



**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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Mr. Md Golam Mostofa



Bangladesh

Affiliation : Ministry of Road Transport and Bridges  
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**

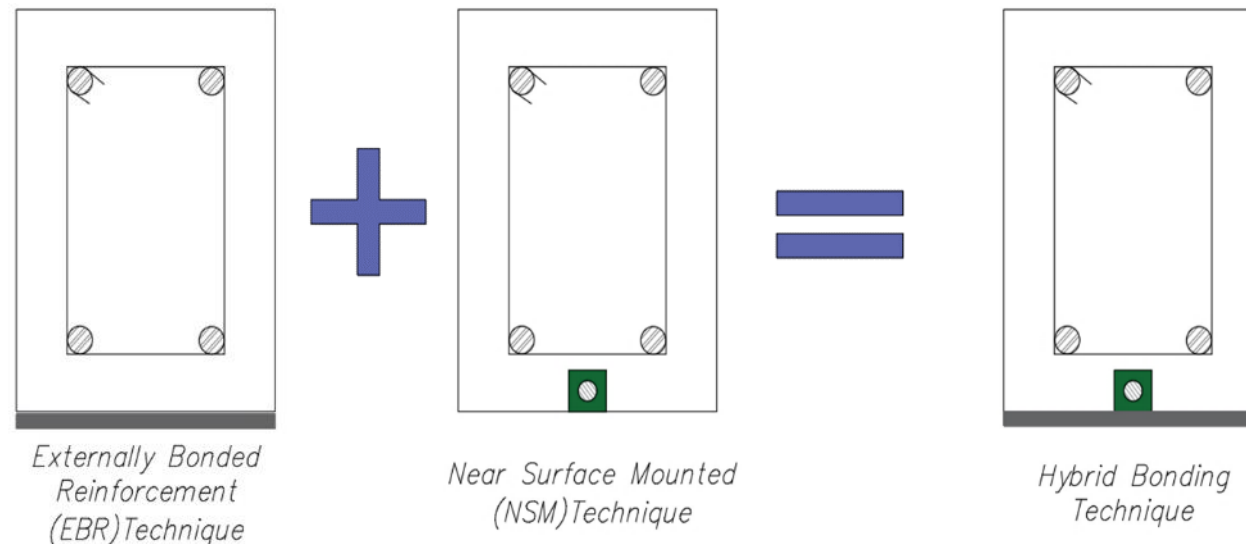
After graduation, I will continue to research in my country and contribute to the strengthening of the existing bridge infrastructures with a low cost solution.

## **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.





# 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!

# 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



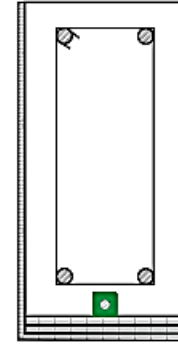
*Fig: CB*



*HP9F1*



*HP9F2*

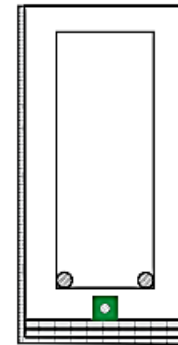


*HP9F2A*

*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

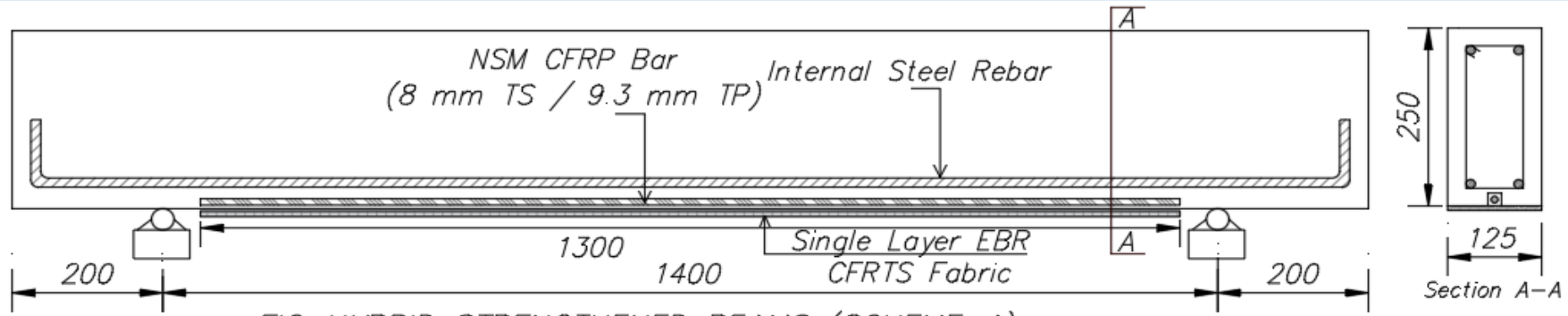


FIG: HYBRID STRENGTHENED BEAMS (SCHEME-1)

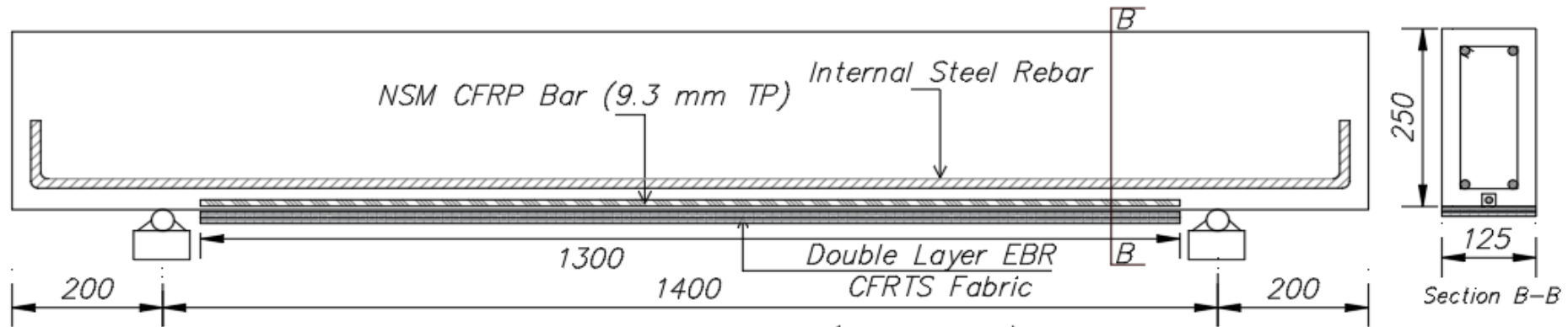


FIG: HYBRID STRENGTHENED BEAMS (SCHEME-2)

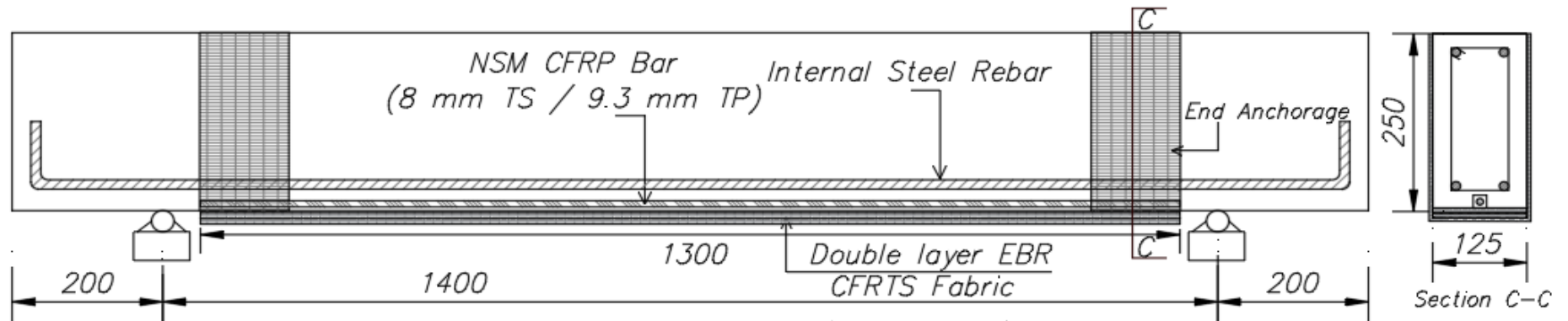


FIG: HYBRID STRENGTHENED BEAMS (SCHEME-3)

# Specimen and material properties

W/C(%)	s/a(%)	Mix composition (kg/m <sup>3</sup> )				
		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)	$\geq 80$
	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 $\pm$ 1°C, 7 days	Bending strength (Mpa)	$\geq 40$
	Tensile strength (MPa)	$\geq 30$
	Tensile shear strength (MPa)	$\geq 12.5$
Epoxy primer	Viscosity (mPa·s)( at 23°C)	400

# Internal steel and strengthening material



Fig: Rebar framework



Fig: CF RTP bar( $\varnothing = 9.3$  mm)



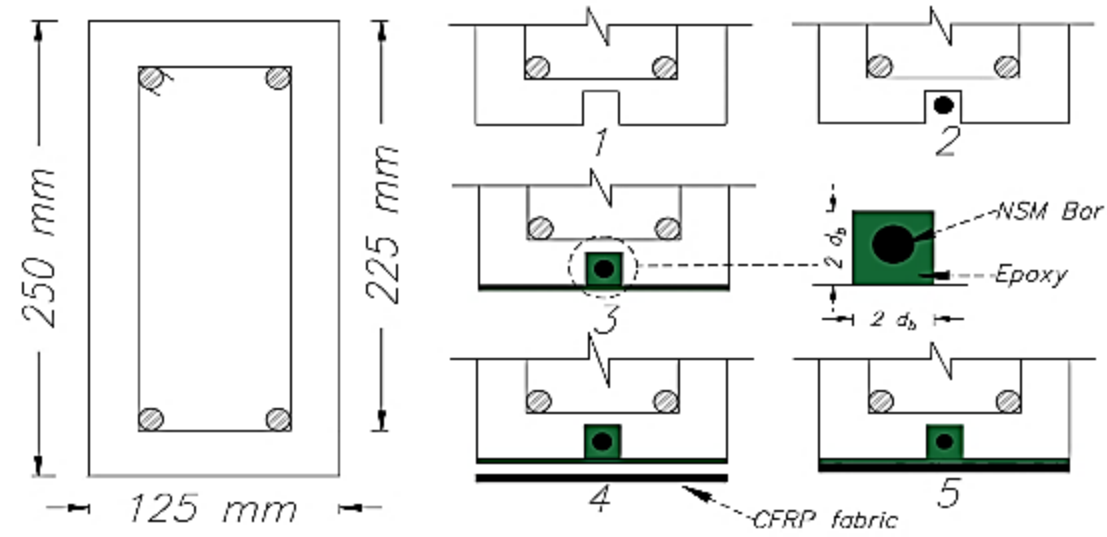
Fig: CF RTS bar( $\varnothing = 8$  mm)



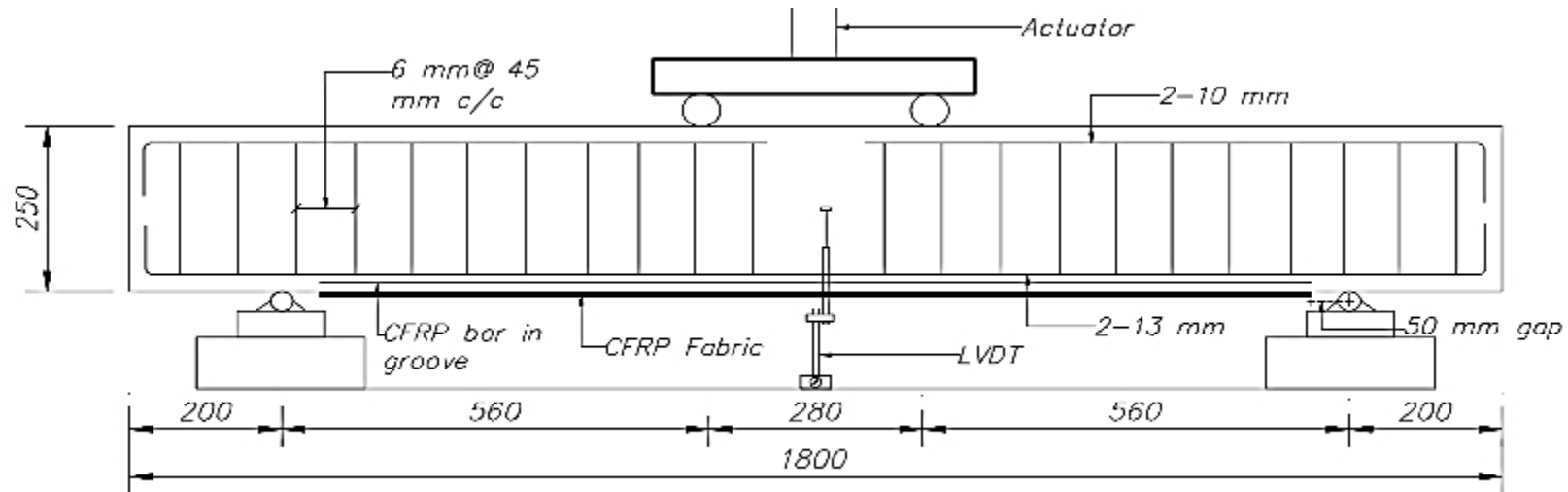
Fig: CF RTS Fabric (t=0.167 mm )



# 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

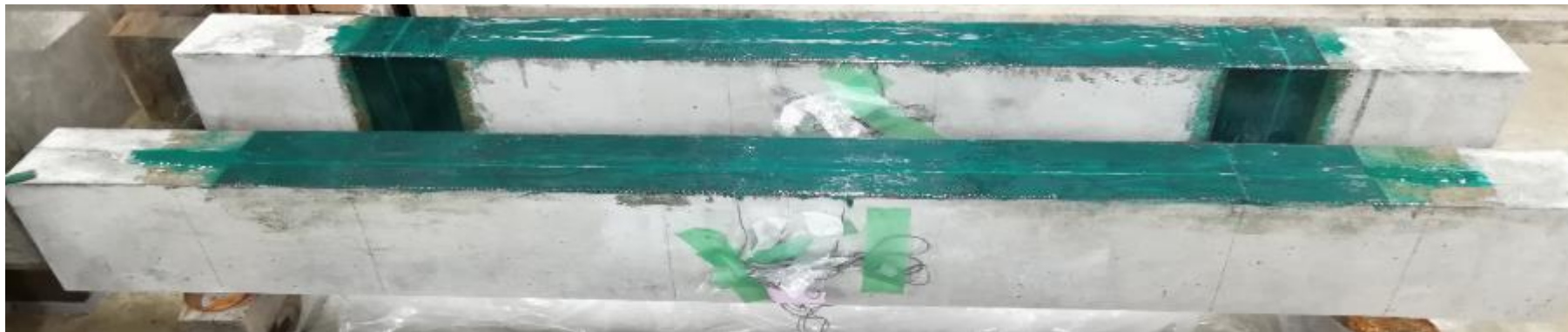


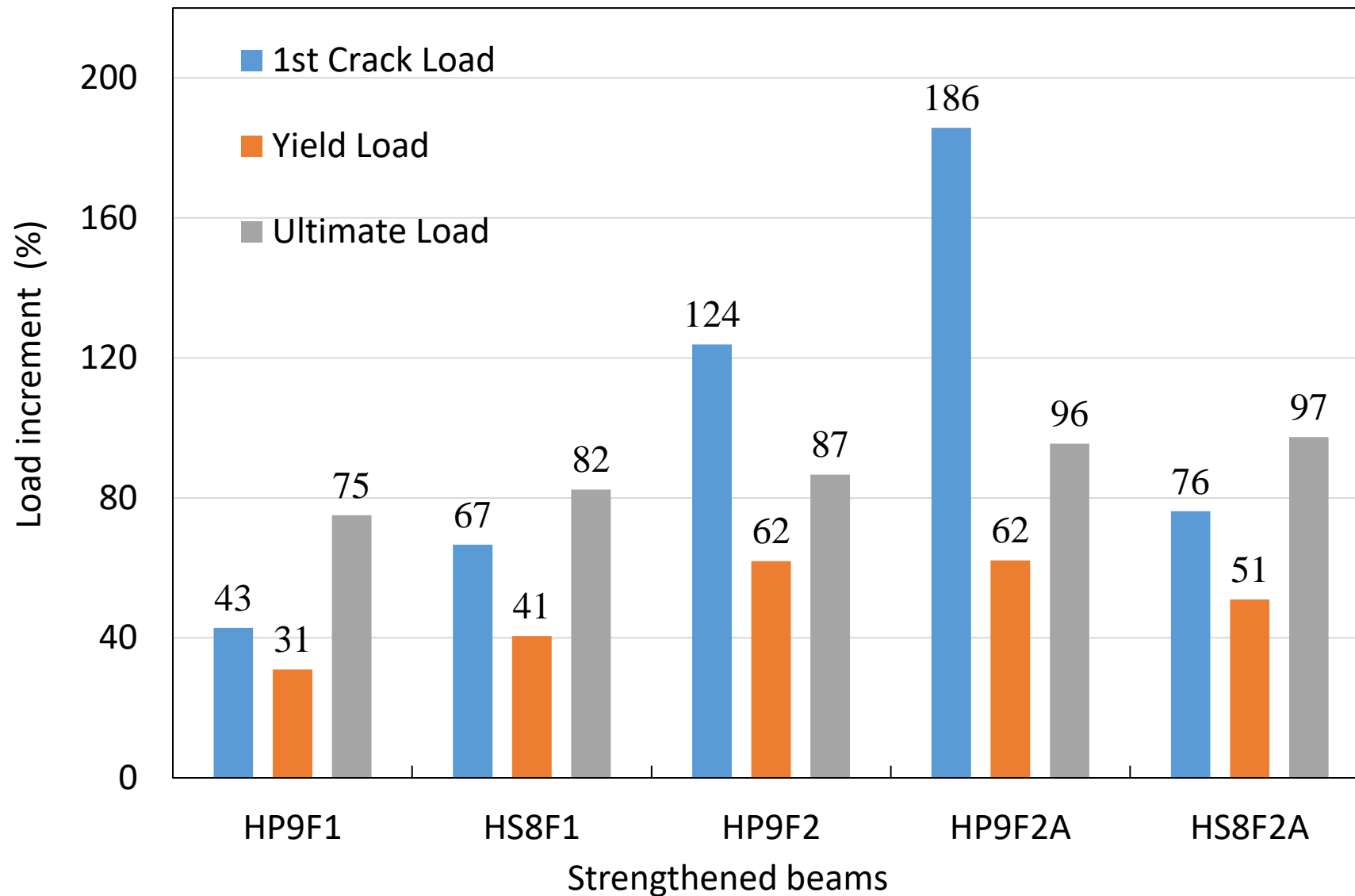
Fig: Attached EBR CFRP by Epoxy adhesive

## Result and Discussion

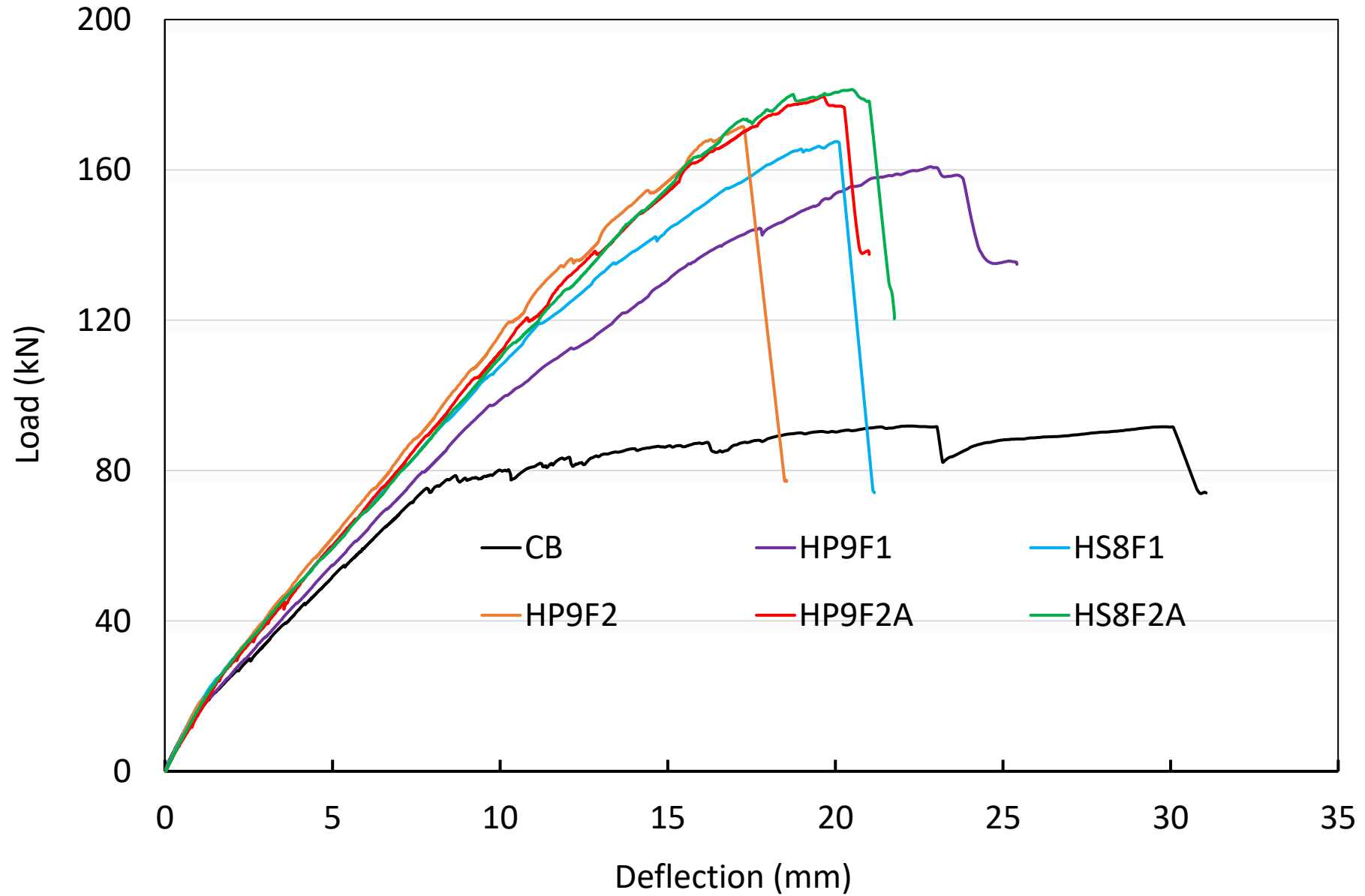
Beam ID	$P_{cr}$ (kN)	$\Delta_{cr}$ (mm)	$P_y$ (kN)	$\Delta_y$ (mm)	$P_u$ (kN)	$\Delta_u$ (mm)	Failure modes
CB	21	1.15	74	7.67	92	22.33	FFC
HP9F1	30	2.42	97	9.71	161	22.86	FFC
HS8F1	35	2.52	104	9.58	168	20.06	CS
HP9F2	47	3.60	120	10.49	172	17.26	CS
HP9F2A	60	5.00	121	11.00	180	19.63	CS
HS8F2A	37	2.75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

