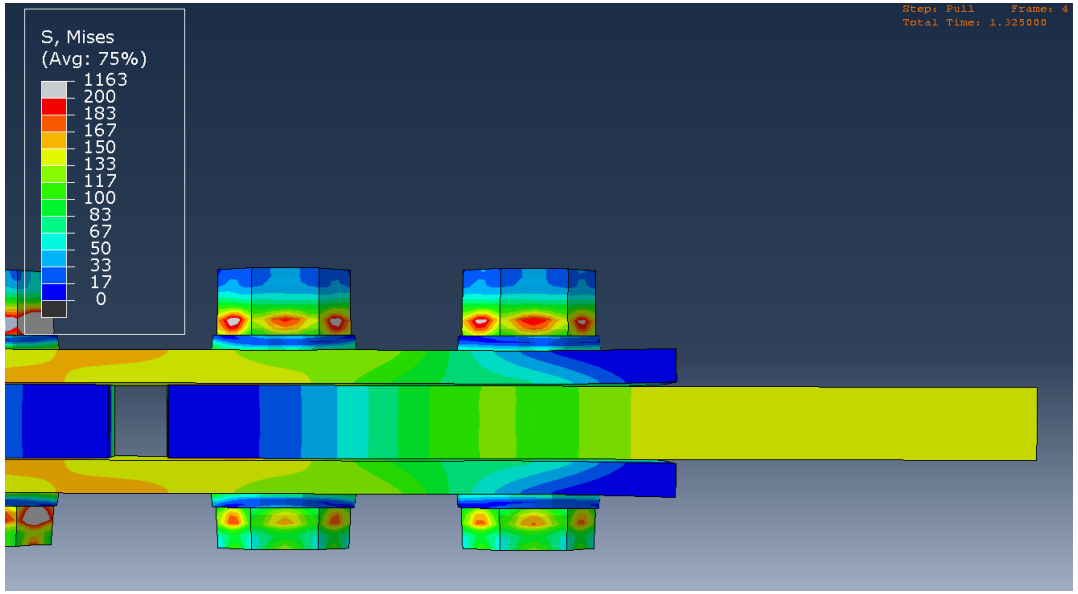



No and ring cases are similar. Uniform case has significant reduction.

# Experiment and analysis results





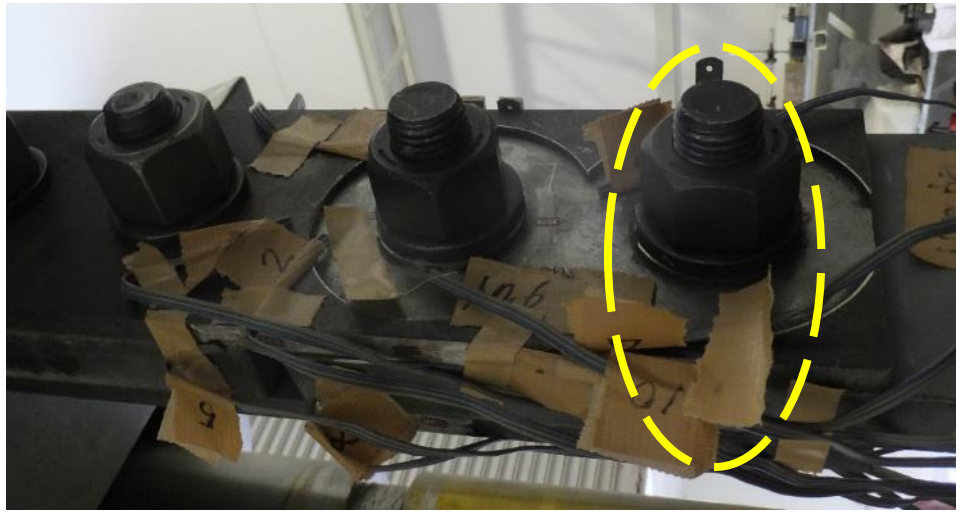

| Case | Slip strength (kN) | | |
|---|---|---|---|
| | 100% AF | 110% AF | 120% AF |
| ***N*** | 416 | 426 | 450 |
| ***R*** | 400 | 420 | 435 |
| ***U*** | 377 | 375 | 380 |

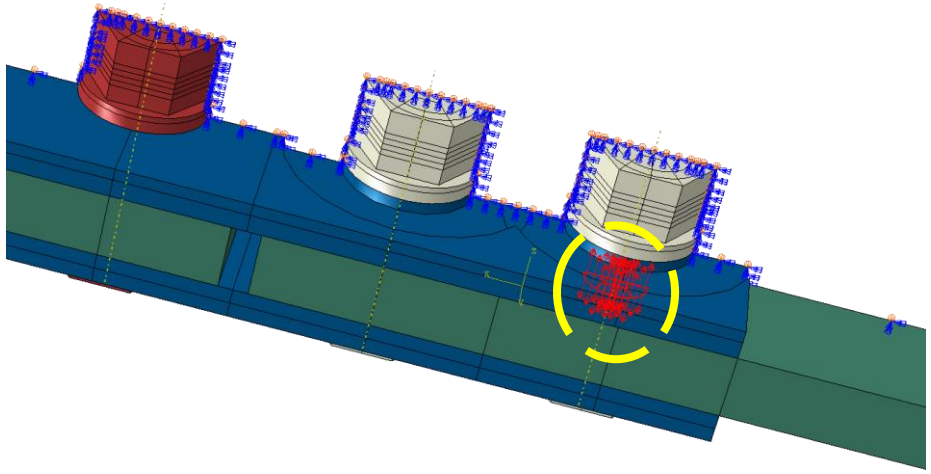
| Case | Slip strength (kN) | | |
|---|---|---|---|
| | 100% AF | 110% AF | 120% AF |
| ***N*** | 415 | 429 | 448 |
| ***R*** | 395 | 411 | 433 |
| ***U*** | 380 | 383 | 380 |

| Accuracy |
|---|
| 99.54% |
| 98.72% |
| 99.02% |

Stiffness in FEM is slightly different, but slip strength is accurate.

# Axial force (outside bolt)





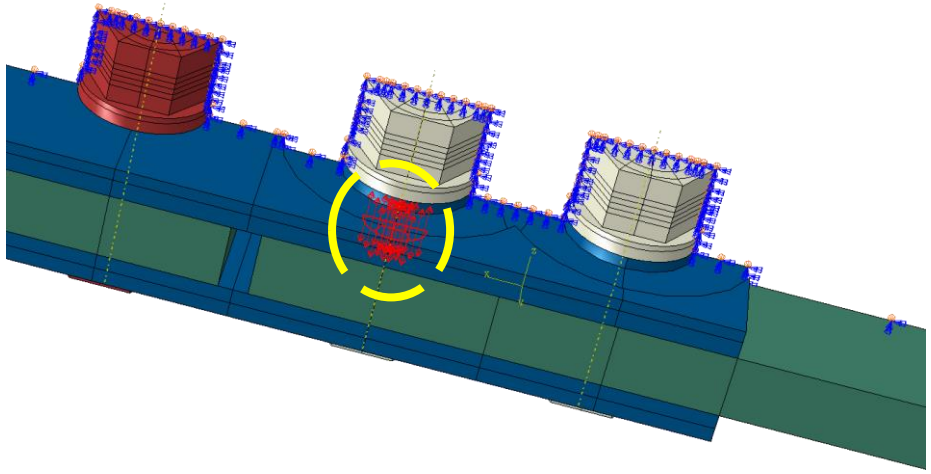
| Case | Axial force during slip (kN) | | |
|---|---|---|---|
| | 100% AF | 110% AF | 120% AF |
| ***N*** | 186 | 204 | 225 |
| ***R*** | 186 | 205 | 225 |
| ***U*** | 185 | 199 | 241 |

| Case | Axial force during slip (kN) | | |
|---|---|---|---|
| | 100% AF | 110% AF | 120% AF |
| ***N*** | 185 | 203 | 222 |
| ***R*** | 185 | 203 | 223 |
| ***U*** | 185 | 198 | 238 |

| Accuracy |
|---|
| 99.21% |
| 99.20% |
| 99.42% |

Experiment and FEM results for all cases are almost the same.