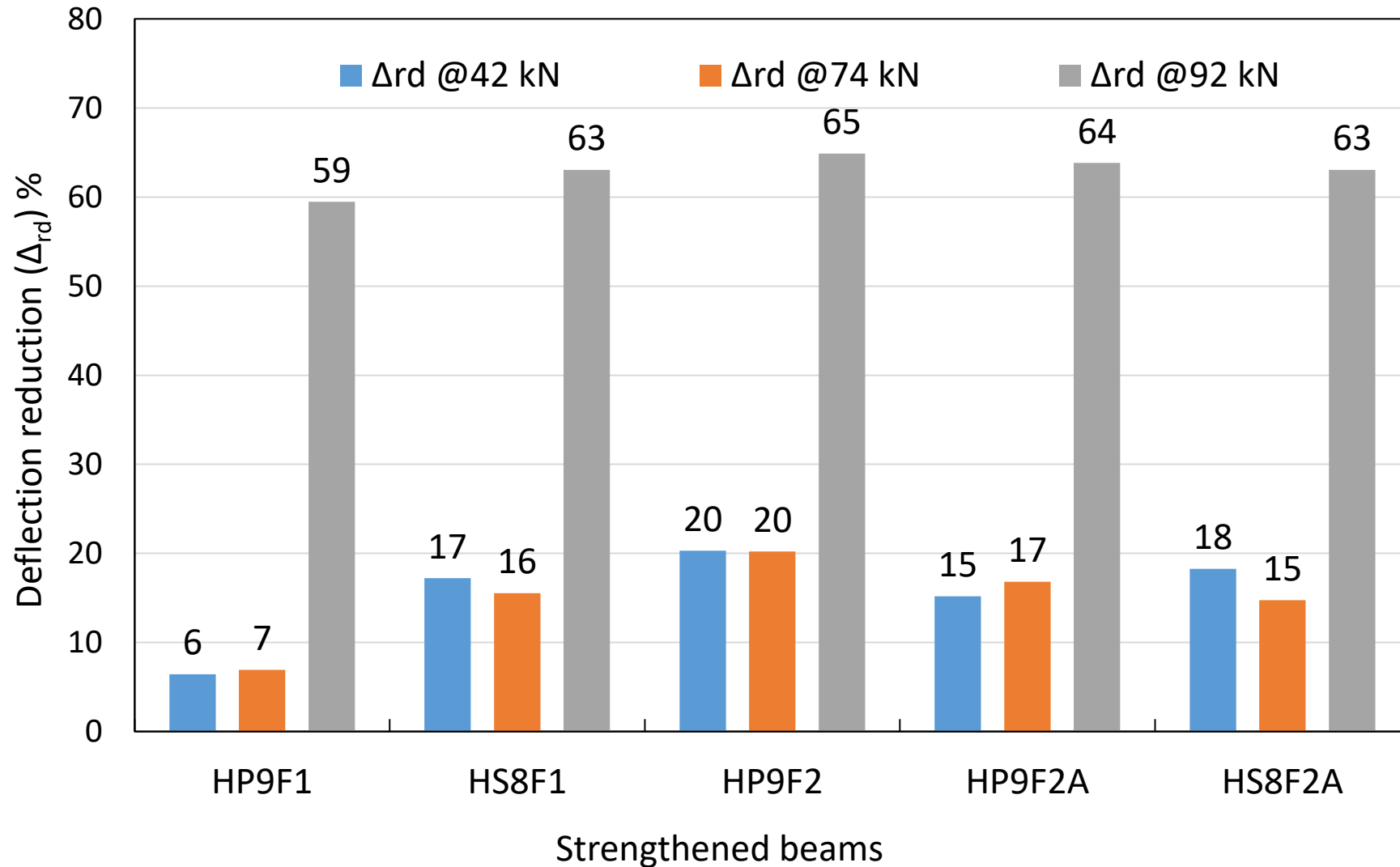
# Percentage Load Increment compared with Control Beam



# Load-deflection behavior

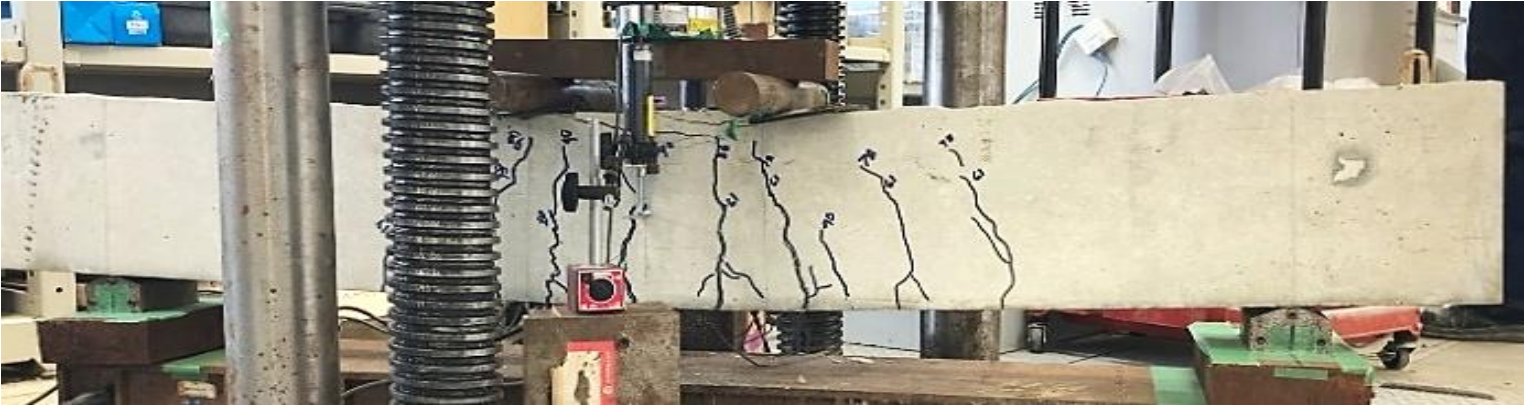


# Deflection reduction compared with Control Beam

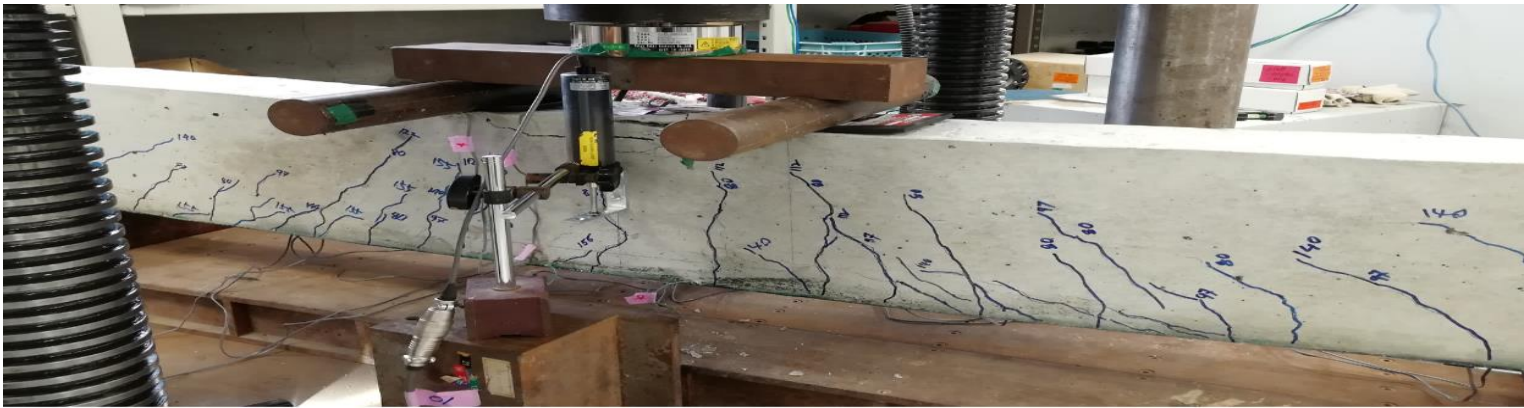




# Failure modes



**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

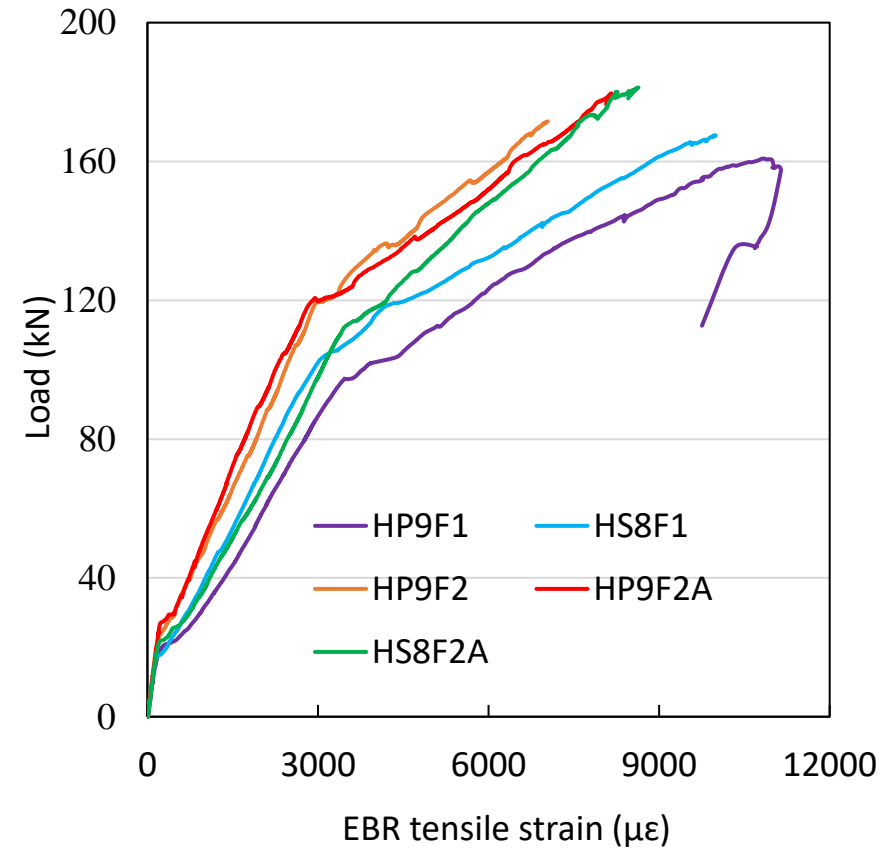
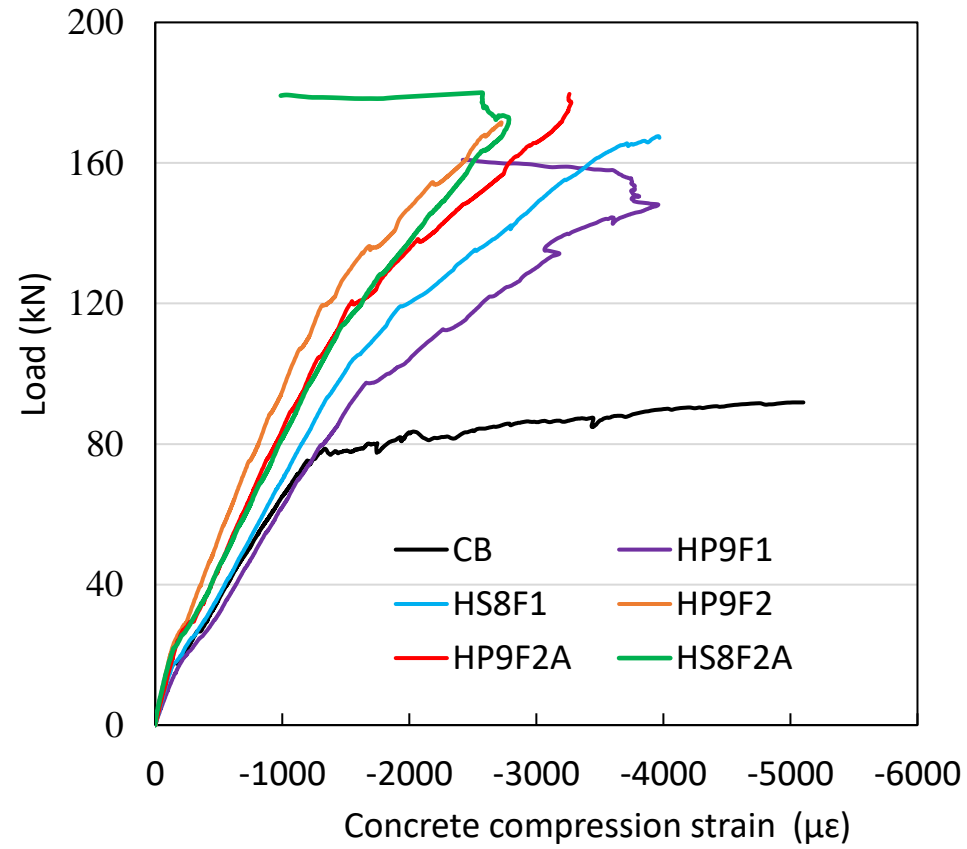
Beam ID	$S_{r,max}$ (mm)	$S_{r,min}$ (mm)	$S_{r,mean}$ (mm)	No. cracks
CB	172	48	93	10
HP9F1	117	13	48	27
HS8F1	125	10	53	22
HP9F2	171	15	54	24
HP9F2A	82	12	48	22
HS8F2A	78	16	39	25

Better Energy Dissipation

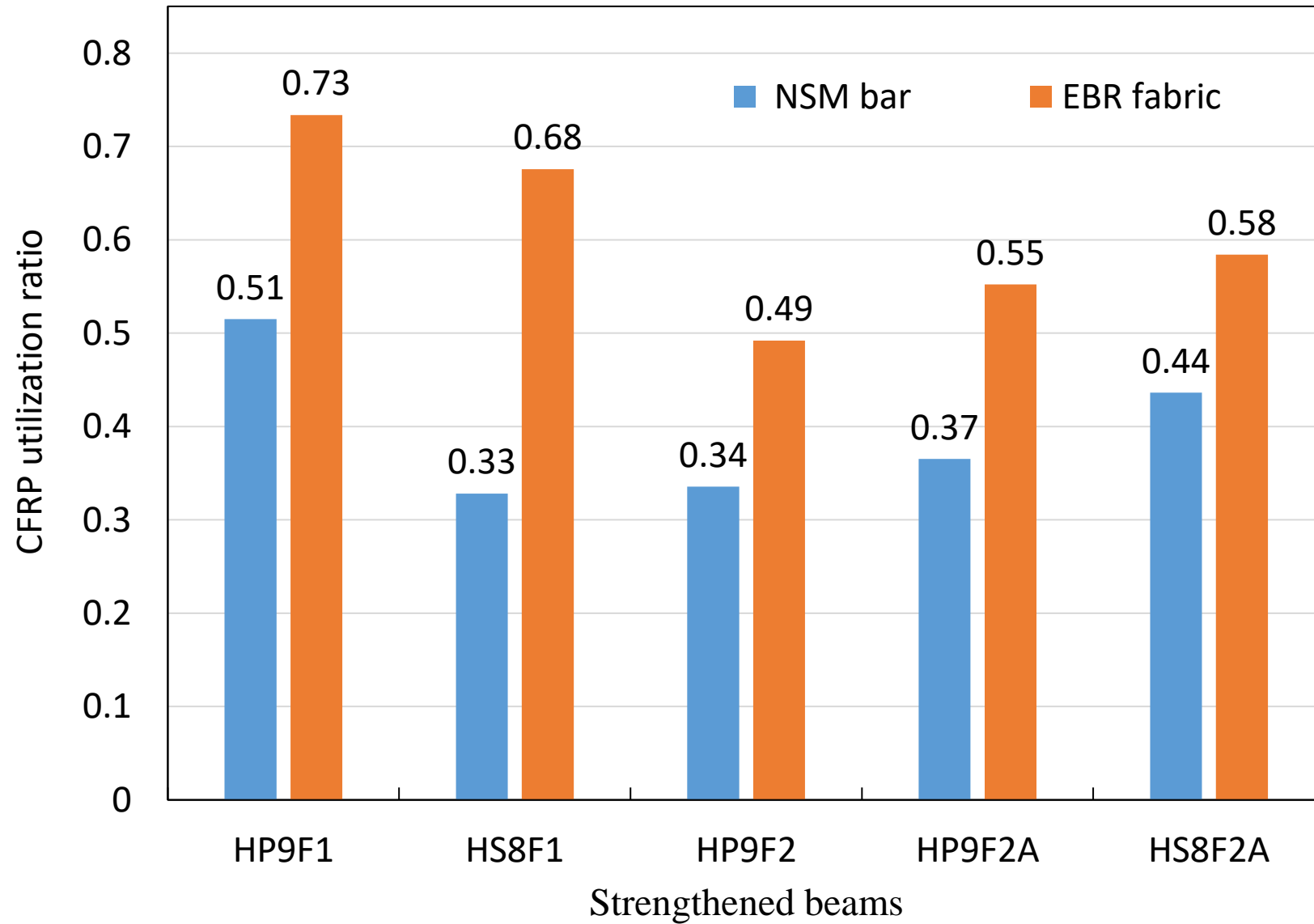
$S_{r,max}$  = Maximum crack spacing;  $S_{r,min}$  = Minimum crack spacing;  
 $S_{r,mean}$  = Average crack spacing



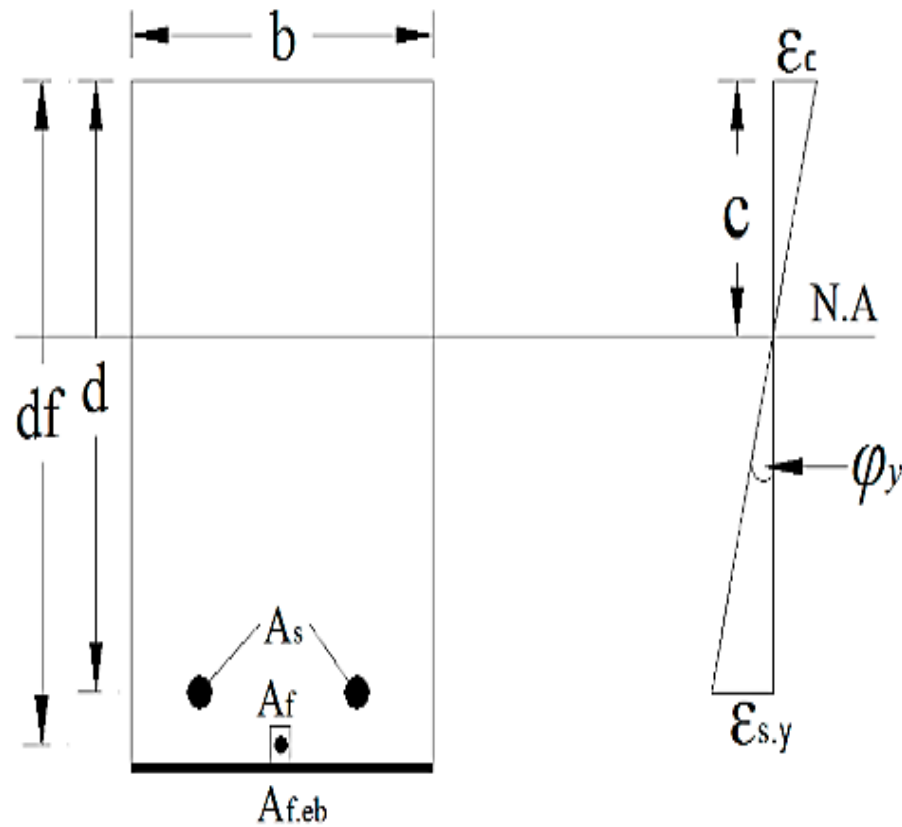
# CFRP tensile strain



# CFRP utilization ratio



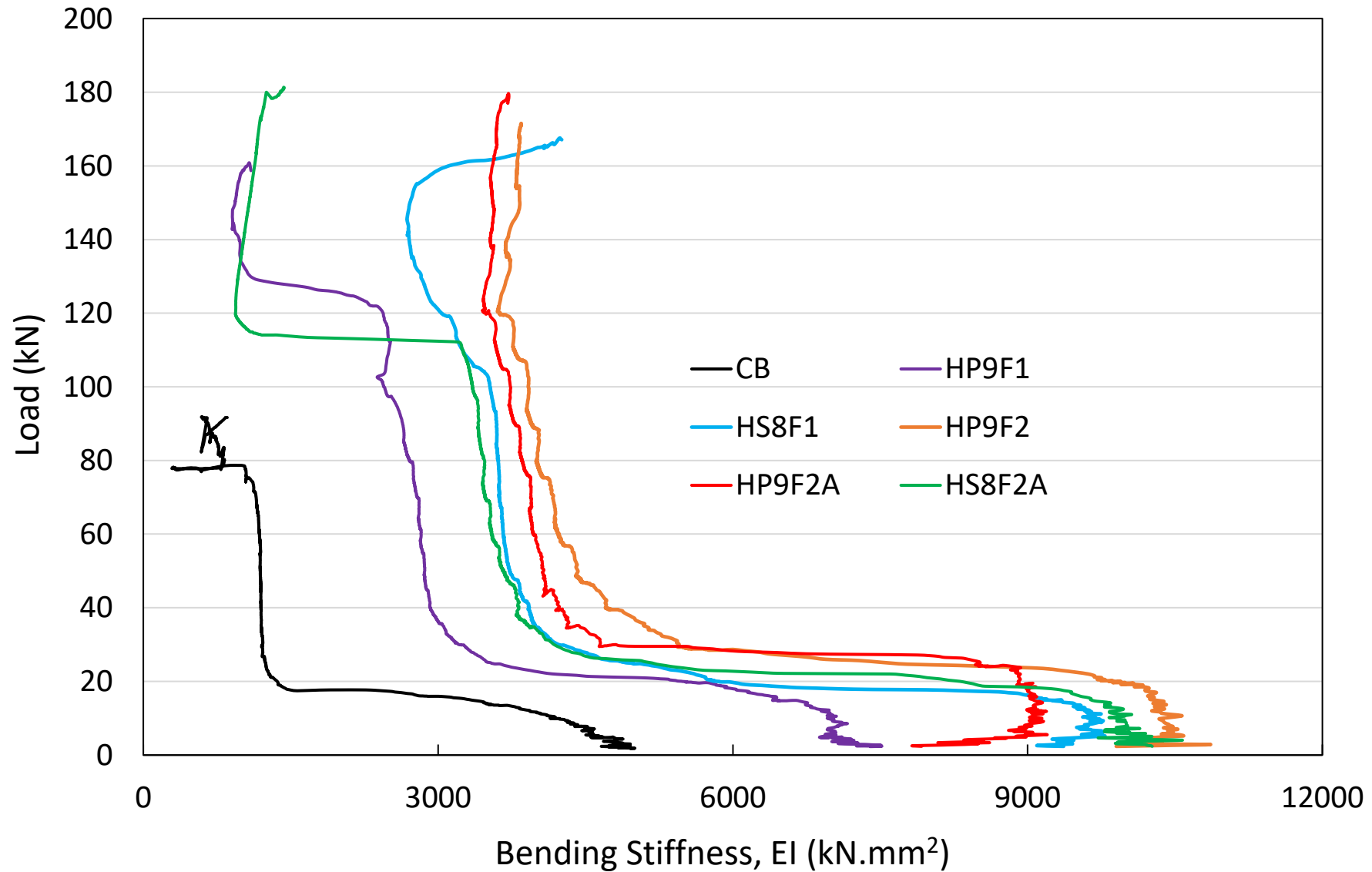
# Bending Stiffness



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

$$\phi = \frac{\epsilon_c + \epsilon_s}{d}$$

# 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*

*M2 student  
Supervisor*

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Ms. Tsogkhuu  
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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

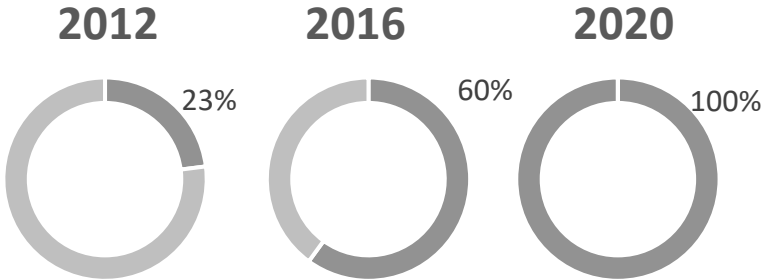
1. Road network development in Mongolia
2. Strategic systematic maintenance -Road Asset Management in Japan
3. Advanced technologies in bridge inspection
4. Research objectives and workflow
5. Image processing by Deep Learning method
6. Future works

# 1. Road network development in Mongolia

Road network in 2012

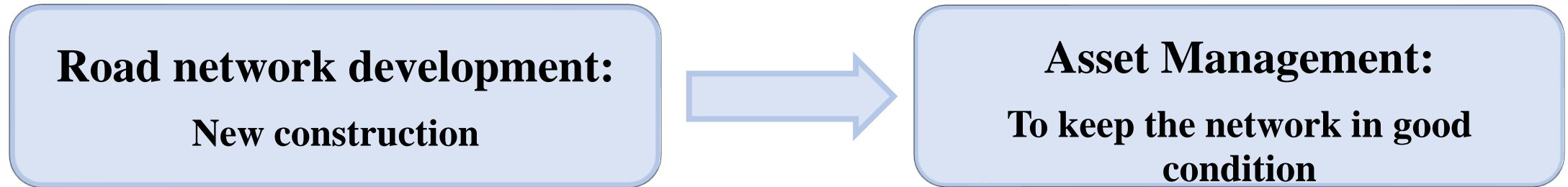


Road Network Development



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 ?