# Axial force (inside bolt)



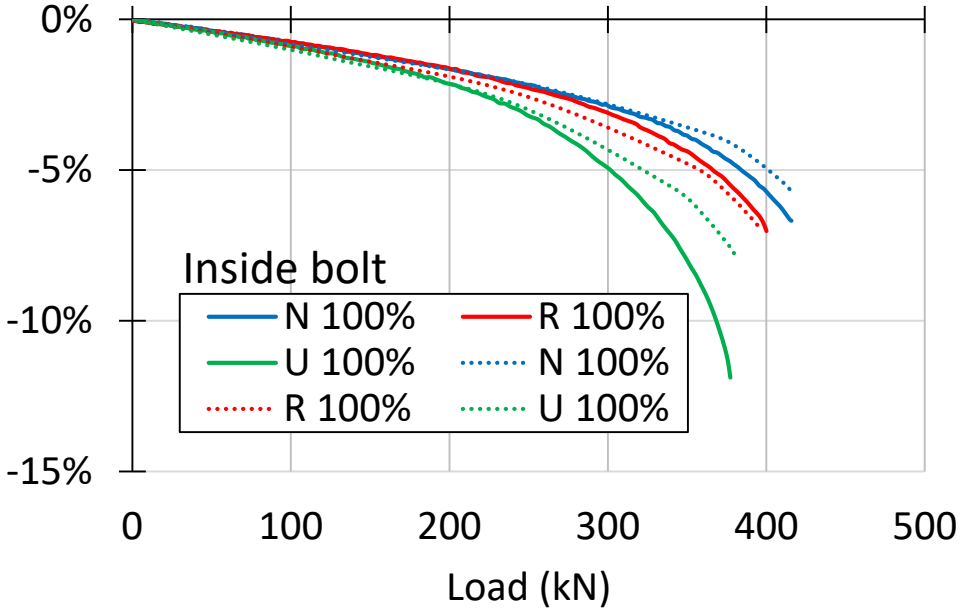
| Case | Axial force during slip (kN) | | |
|---|---|---|---|
| | 100% AF | 110% AF | 120% AF |
| ***N*** | 182 | 200 | 213 |
| ***R*** | 179 | 197 | 208 |
| ***U*** | 166 | 172 | 210 |

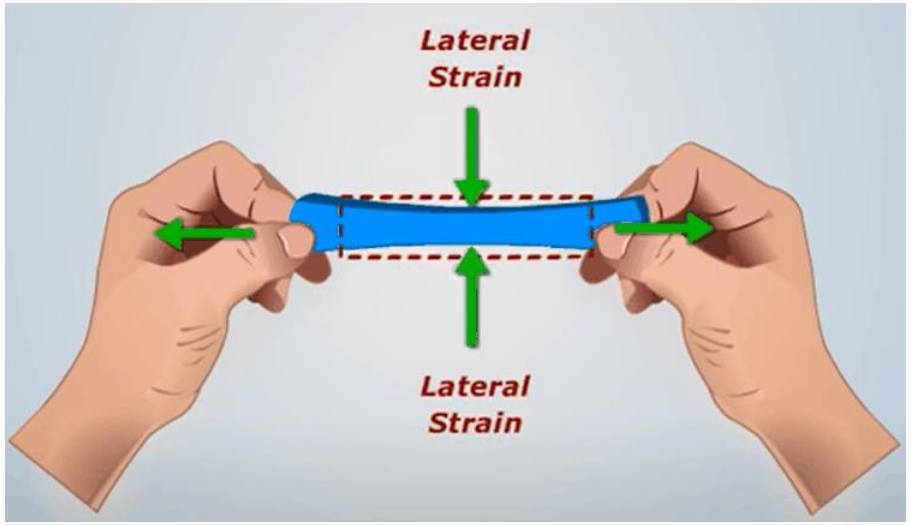
| Case | Axial force during slip (kN) | | |
|---|---|---|---|
| | 100% AF | 110% AF | 120% AF |
| ***N*** | 184 | 200 | 216 |
| ***R*** | 179 | 195 | 213 |
| ***U*** | 174 | 186 | 222 |