- 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'**

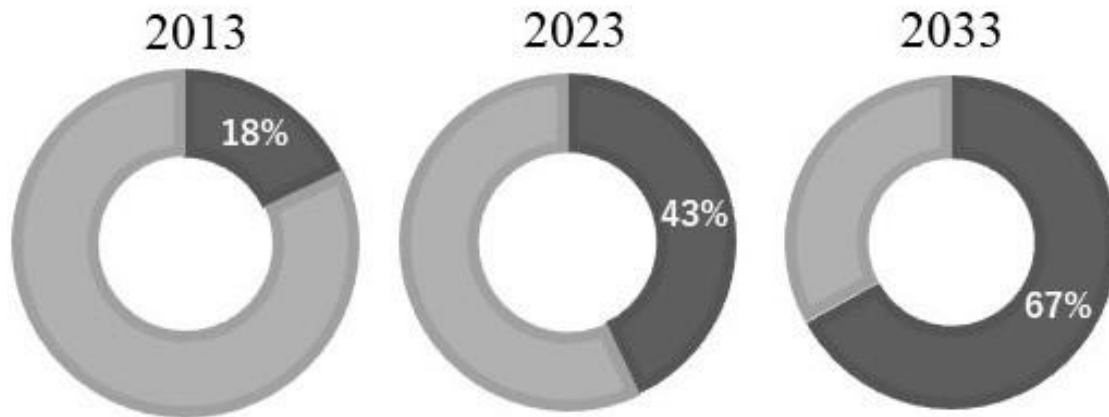


## 2. Strategic systematic maintenance -Road Asset Management in Japan

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

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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



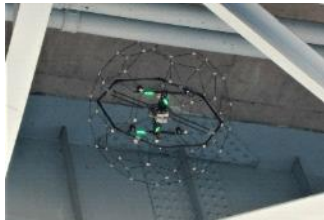



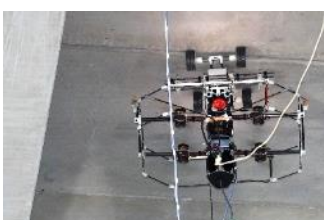



# Bridge inspection

## a) Conventional method

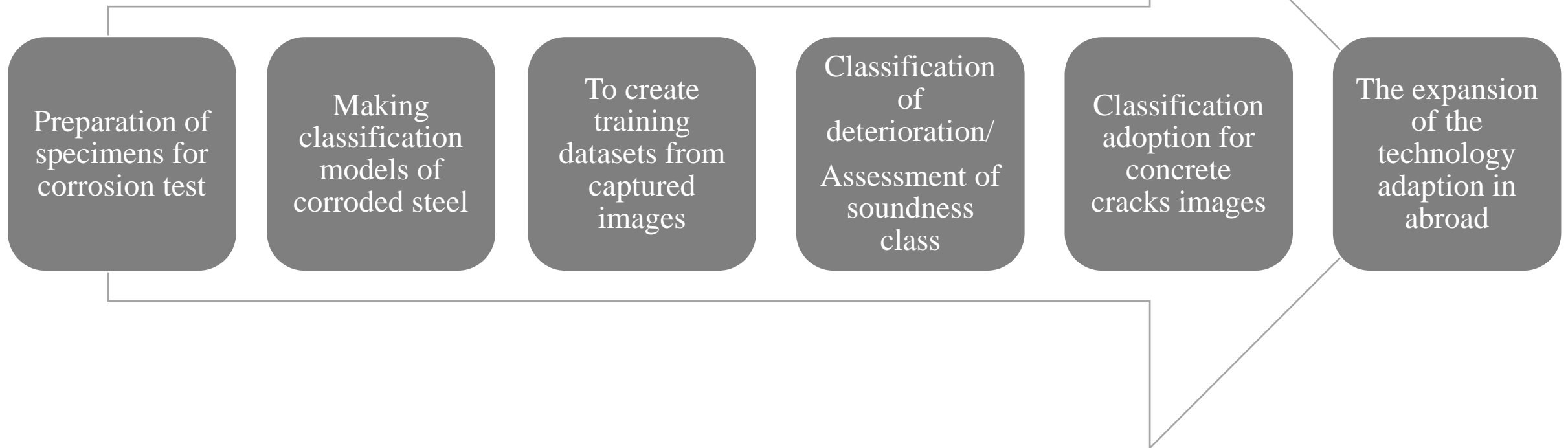


## b) Advanced technology

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.

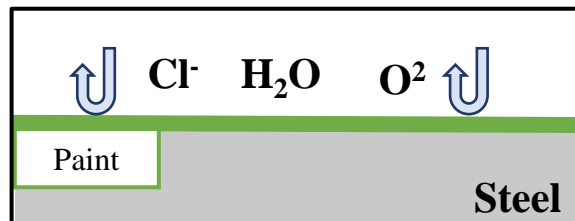


# Weathering steel characteristics

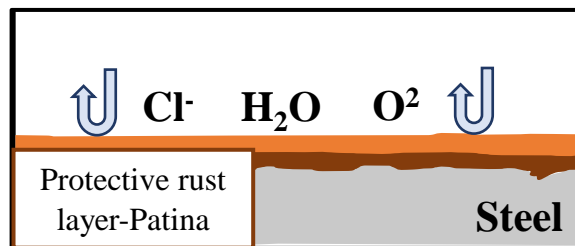
In Japan, the use ratio of weathering steels in steel bridges has increased rapidly, approximately tripling in the last 10 years, and now exceeds 15%.



Ordinarily steel



Weathering steel



## Attractiveness:

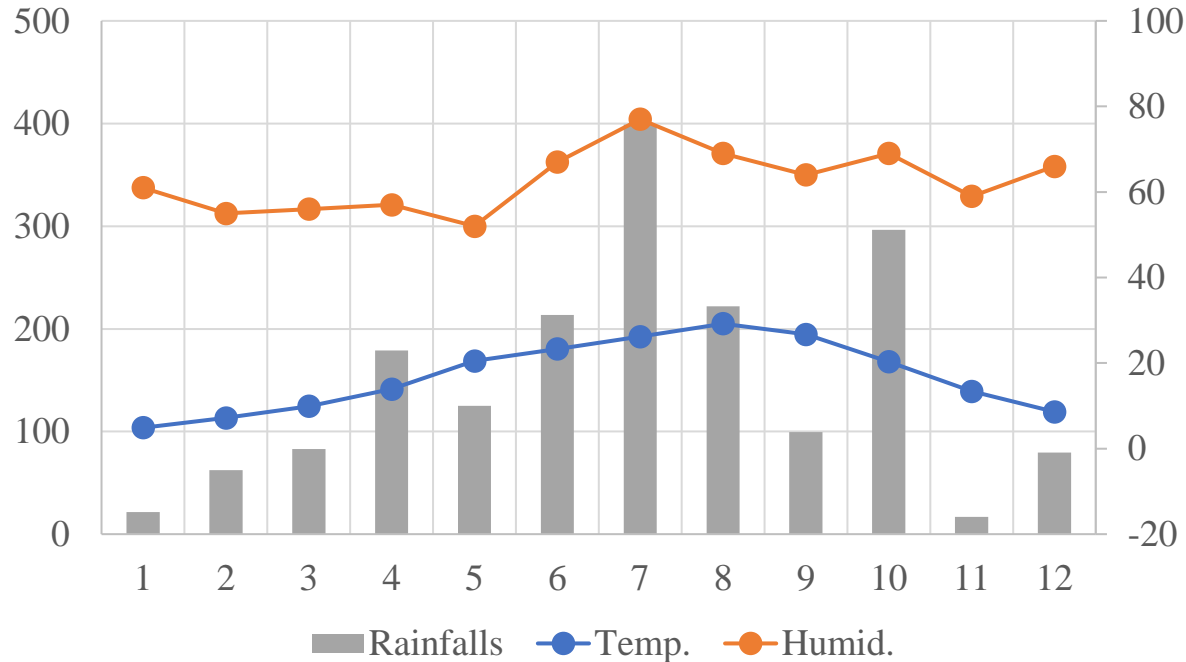
- Paint is not required. Enhanced resistance to rusting compared with ordinary carbon manganese steels.
- Initial and maintenance cost is lower: elimination of the additional painting material cost and labor time .
- The environmental problems such as Volatile Organic Compound (VOC) emissions from paint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

## Issues:

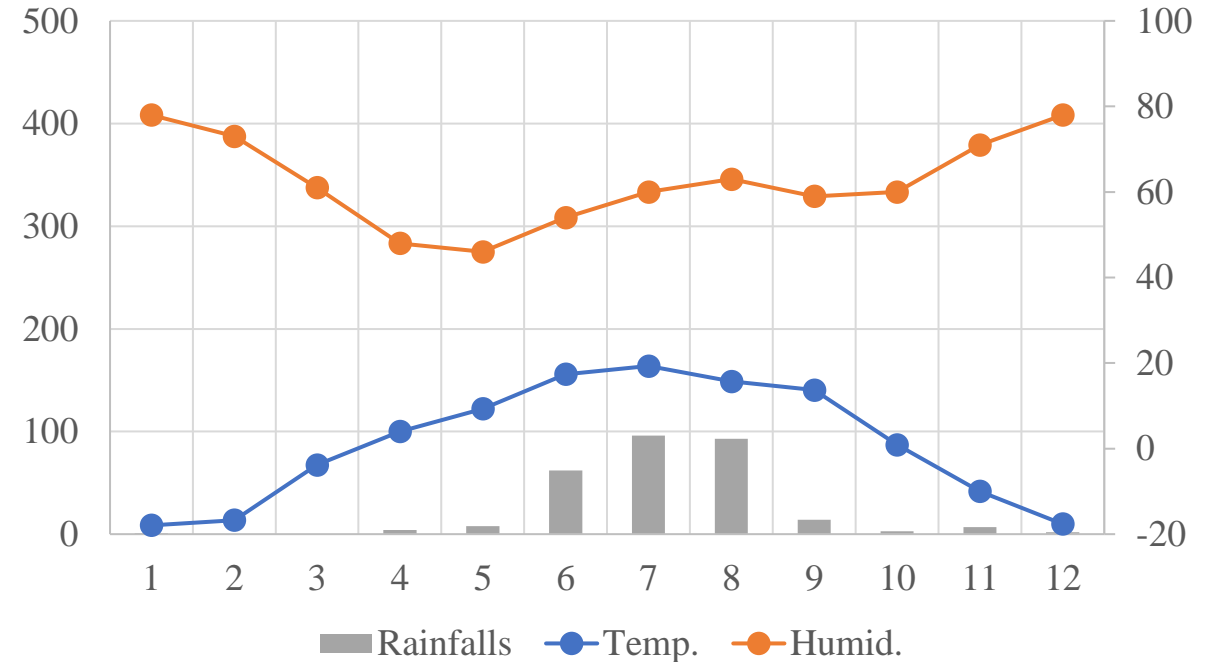
- Consideration to environment high concentration airborne salt, high humidity etc., the protective rust cannot be produced.
- When abnormal corrosion occurred, to remove and repair it are difficult.
- The weak point of weathering steel bridge is the end of girder: due to high humidity, accumulating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

# Applicability of weathering steel

Gifu in 2019



Ulan Bator in 2019



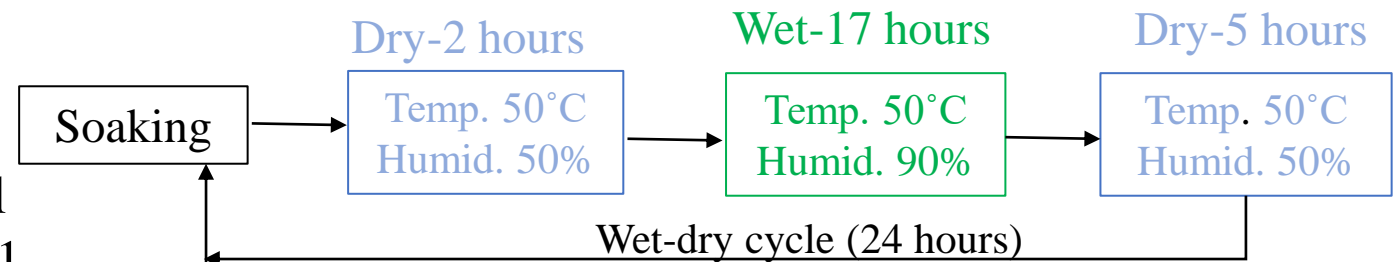
- Mongolia has good environment to weathering steel.
- Maintenance cost is lower: Reduce the LCC by eliminating of the additional painting material cost and labor time
- Enables rapid construction

## 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



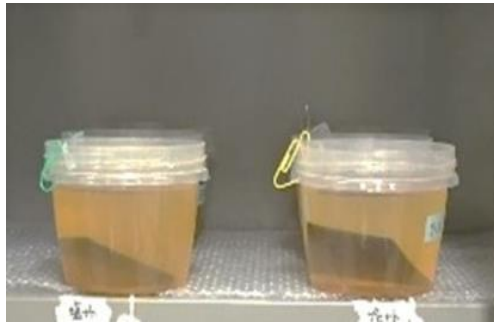
The wet-dry cycle test was conducted to boost the corrosion process and the specimens were soaked into each solution and exposed to the environment. One cycle takes 24 hours.



## 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.

The weathering steel specimens' surfaces after 250 cycles



Corrosion test cycle-Soaking



Corrosion test cycle-Exposing



(a) Chloride

(b) 0.25% inhibitor

(c) 0.5% inhibitor

(d) 2.5% inhibitor



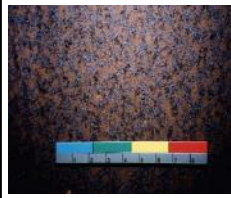

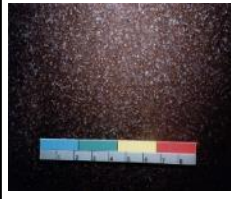

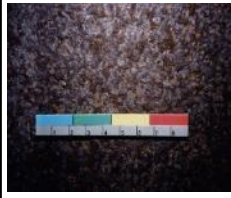
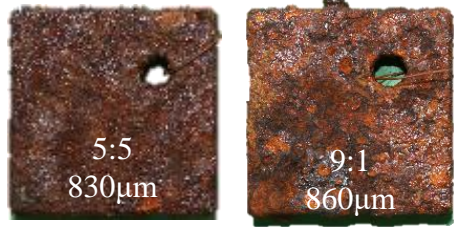
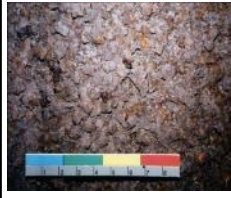
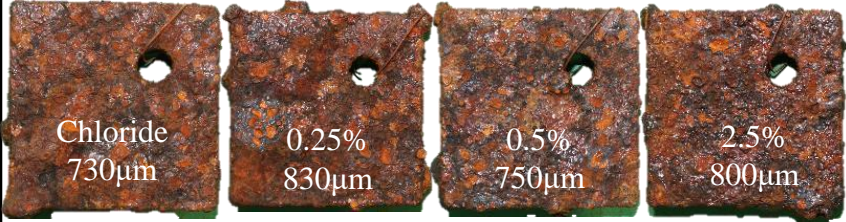

(e) Non-chloride

(f) mixed as 9:1

(g) mixed as 5:5

(h) mixed as 1:9

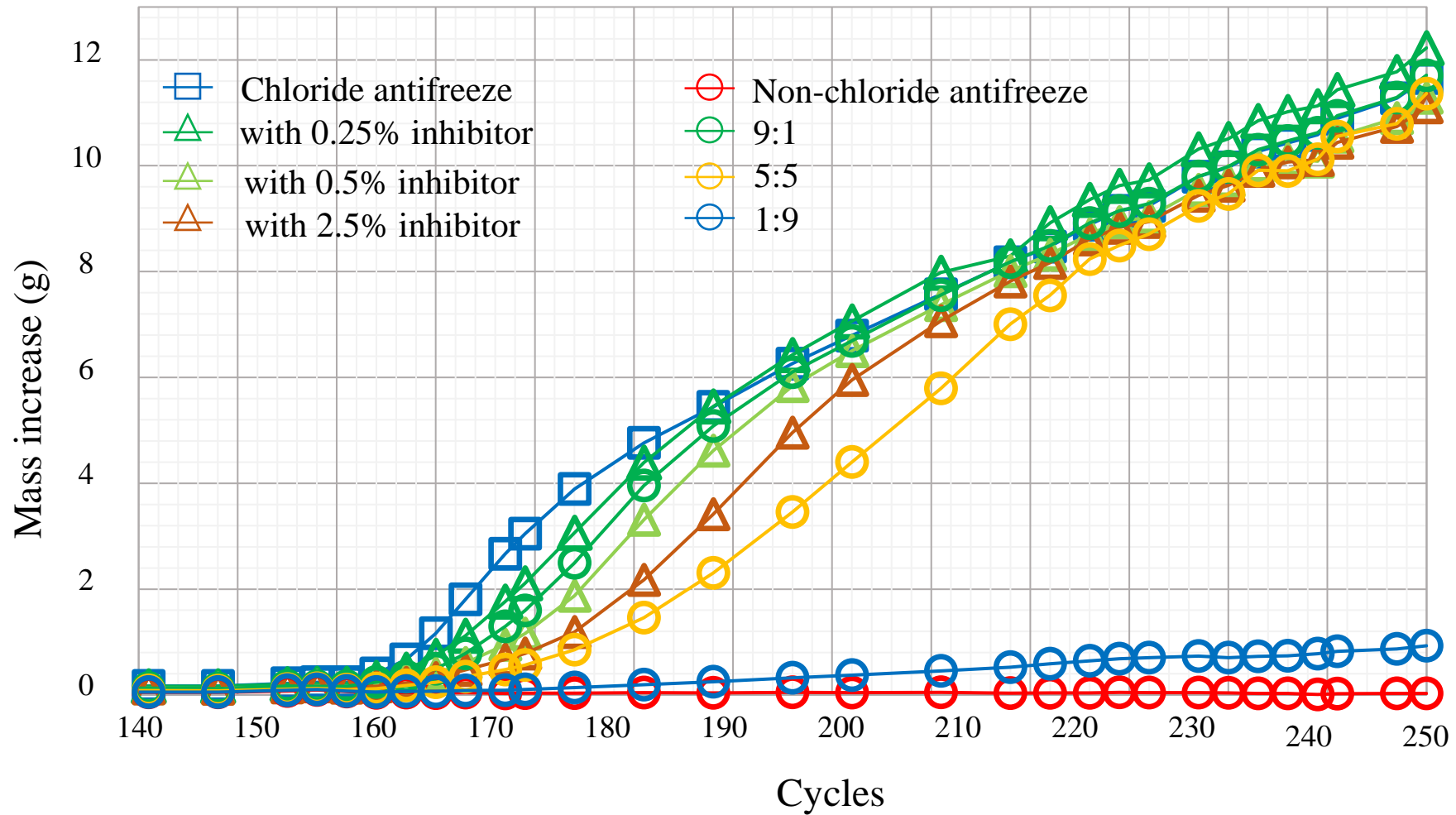
# Comparison of rust appearance rating criteria for weathering steel

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

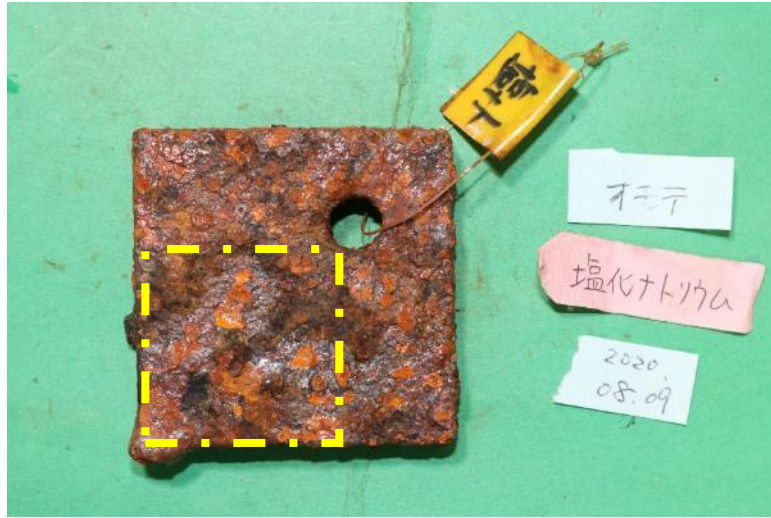


The gained weight of the specimens due to corrosion is measured.

Mass increase of the weathering steel specimen after 250 cycles



## c. To create training datasets from captured images



Before trimming  
1560 × 1560 pixel



After trimming  
128 × 128 pixel



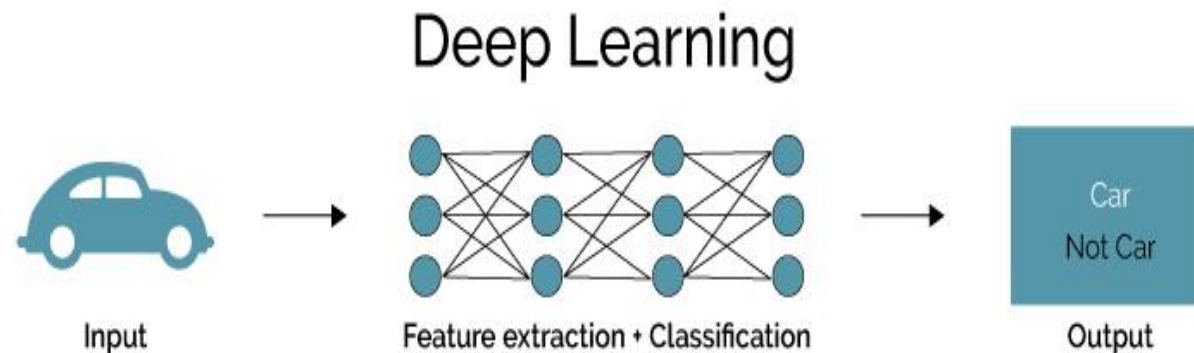
Data augmentation techniques to enhance the dataset size.

## 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.

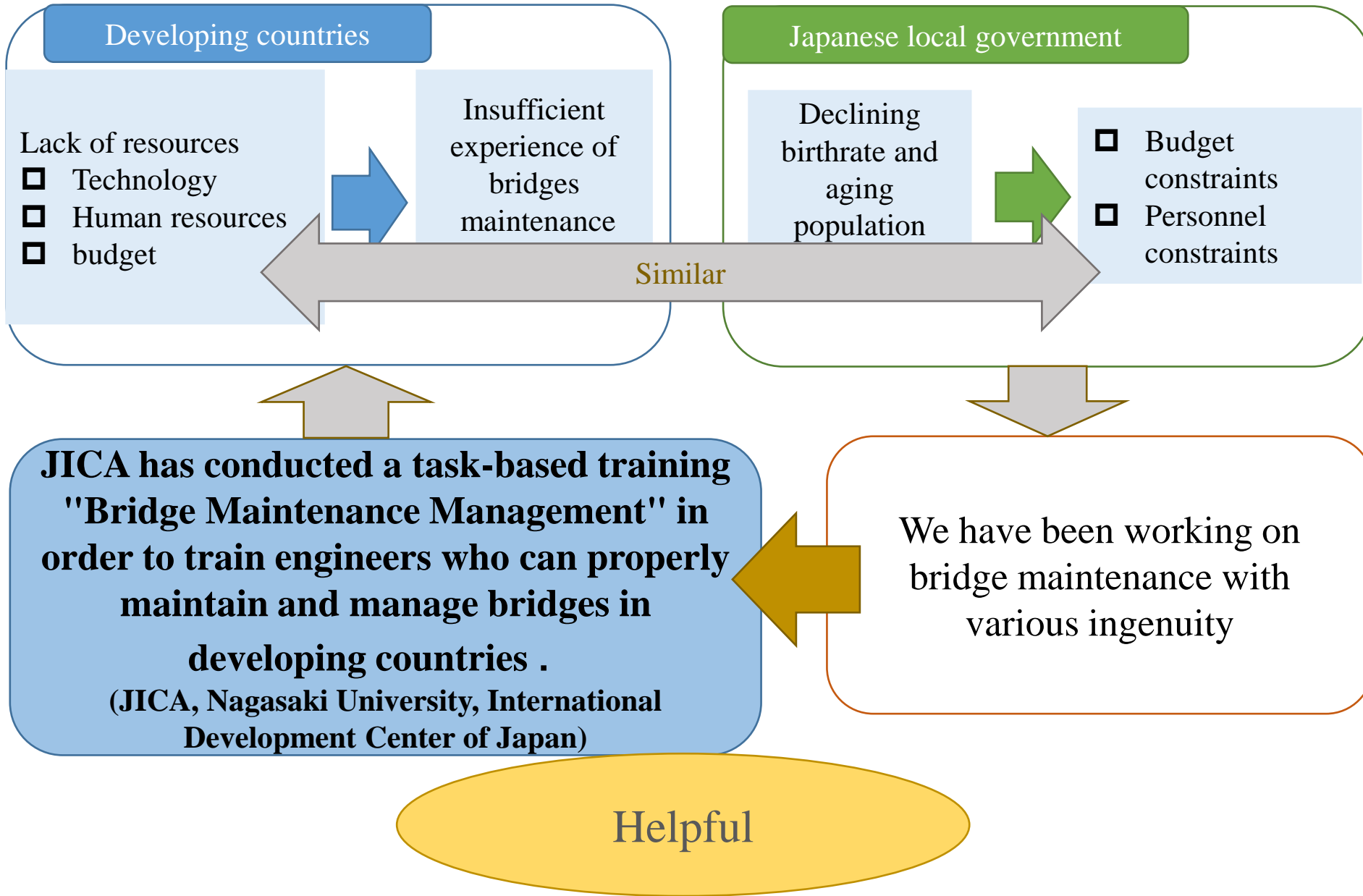
## Daily life

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

Analyzing the current situation and issues from countries reports on bridge maintenance in developing countries

Survey of the current state of bridge maintenance in Japanese local governments

Comparing local governments in developing countries and Japan

Finding knowledge that contributes to improving maintenance management capacity in developing countries

# 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	<b>33 countries in total</b>

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

	Main Current Status
Budget	<ul style="list-style-type: none"><li>▪ Insufficient maintenance budget.</li><li>▪ Bridges cannot be prioritized and the budget cannot be used efficiently.</li></ul>
Human resources	<ul style="list-style-type: none"><li>▪ The number of people in the workplace is small (insufficient manpower)</li><li>▪ Insufficient experienced and excellent technicians.</li><li>▪ There is no minimum training program.</li></ul>
Inspection / evaluation	<ul style="list-style-type: none"><li>▪ Cannot procure equipment required for inspection (The accuracy of the equipment required for inspection is low).</li><li>▪ Don't know how to evaluate (Repair begins only after serious damage to the bridge appears).</li></ul>

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

	Main Current Status
Maintenance plan	<ul style="list-style-type: none"><li>▪ There is no inventory of bridges and it is not possible to make a plan.</li><li>▪ Don't know how to do it because no experience in maintenance planning.</li></ul>
BMS (Bridge maintenance system)	<ul style="list-style-type: none"><li>▪ Data is not unified by region.</li><li>▪ Cannot utilize BMS sustainably (BMS itself has not been developed).</li></ul>
Other	<ul style="list-style-type: none"><li>▪ The security of the country is bad.</li><li>▪ Standards for maintenance are not unified nationwide.</li></ul>

# 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

Nagasaki Prefecture Bridge

Bridges with a length of 15 m or more

General bridge

Important maintenance bridge

Special bridge

Bridges with a length of less than 15 m

Specific bridge

# 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	<ul style="list-style-type: none"><li>▪ Budget is not allocated properly</li></ul>	<ul style="list-style-type: none"><li>▪ Prioritizing social security, no planned budgetary measures have been taken.</li></ul>
Human resources	<ul style="list-style-type: none"><li>▪ There is no experienced technician</li></ul>	<ul style="list-style-type: none"><li>▪ Insufficient number of people to carry out bridge inspection.</li></ul>
Technical capabilities	<ul style="list-style-type: none"><li>▪ There is no data for existing bridges.</li><li>▪ There is no clear maintenance standard.</li><li>▪ It does not have the ability to construct bridges or repair individual bridges.</li></ul>	<ul style="list-style-type: none"><li>▪ There are OBs who have the ability to construct bridges and repair individual bridges.</li><li>▪ Engineers also exist in consulting companies.</li></ul>

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

<b>Budget</b>	<ul style="list-style-type: none"><li>➤ Set maintenance level for each bridge and allocate budget according to importance</li></ul>
<b>Human resources</b>	<ul style="list-style-type: none"><li>➤ Build human resources training and qualification systems such as “Michimori” and “ME”</li></ul>
<b>Technical capabilities</b>	<ul style="list-style-type: none"><li>➤ Create a manual by conducting questionnaires and workshops</li><li>➤ Training how to use while revising the manual</li></ul>

# 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

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

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

➤ 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.

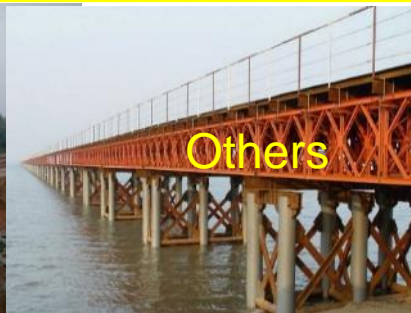
The bridges have been adapting for civil works in developing counties, especially rural area for a long-term service.



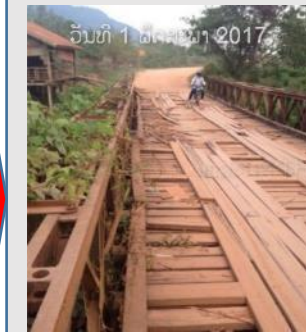
Flooding and disaster recovering



Rural areas access

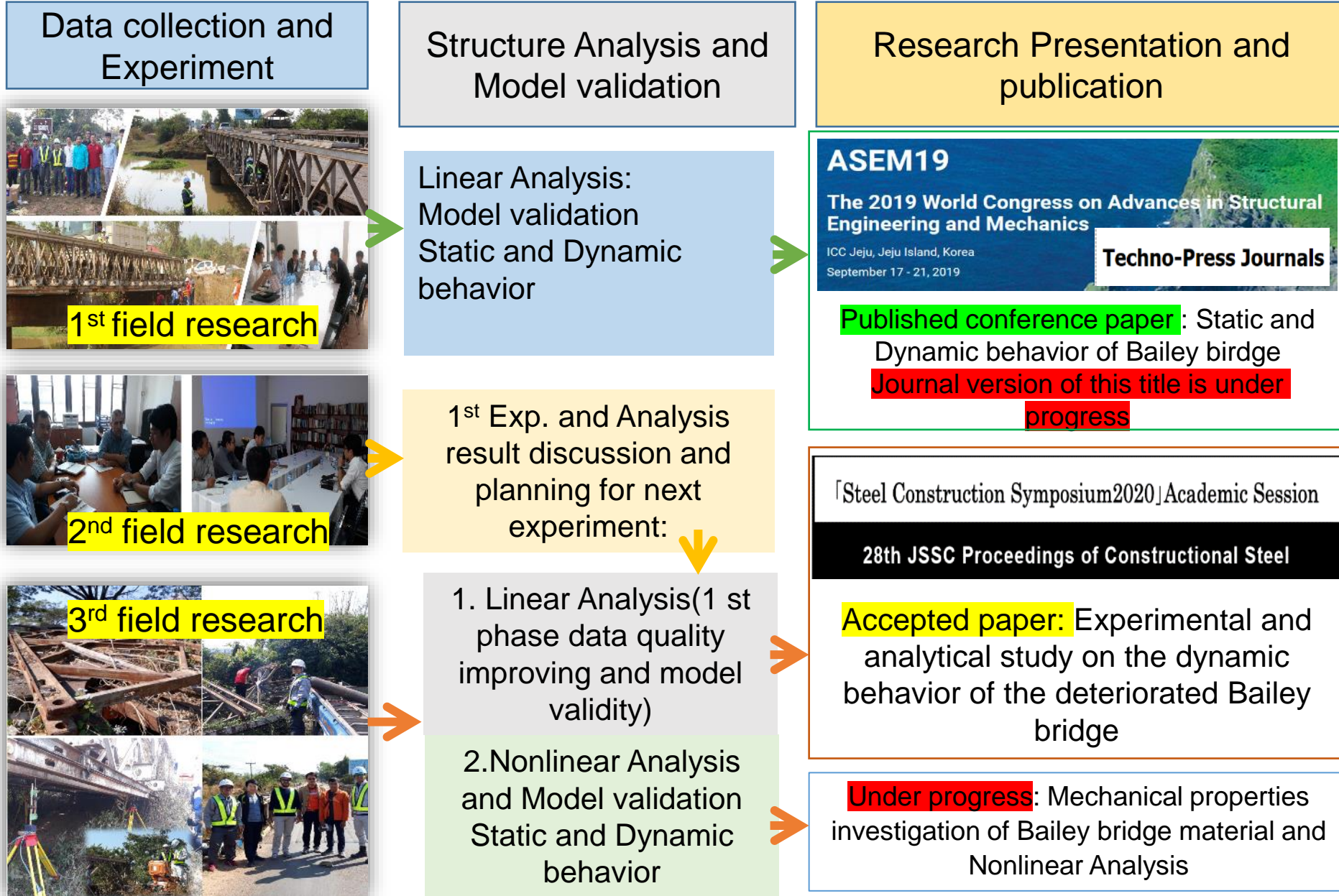


Others



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




# Other Presentations

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



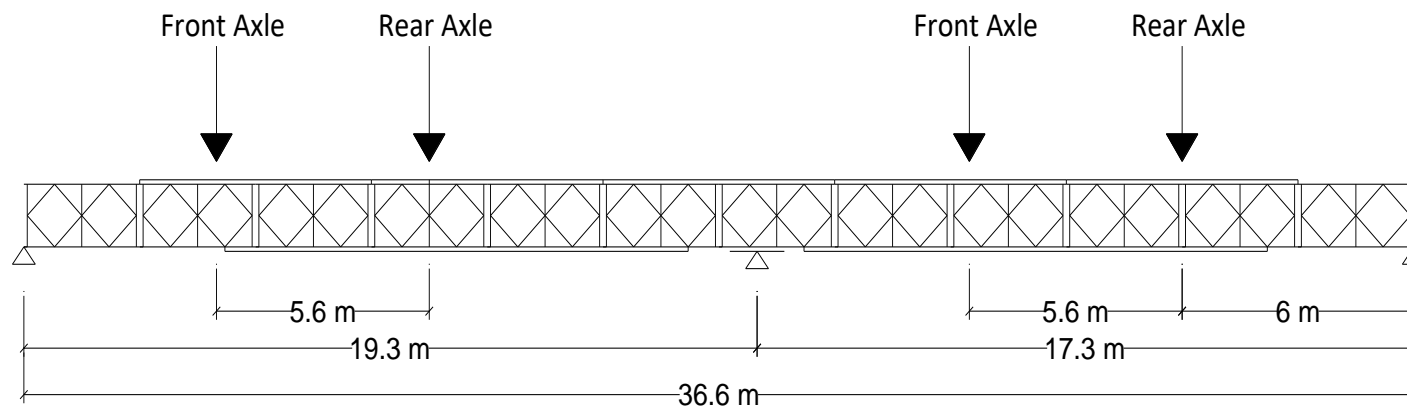
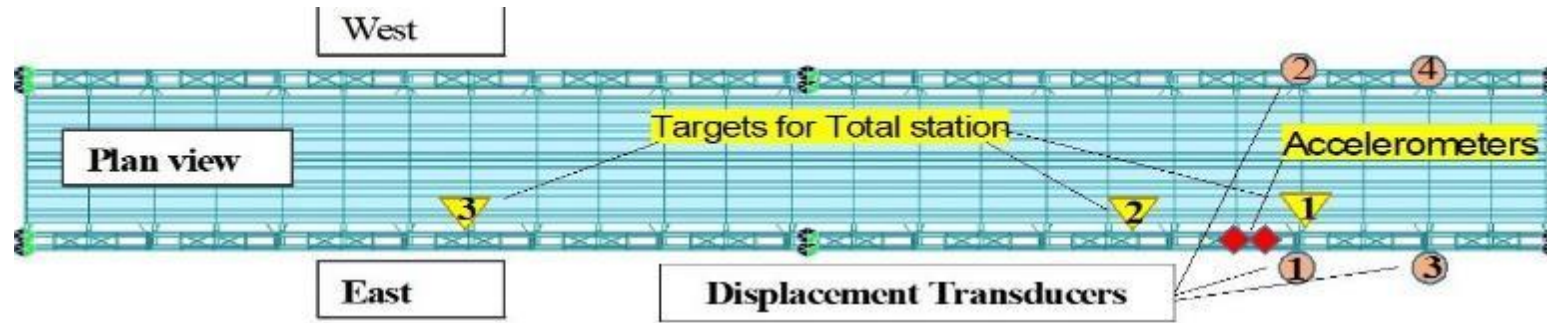
# Graduation

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 Final Dec 2020
Graduation			Hopefully Expected: Marc 2021

A photograph of a field with a blue gradient overlay. The text "2 Field testing and Data collection" is centered in white.

## 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

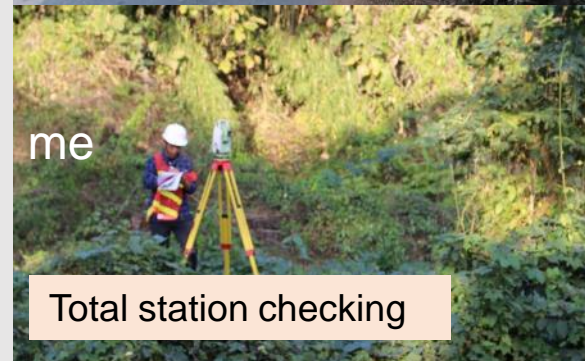
Point load marking

## Testing



Prof. Nakamura,  
Nagasaki Univ.

Traffic and Loading controlling.



me

Total station checking



Prof.  
Nishikawa  
Nagasaki Univ.

Testing data recording

A landscape photograph of a field with a blue sky and a dark blue horizontal band across the middle. The text "3 Research Finding" is overlaid in white on the dark blue band.

# 3 Research Finding



# Static and Dynamic behavior FEA approach

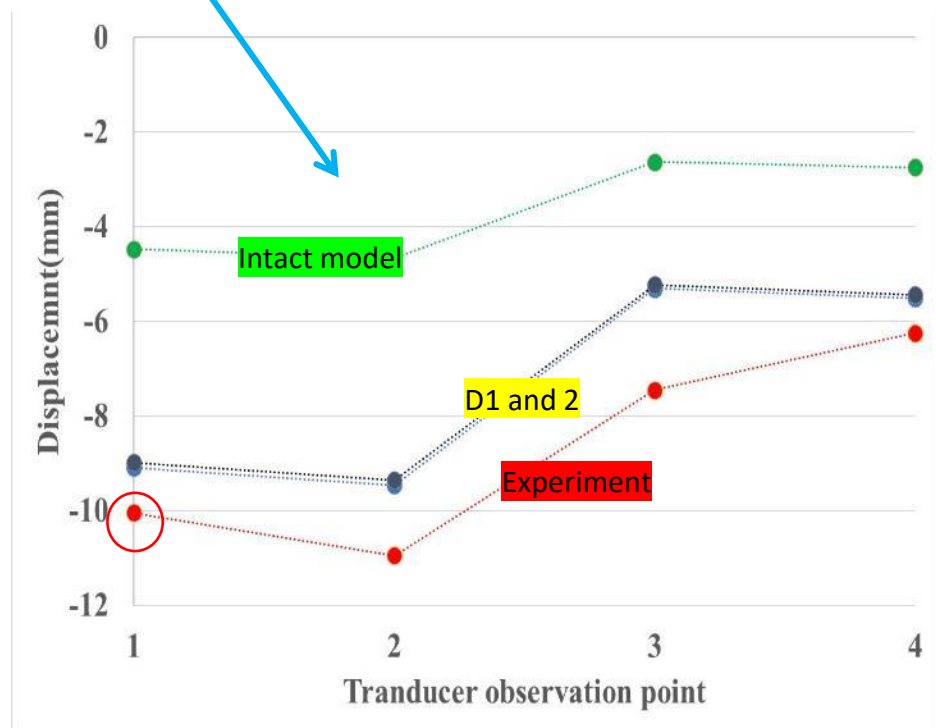
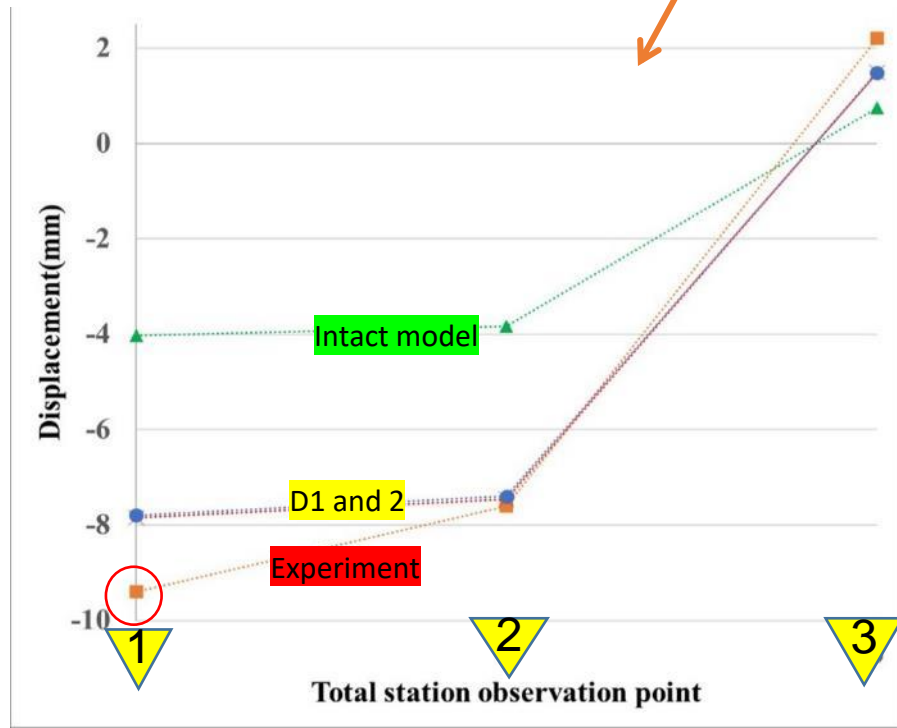
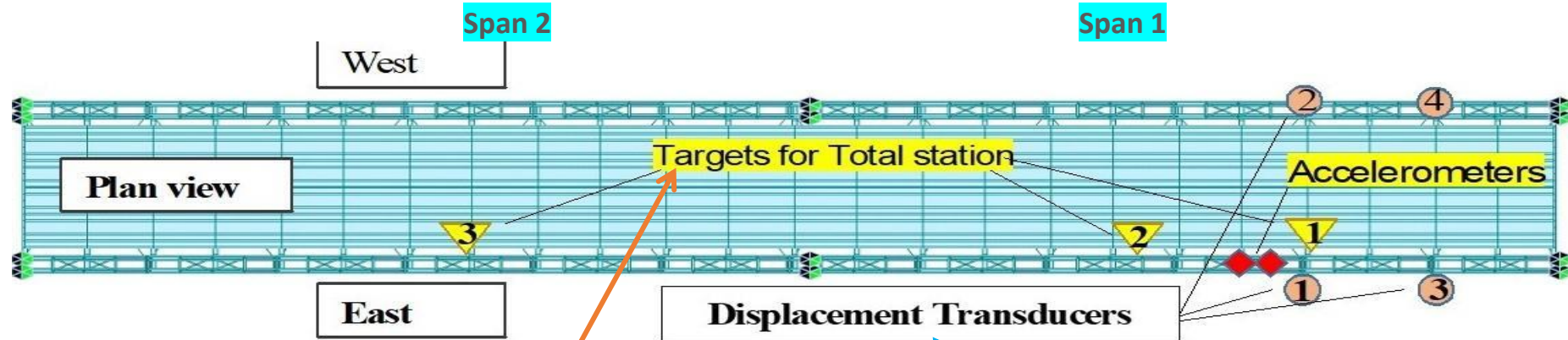
# Static behavior