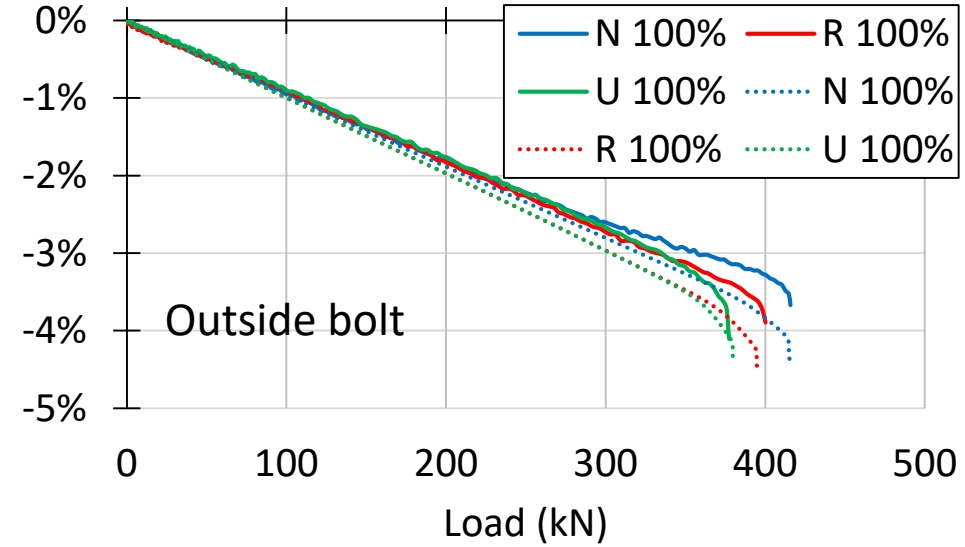
| Accuracy |
|---|
| 99.16% |
| 98.86% |
| 93.78% |

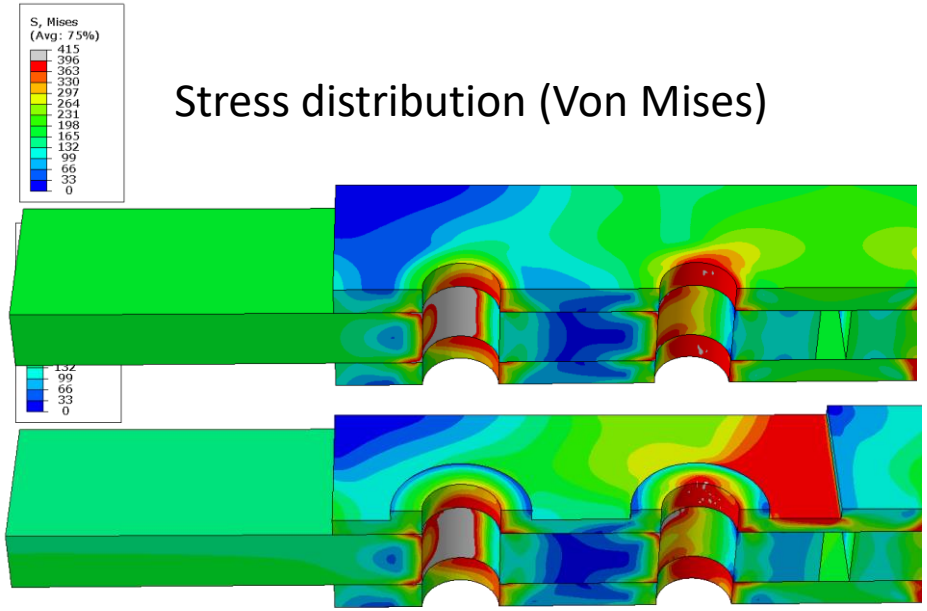
Uniform corrosion case has lower accuracy compared to other cases.

# Axial force reduction




Inside bolt has considerable reduction due to yielding.

## まとめ (Summary)

- Experiments were conducted to gather baseline data for reference.
- Analysis models established using Abaqus produced good results.
- Yielding of corroded splice plate causes considerable reduction of bolt axial force.
- The analysis can estimate the slip strength of actual friction joints before and after corrosion.

## Future activities

- Use multiple parameters and plot the results to introduce an adjustment factor.

$$Slip\ strength = \mu \cdot \sum Bolt\ axial\ force \cdot n \cdot [Adjustment\ factor]$$

ご清聴ありがとうございました。

Thank you for listening.