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

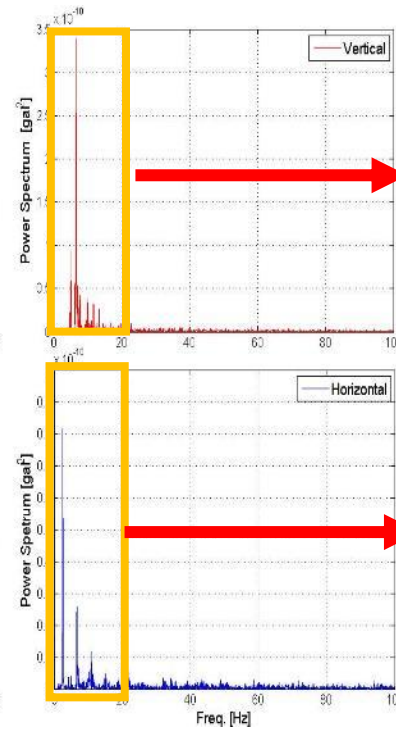
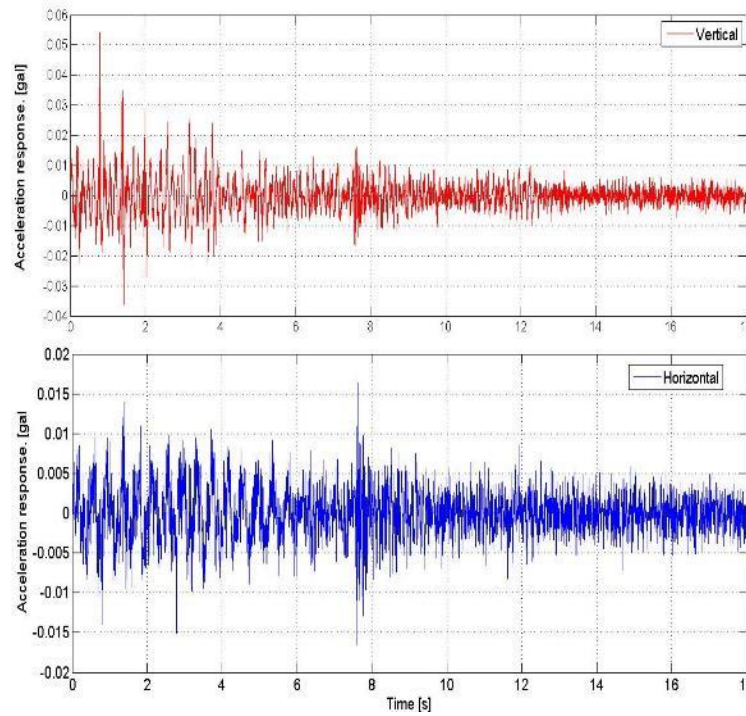


# Static Deflection

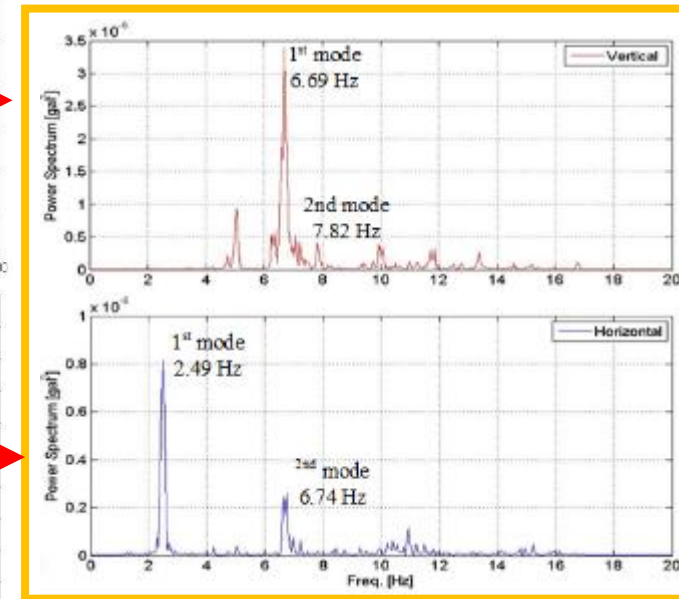


# Dynamic behavior

Noisy signal in time domain and frequency domain

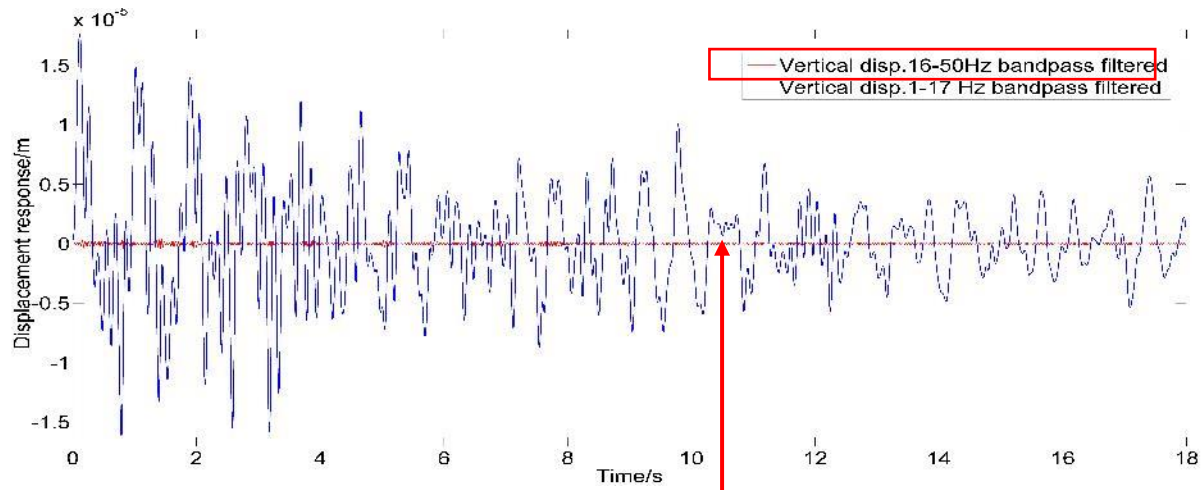


Frequency domain after filtering

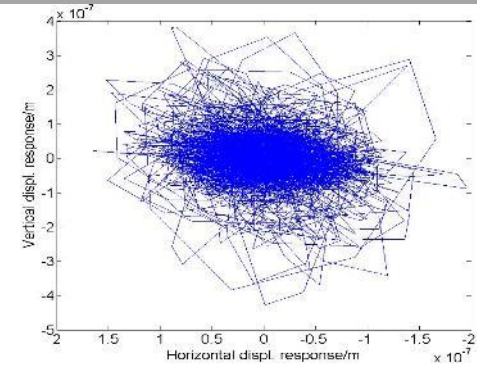
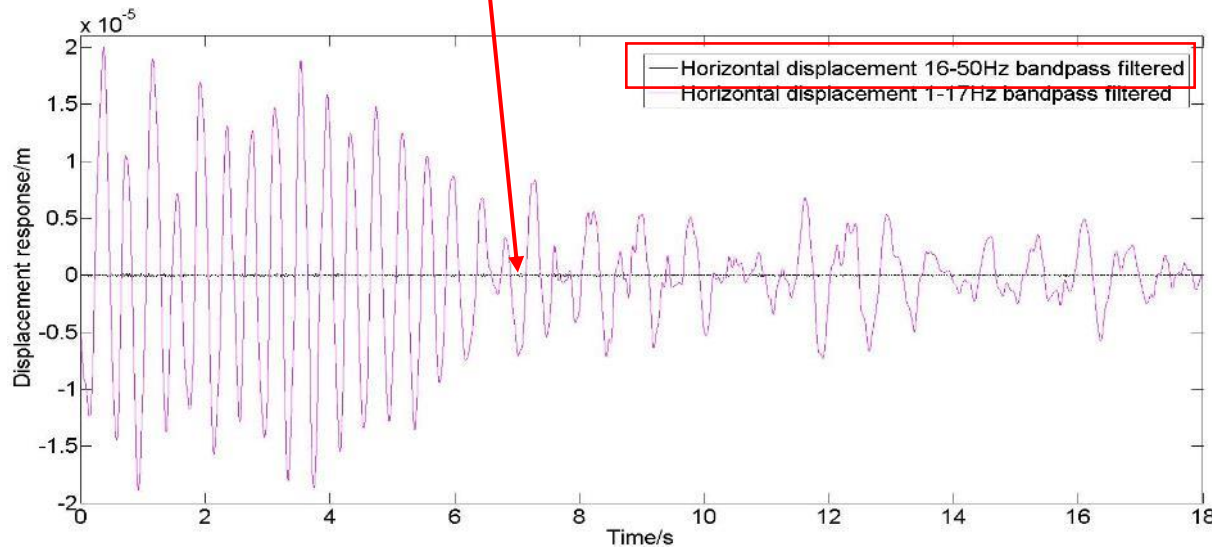


Data acquiring by ambient traffic condition

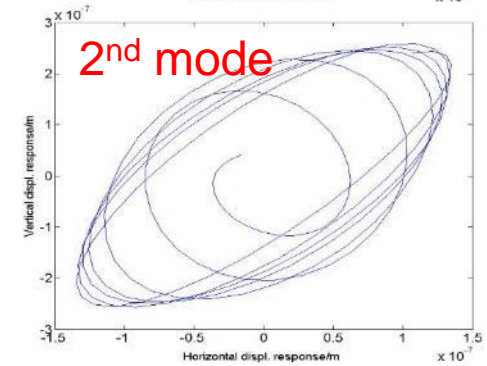
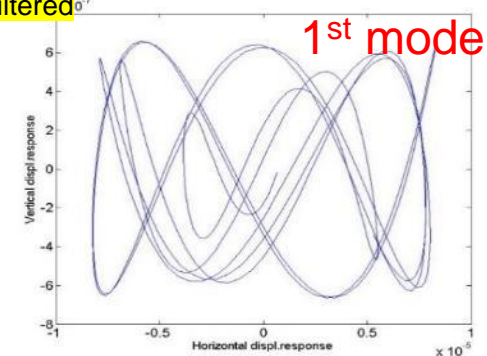
# Displacement response by acceleration data



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



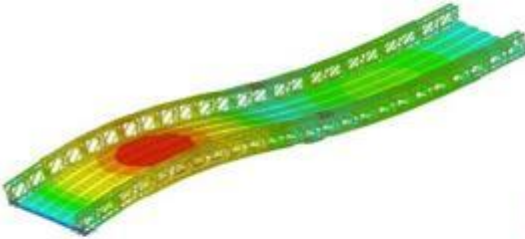
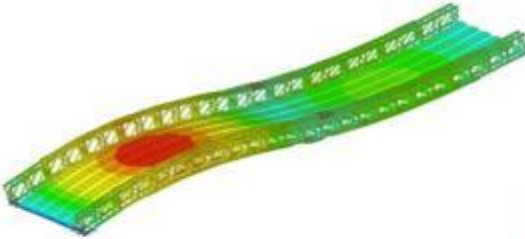
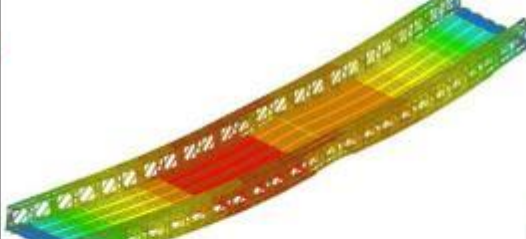
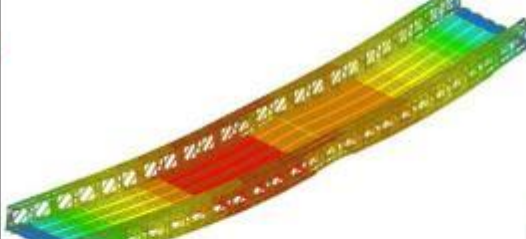
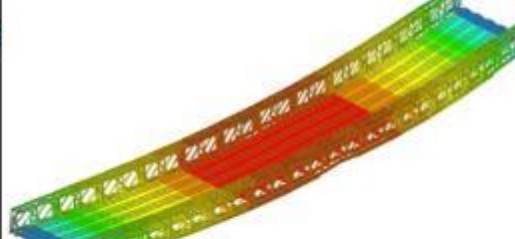
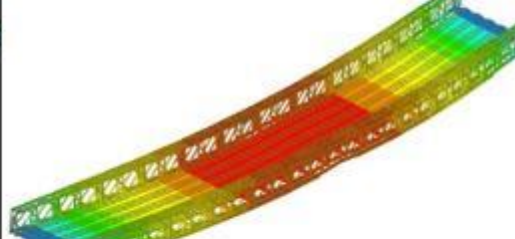
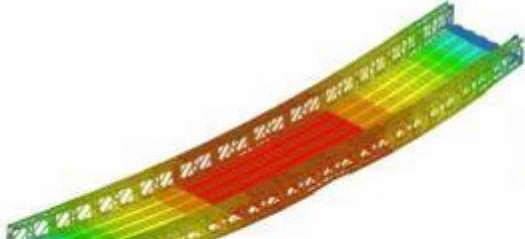
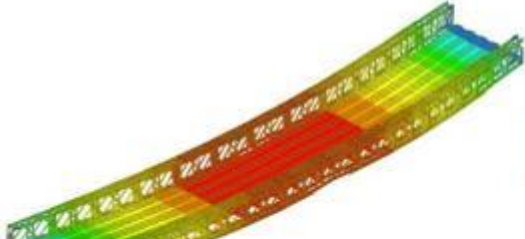
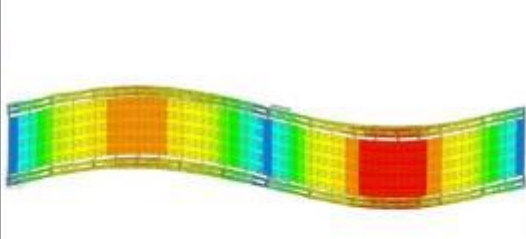
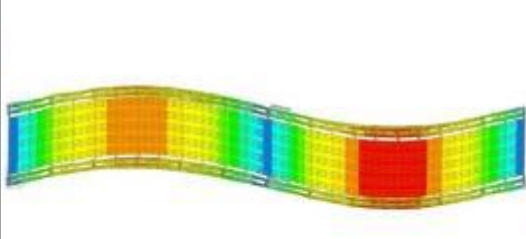
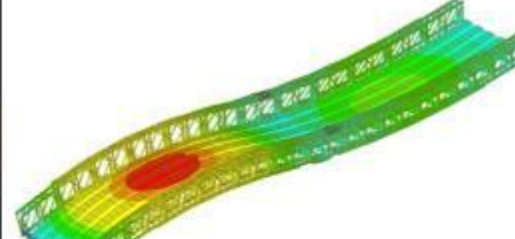
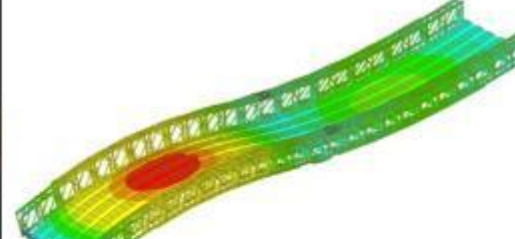
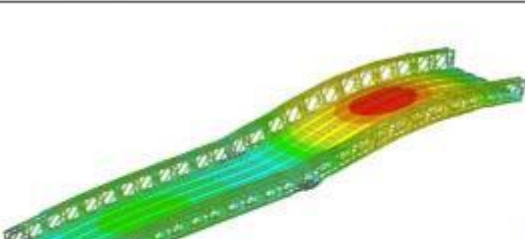
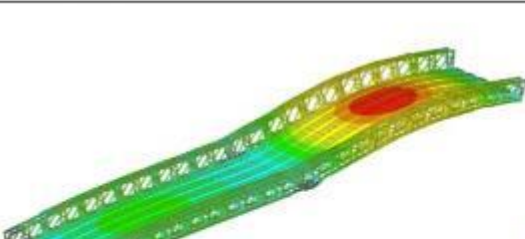
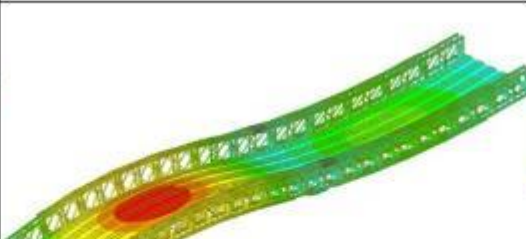
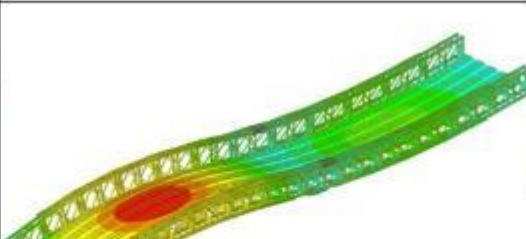
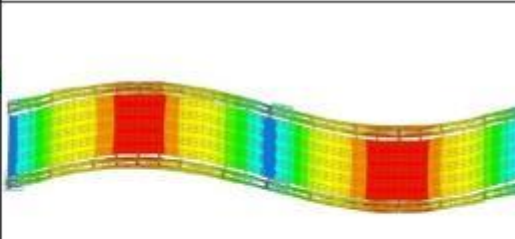
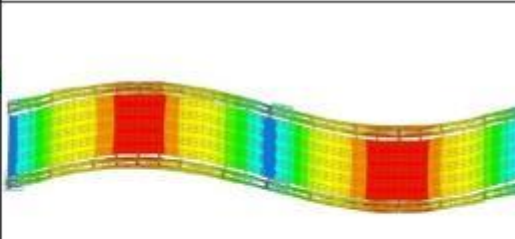
Lissajous pattern of 16 Hz high pass filtered



Lissajous pattern of structure vibration



# Vibration mode shape by eigen-analysis

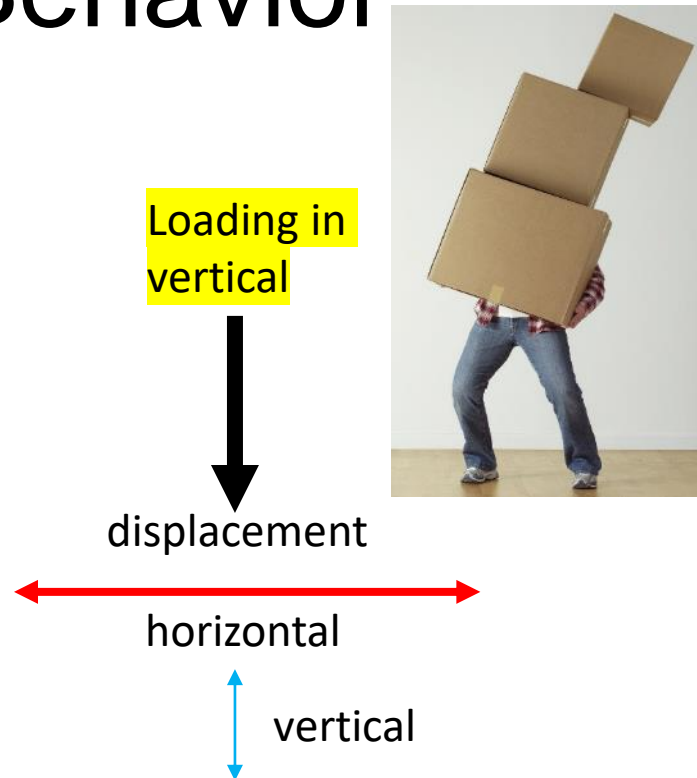
Mode	Vibration shape					
	Intact		D1		D2	
	Span 2	Span 1	Span 2	Span 1	Span 2	Span 1
1						
2						
3						

## 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.

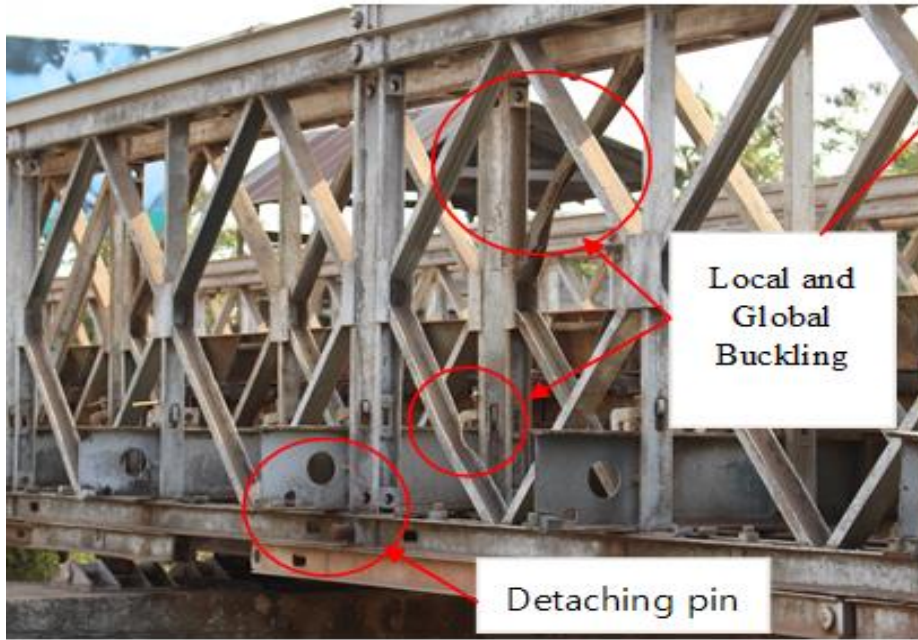
# Timber deck and sways bracing damage are directly affected the whole structure stiffness.

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

# Some critical structure condition



Holed by corrosion and detaching pin



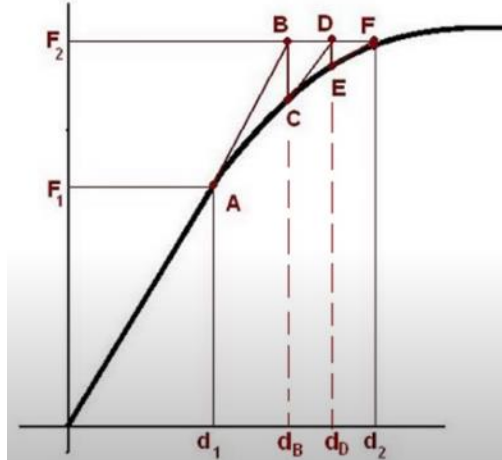
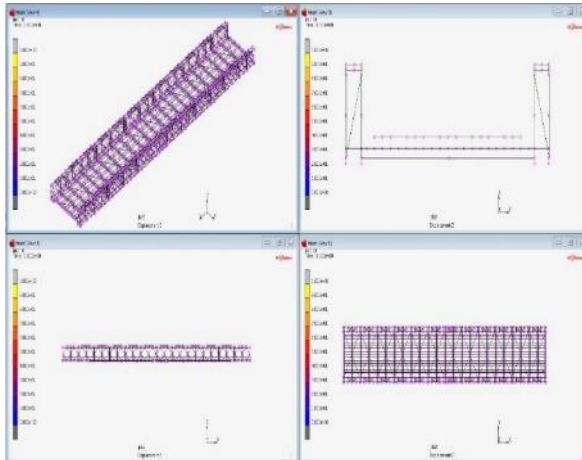
Local and Global Buckling

Detaching pin



Loosening sway bracing





# Material properties investigation and Nonlinear Analysis

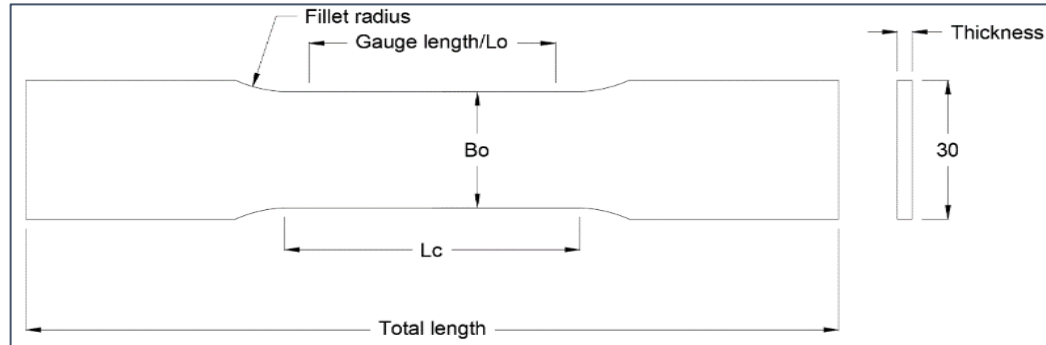
# Material properties

Sample collected from the site at  
**Sungthong district Vientiane**  
**Capital**



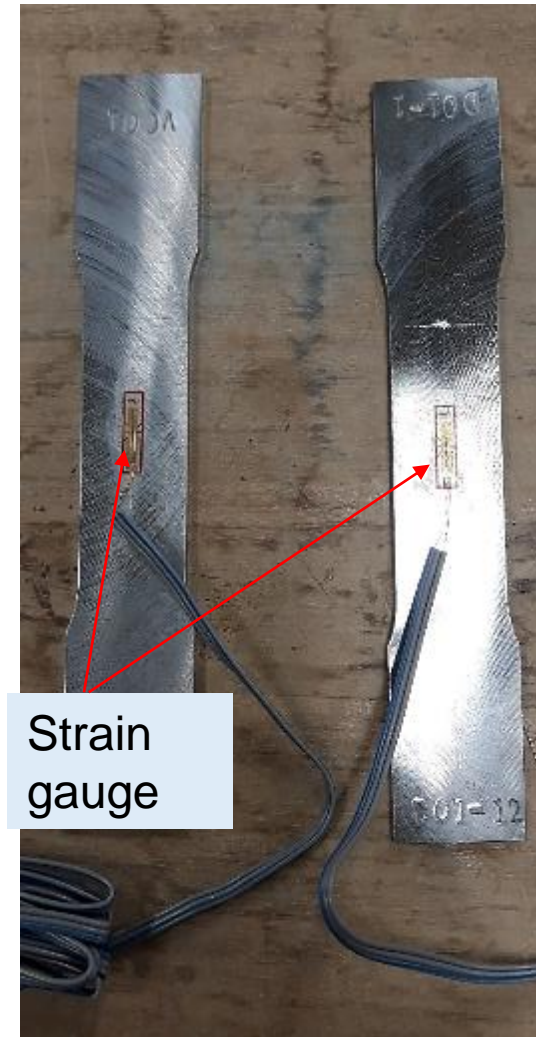
No.	Code	Description	Illustration
1	BC 01 to 02 (Channel section)	Cut off from the panel that placed at the northern side of OPWT building (Panel 1)	
2	BT 01 to 02 (Channel section)	Cut off from the panel that placed southern of OPWT building (Panel 2)	
3	N01 and N02 (Channel section)	Cut off from the panel that placed at southern of OPWT building (Panel 3)	
4	B01 to B04 (I section)	Randomly picked of Stored of Raker	
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/ $L_0$  50 mm,  $\pm 1\%$  or 0.5 mm,  
 $L_c = 60$  mm  
Fillet radius 25 mm,  
width/ $B_0$  is 25 mm,  
thickness is 3 mm,  
Total length is approximately 165 mm.





# Testing machine

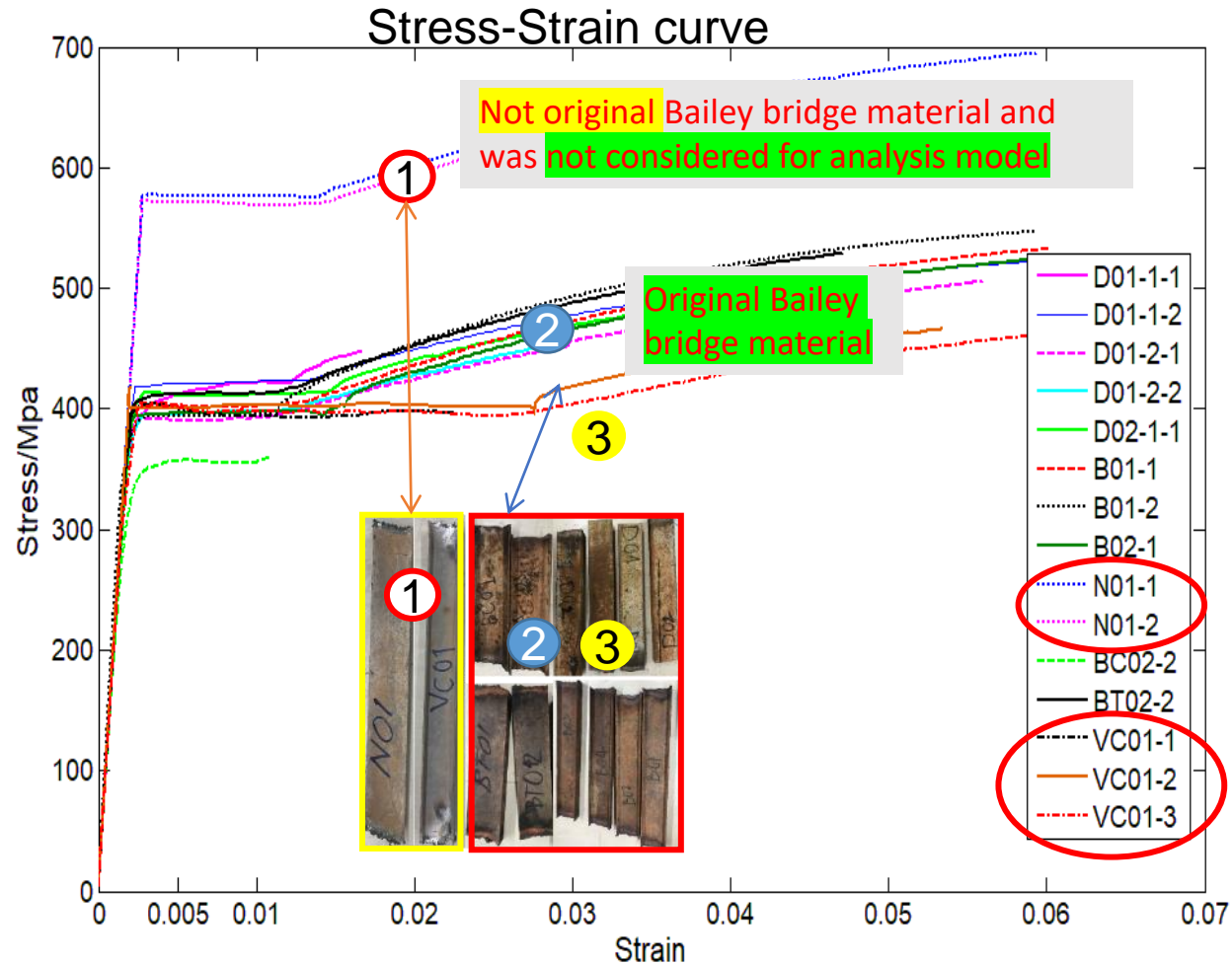
Hydraulic Universal Testing Machines UH-F100kNX.

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

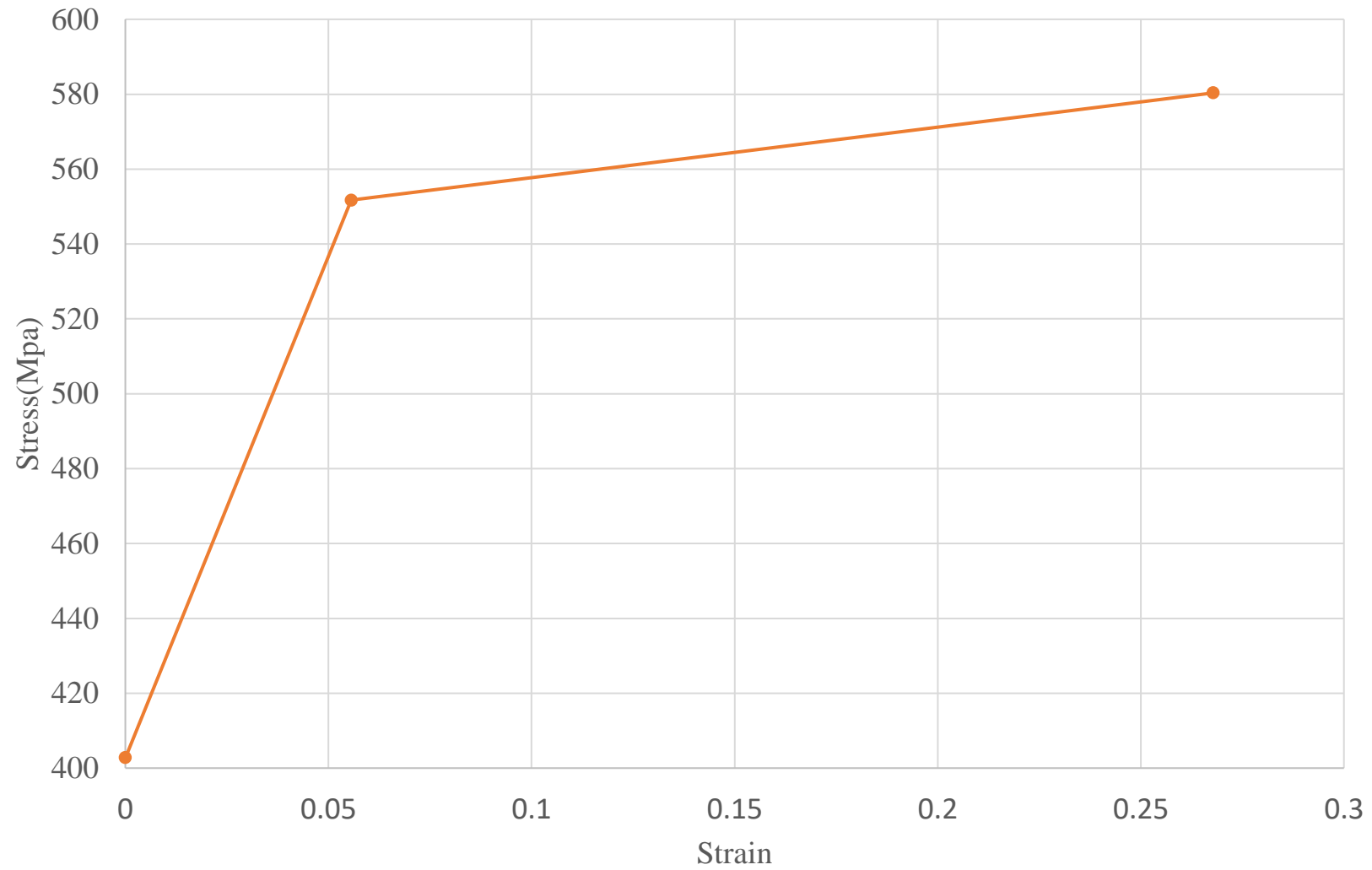
1. N01-N02 Higher yield strength\*
2. Common yield strength
3. Common yield strength, higher ductile(VC01-1 to 3).

\*Related to Weathering steel

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

# Plastic properties

True stress-strain curve

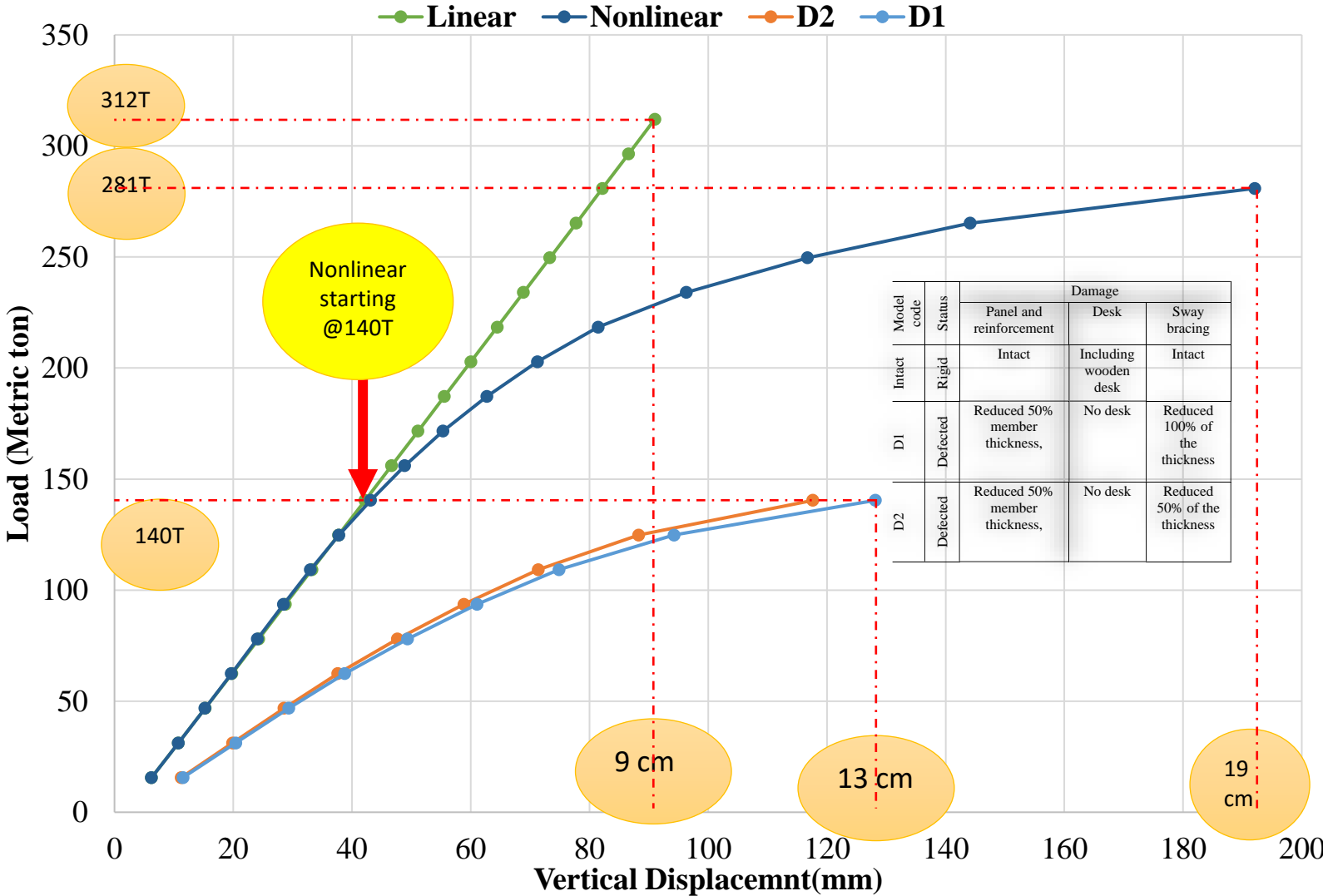


# Material properties summary

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



Thank you so much for your kind attention







**NAGASAKI  
UNIVERSITY**

**RESEARCH PROGRESS**



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

**By**

**Mohamed Saied Gharieb**

**Under the Supervision of**

**Prof. Dr. Takafumi Nishikawa**

Graduate School of Engineering  
Department of Science and Technology  
System Engineering Program  
September 2020



Mohamed Saied  
モーハーメッド  
サイエツド



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**

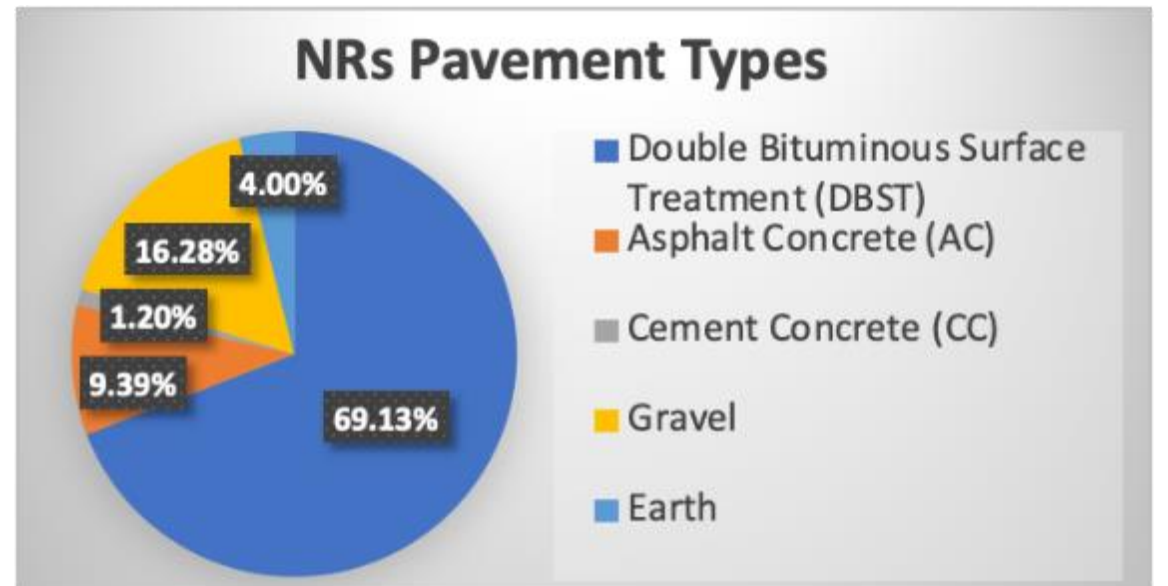
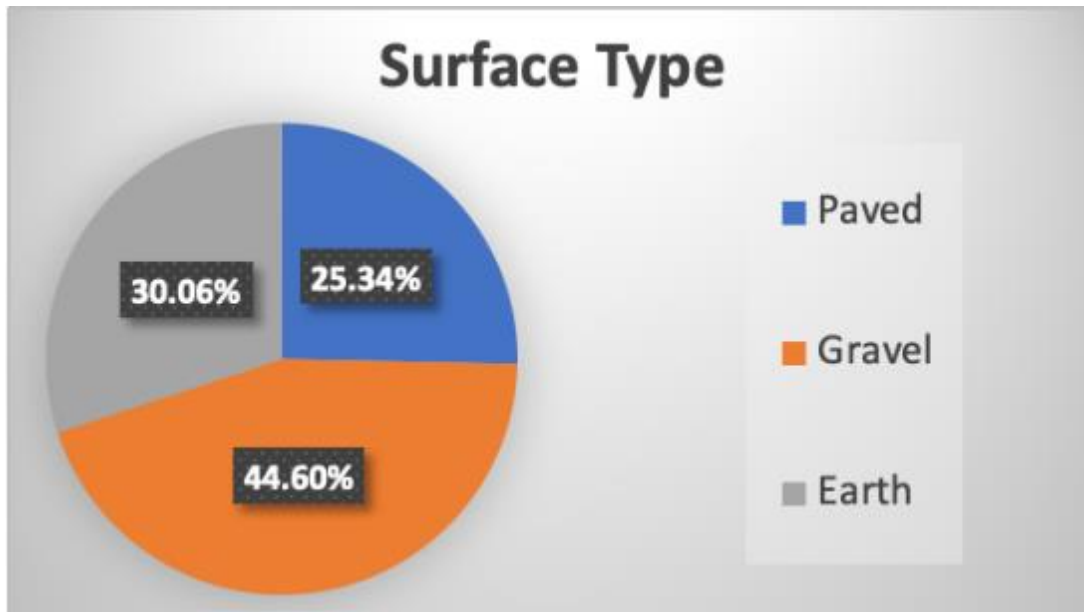
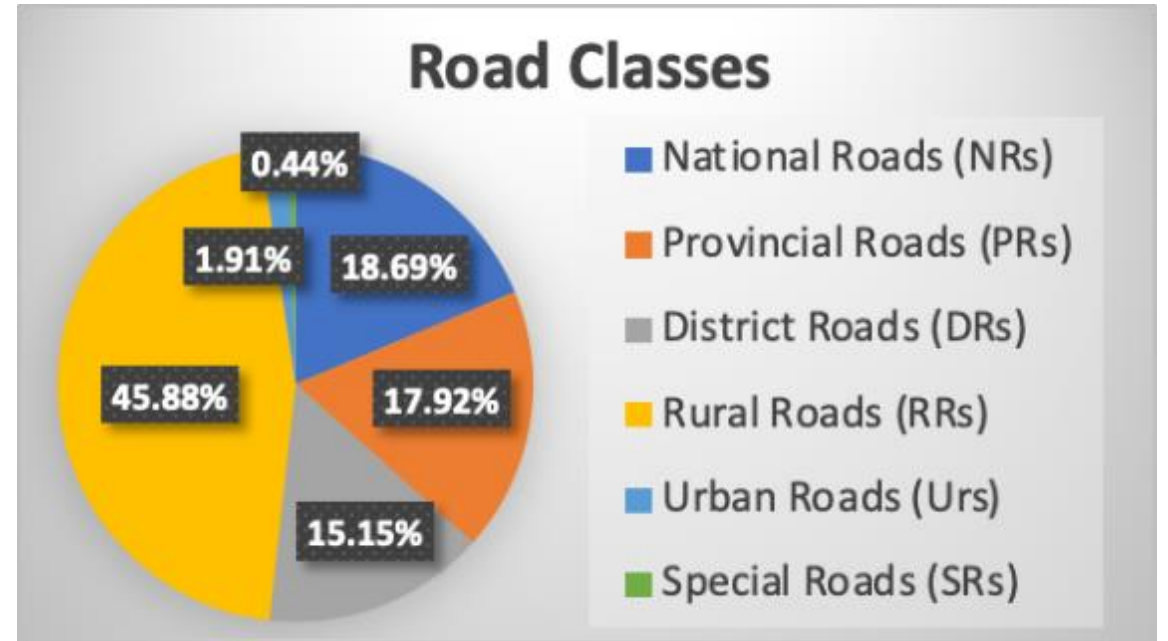
Model Validation

**6**

Sensitivity analysis of the developed Models

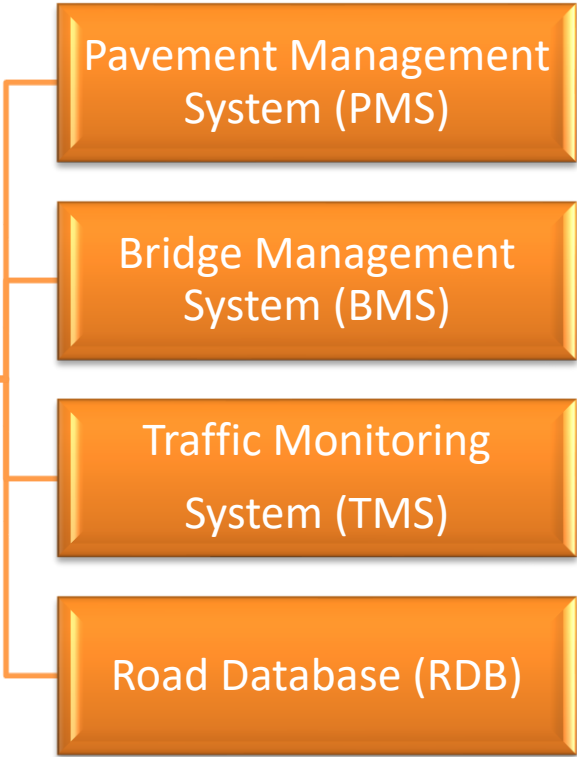
# 1- Introduction

- 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.





# Laos Road Management System (RMS)

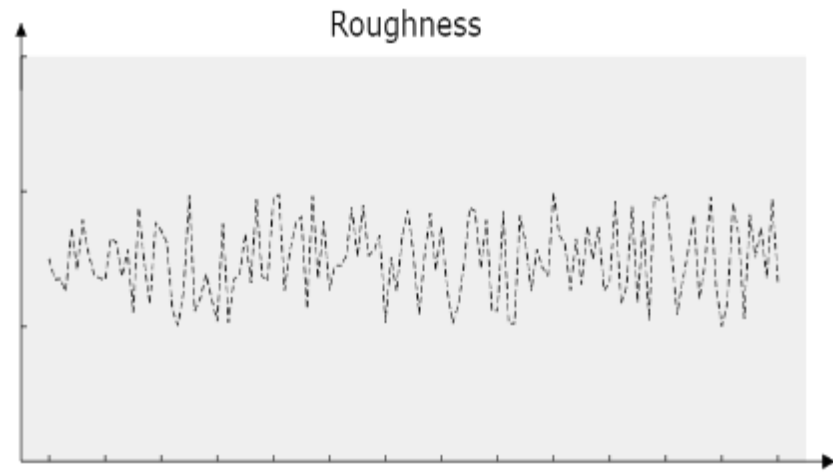
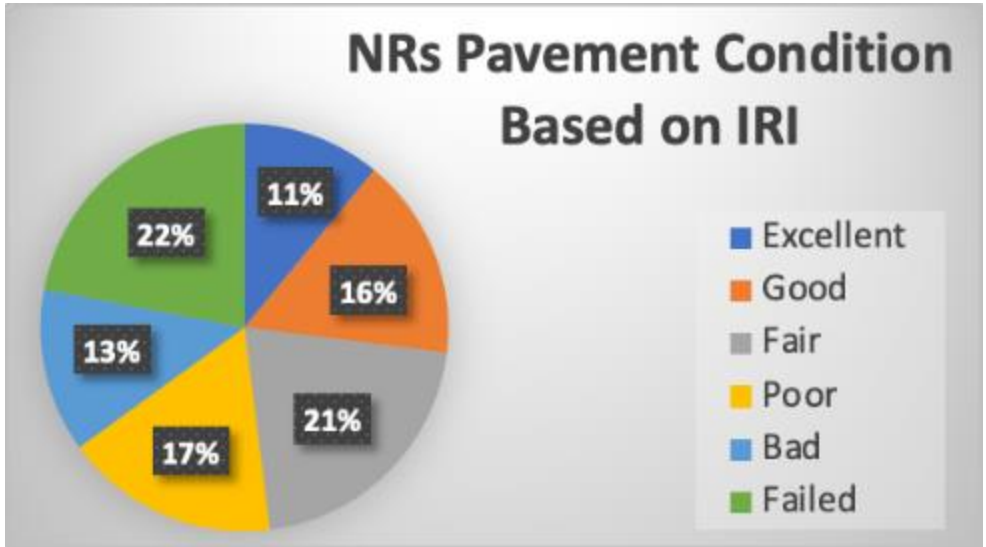


This system is used for formulating short and medium term maintenance management plans, selecting priority projects, and selecting the optimum maintenance methods.

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**.

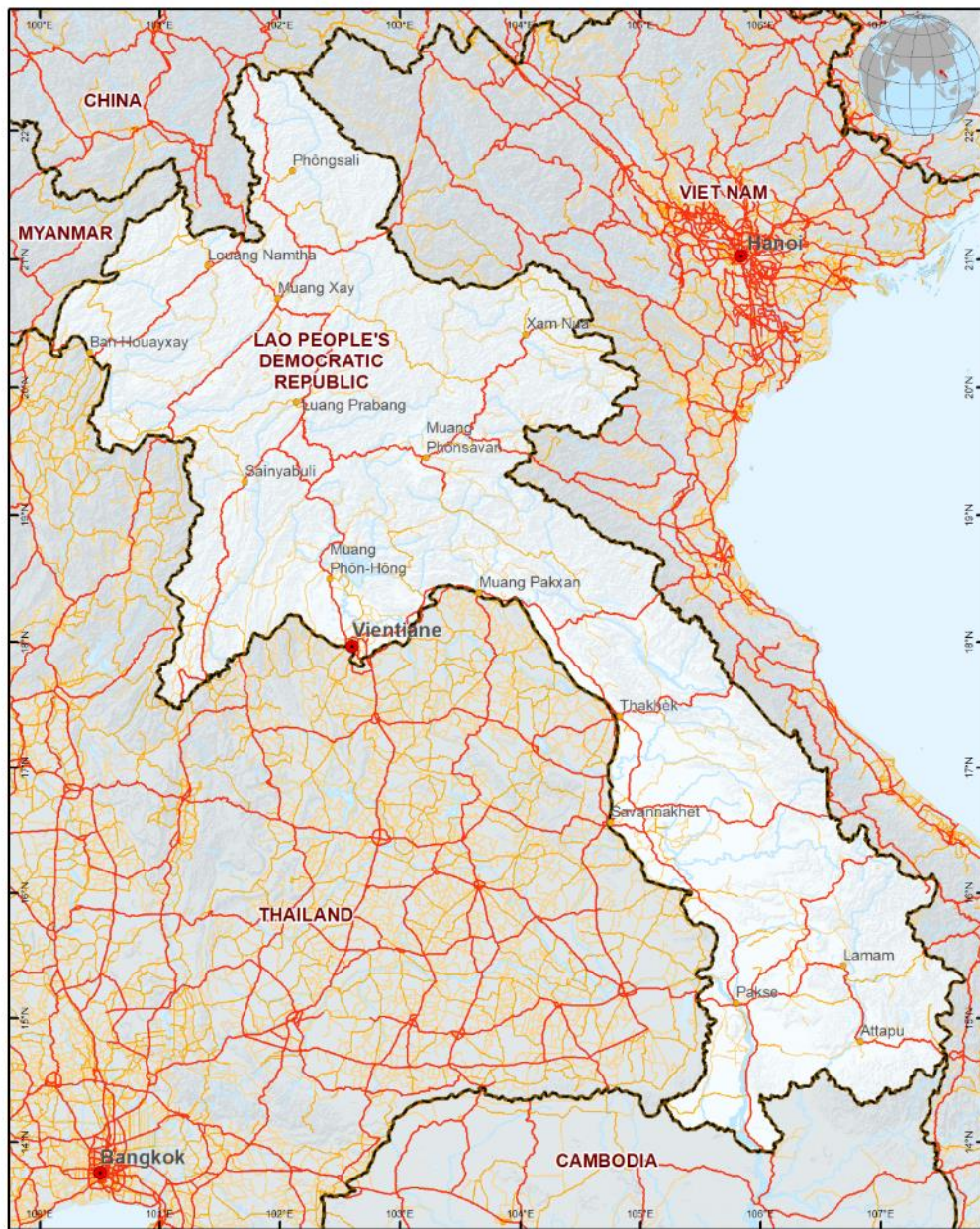
# 3- Data Collection and Processing

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



**LAOS**

**Road Network**

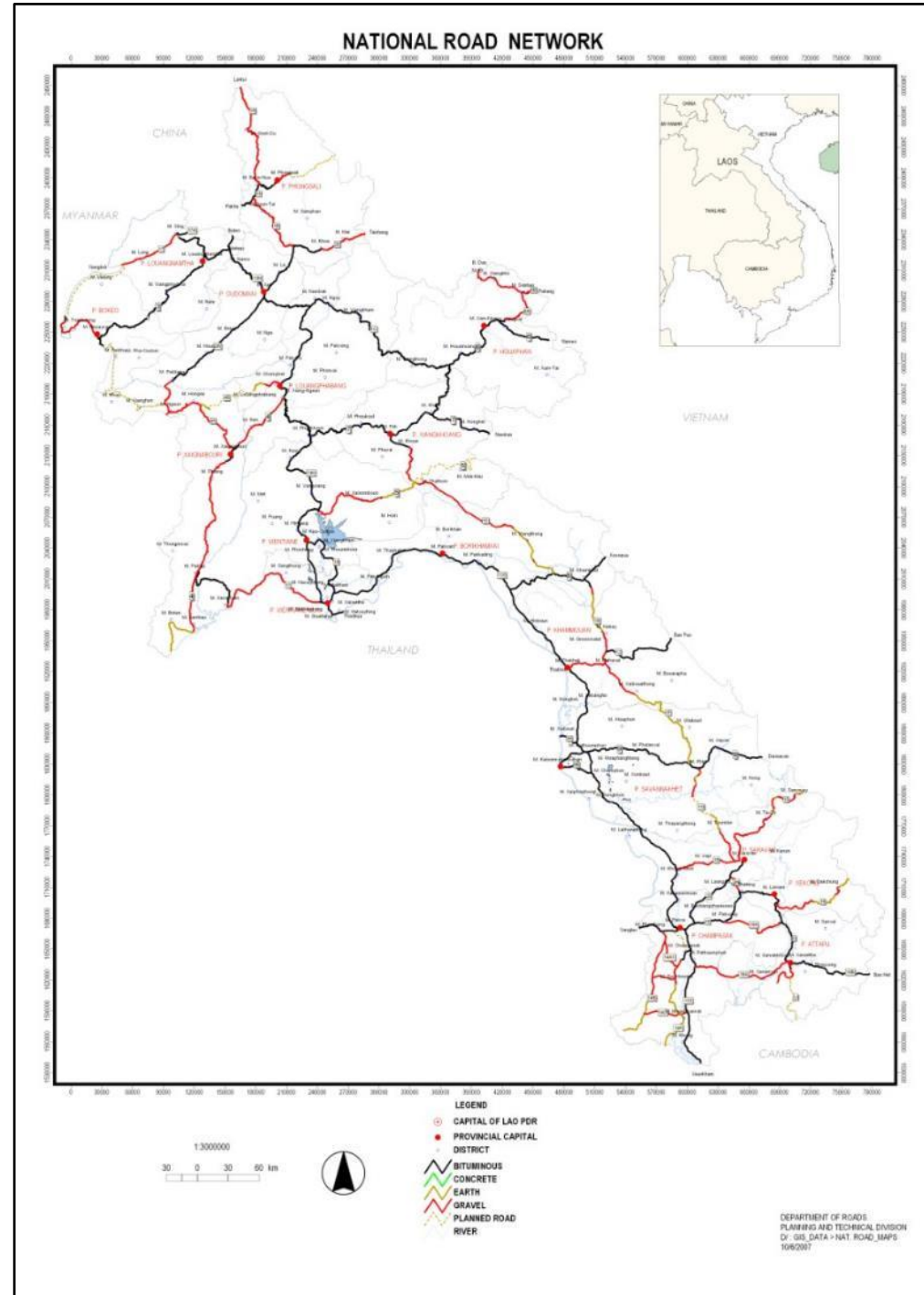
Kilometers

0 100

Nominal Scale  
14,500,000 at A4

- Primary Road
- Secondary Road
- Tertiary Road
- National Capital
- Major Town
- Intermediate Town
- International boundaries
- Undetermined boundaries
- Surface Waterbody

Date Created: 16 - JULY - 2018  
 Map Name: LAO\_C1\_Road\_Net  
 Data Source: WFP UN/WHO, GADM, GLOIS, ESRI, GeoNames, OpenStreetMap  
 Email: mapinfo@logcluster.org  
 Website: www.logcluster.org  
 OGE GIS Unit, WFP HQ, Rome/Ita



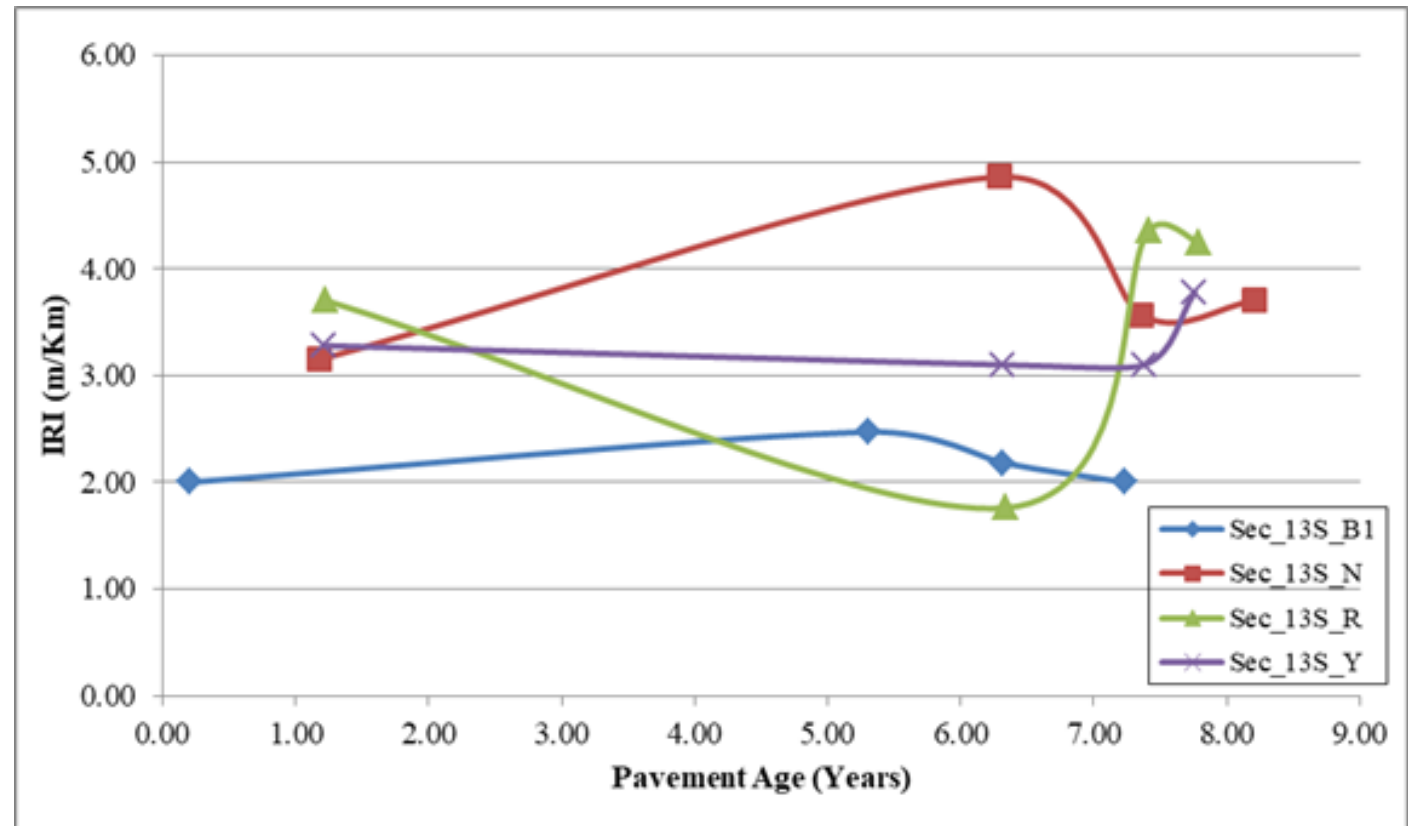


For Roughness modeling, IRI was taken as the dependent variable and the calculated **Pavement Age** and Cumulative Equivalent single axle loads (**CESAL**), were considered as independent variables.

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	<b>0.40</b>
CESAL	0.72	<b>0.40</b>	1

AC Model			
Variable	IRI	Age	CESAL
IRI	1	0.82	0.82
Age	0.82	1	<b>0.56</b>
CESAL	0.82	<b>0.56</b>	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		
<b>DBST Model</b>						
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 <sup>4</sup> Axle/Lane	0.02	130.06	16.08	20.75
<b>AC Model</b>						
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 <sup>4</sup> Axle/Lane	0.03	27.13	5.72	4.41

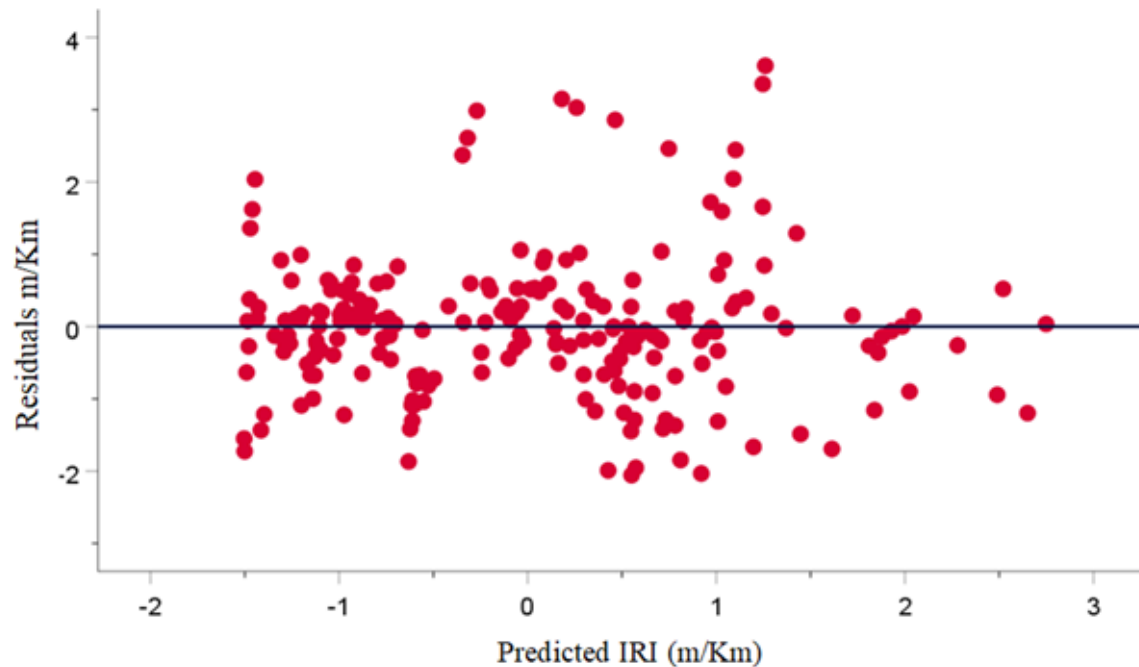
# 4- Roughness Prediction Model

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

$$\text{IRI} = 3.001 + 0.264 \text{ Age} + 0.03 \text{ CESAL}$$

( $R^2=0.944$ ,  $\text{SEE}=0.482$  m/Km,  $N=215$ )

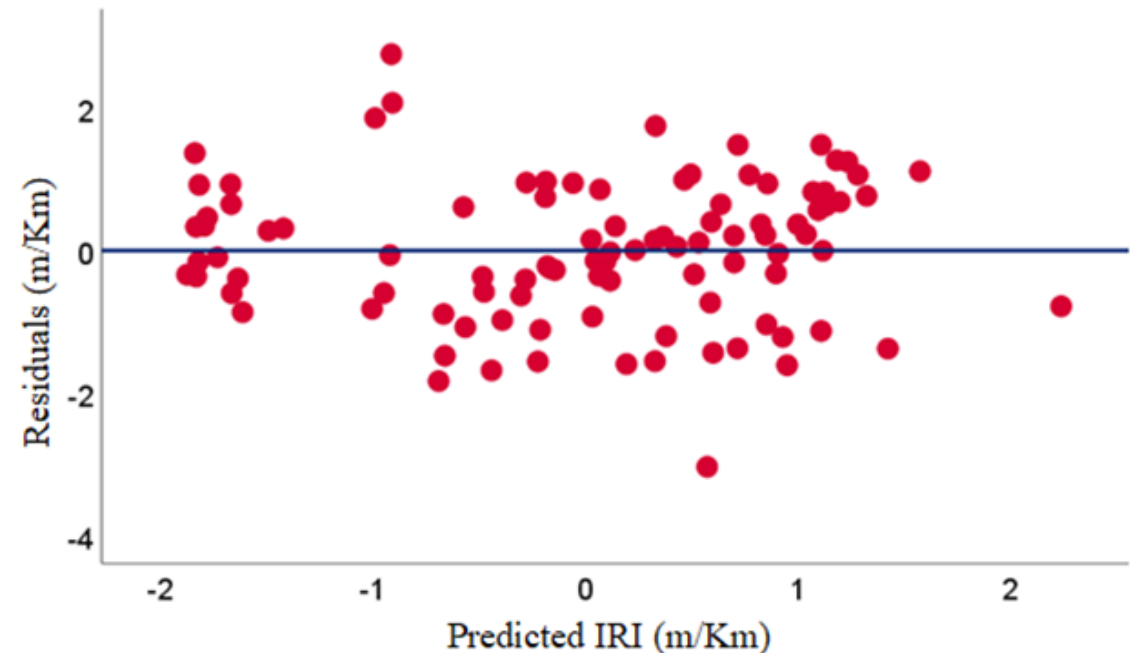


Graph of Residuals versus Predicted IRI for **DBST** Roads

## IRI Model for **AC** Pavement

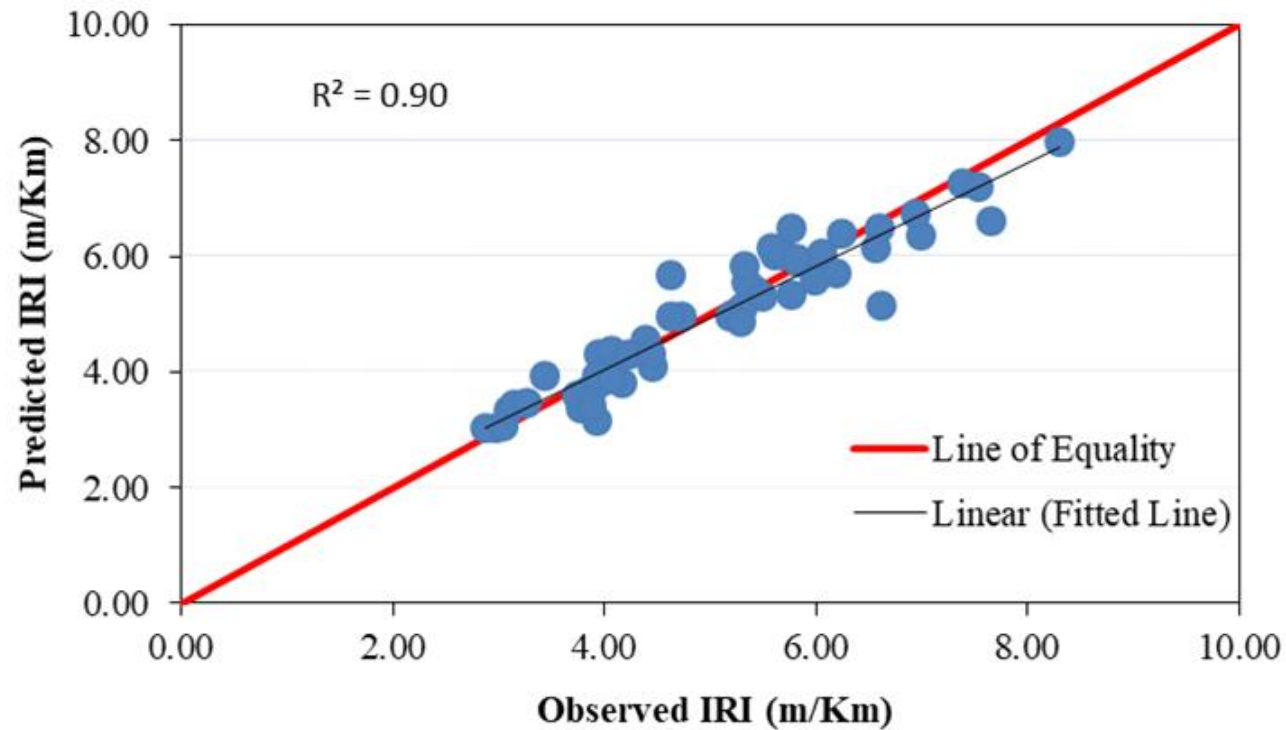
$$\text{IRI} = 1.791 + 0.205 \text{ Age} + 0.091 \text{ YESAL}$$

( $R^2=0.918$ ,  $\text{SEE}=0.402$  m/Km,  $N=98$ )

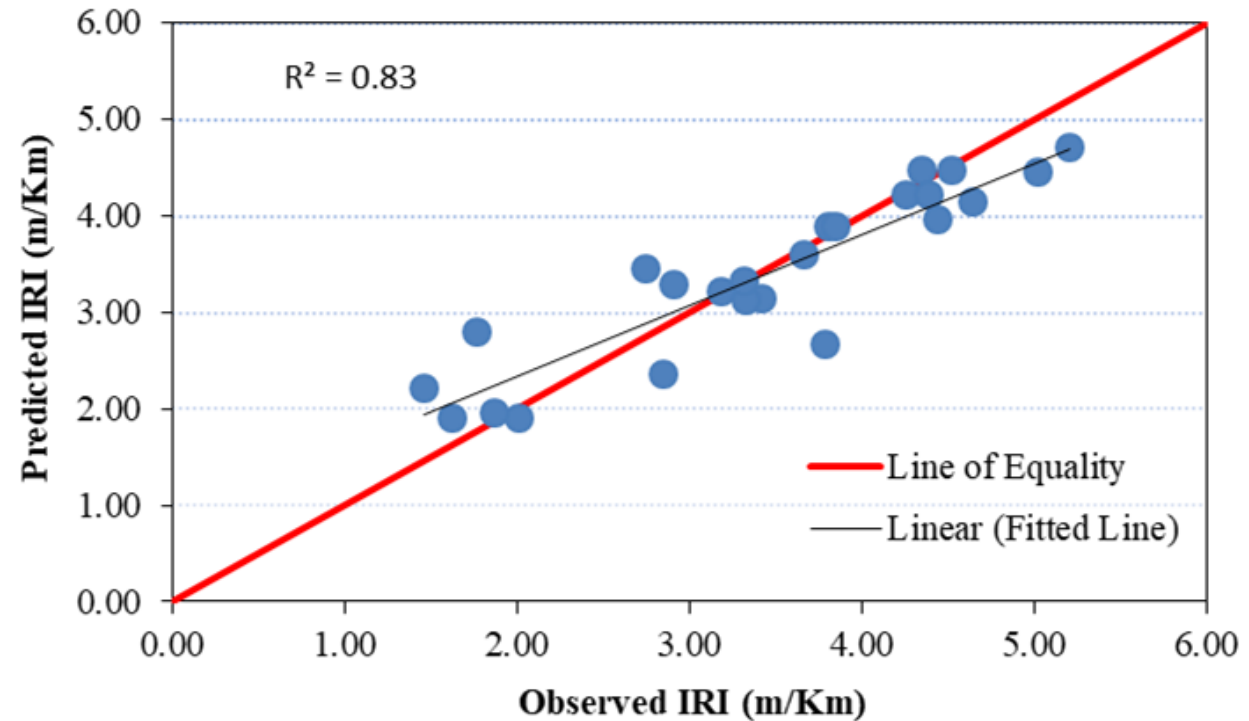


Graph of Residuals versus Predicted IRI for **AC** Roads

# 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
<b>DBST Model</b>				
Age	0.264	27.232	3.7348E-71	1.188
CESAL	0.030	18.309	1.5469E-45	1.188
<b>AC Model</b>				
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**

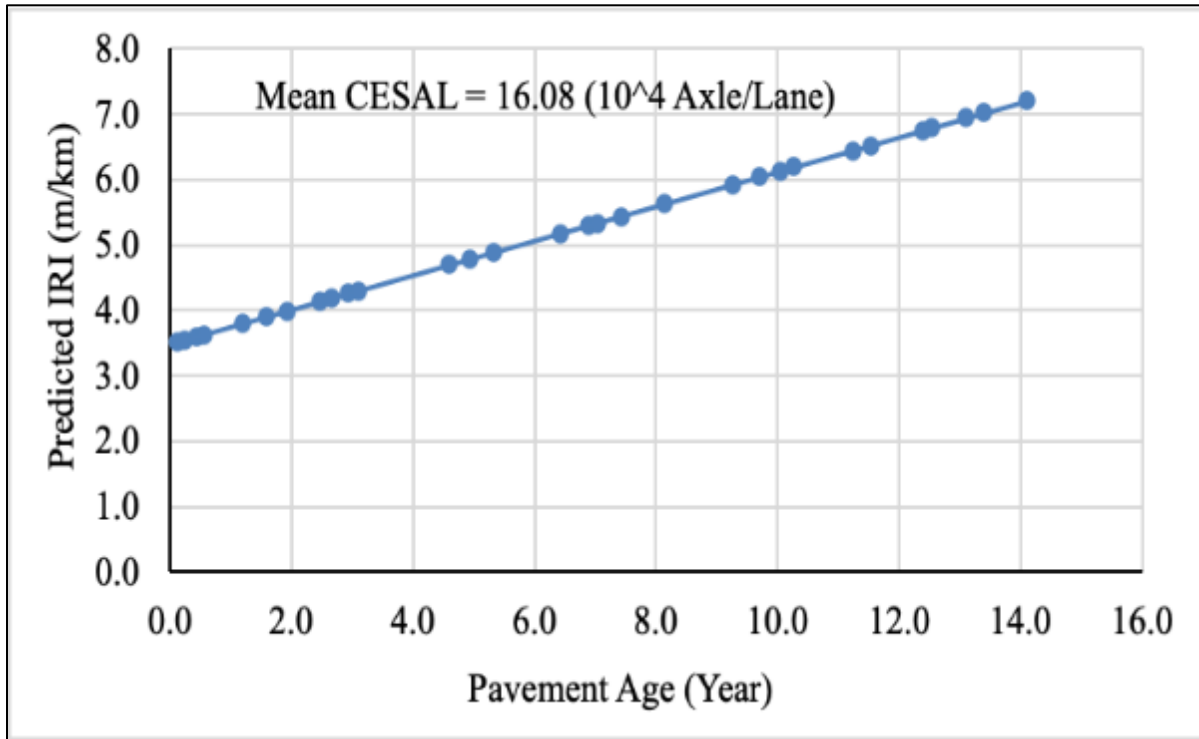
It’s evident that the variance Inflation Factor (VIF) is always greater than **1**

## ANOVA Results of the models

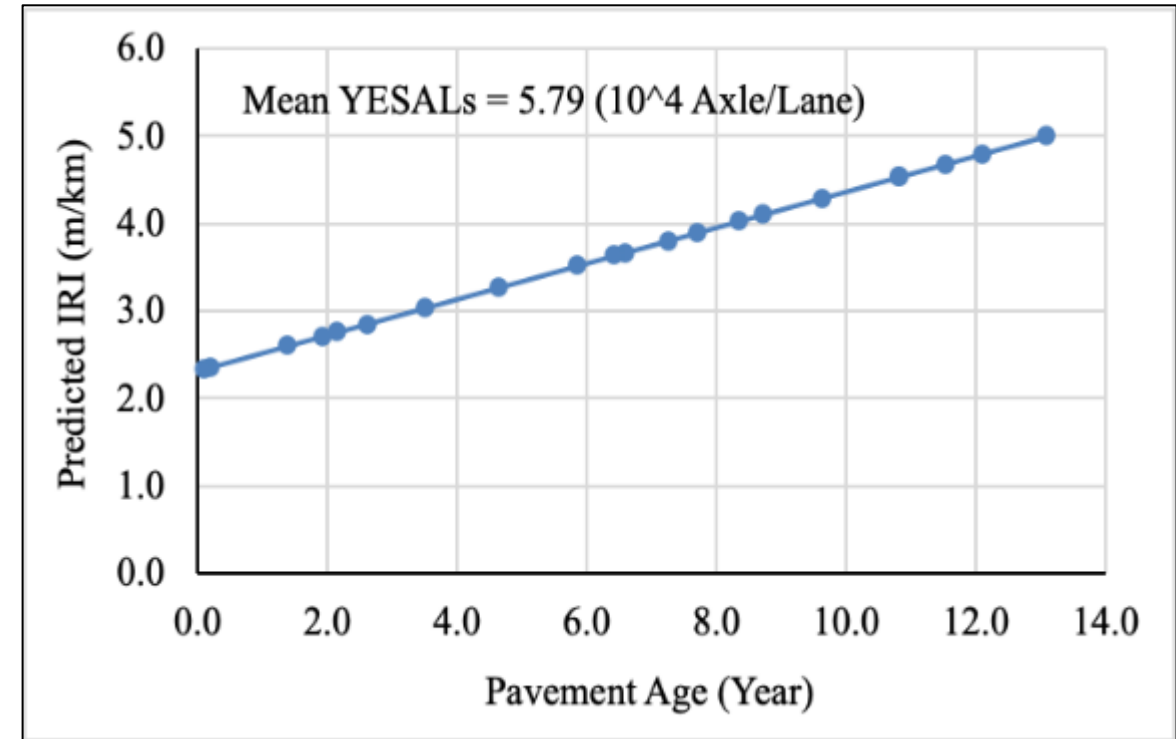
	df	SS	MS	F	Significance F
<b>DBST Model</b>					
Regression	2	407.057	203.529	874.978	3.6858 E-103
Residual	212	49.313	0.233		
Total	214	456.370			
<b>AC Model</b>					
Regression	2	82.00	41.00	253.548	8.0861 E-39
Residual	95	15.362	0.162		
Total	97	97.362			

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

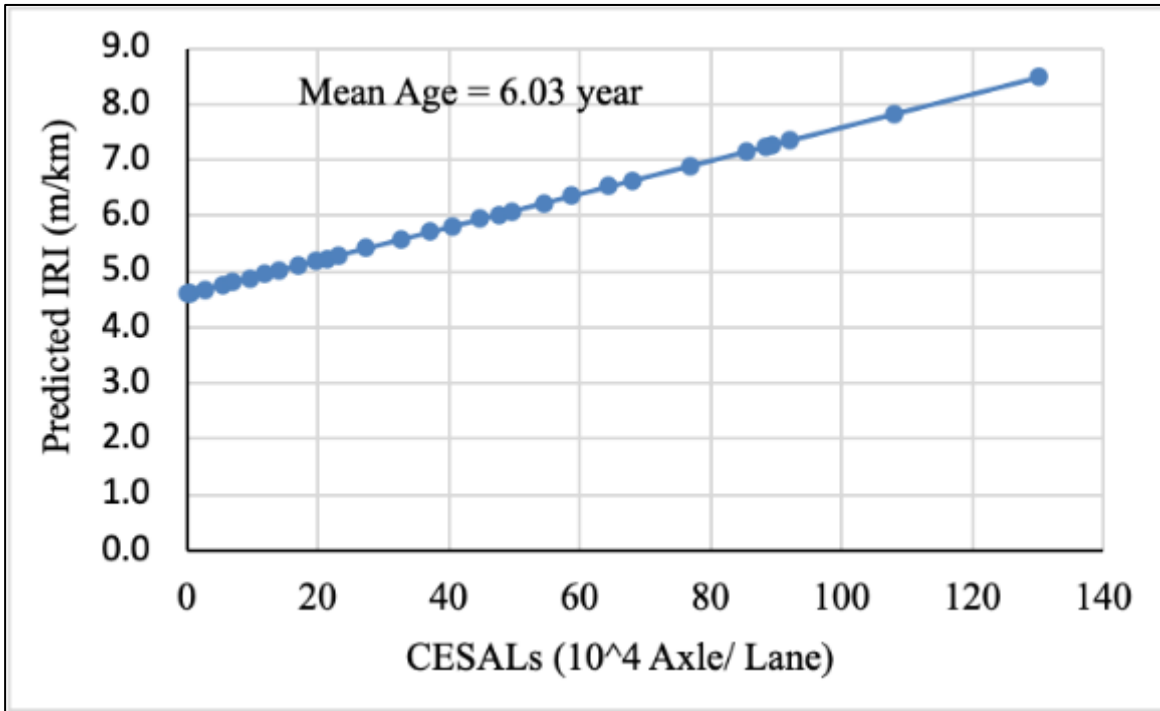


Plot of pavement age and the corresponding IRI for the **DBST** proposed model

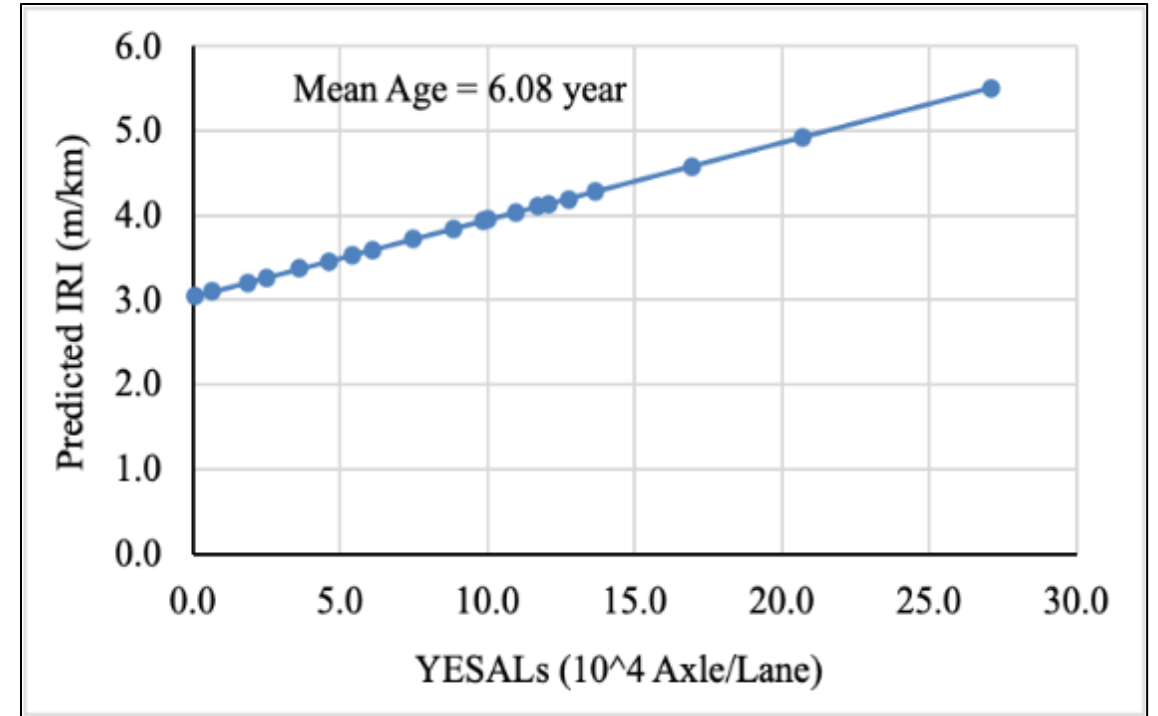


Plot of pavement age and the corresponding IRI for the **AC** proposed model

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





# 琉球大学

## UNIVERSITY OF THE RYUKYUS

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

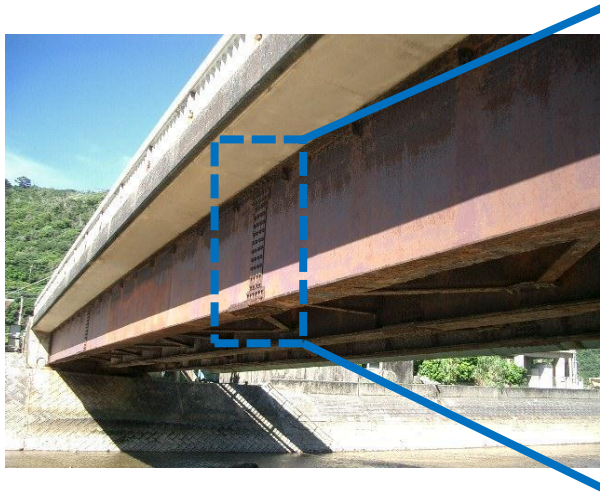
I plan to share the details and results of my research with my superiors and colleagues in the Philippines.

### 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**

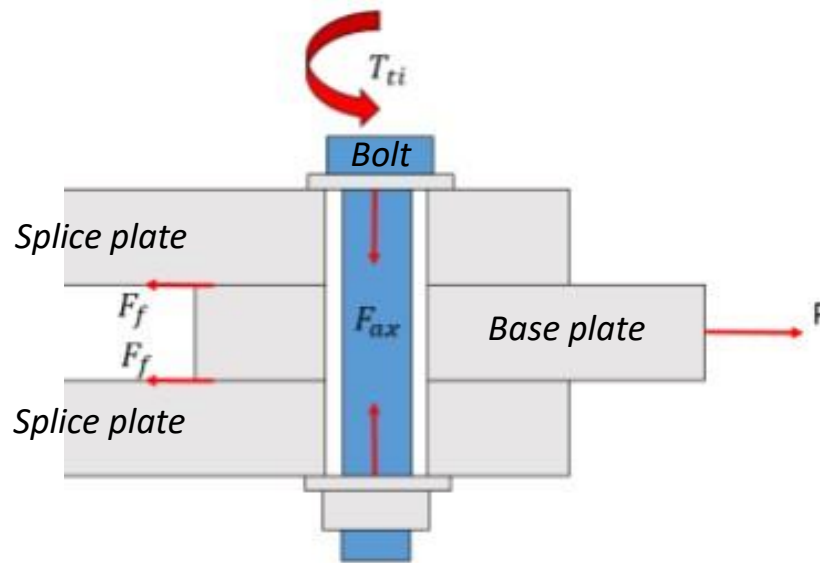
# Background and purpose



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.

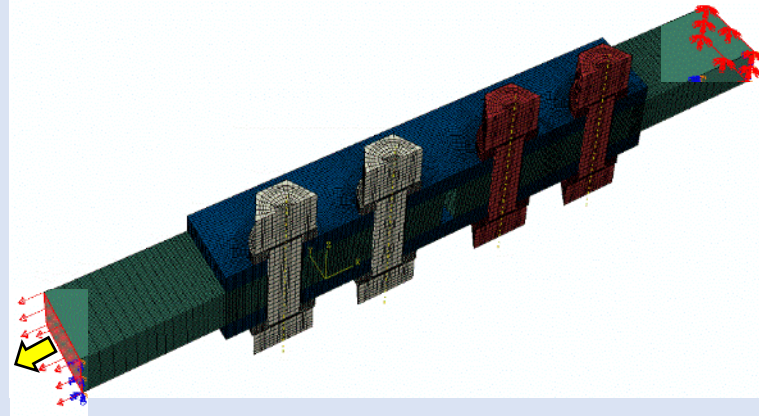


# Research flow

## Conduct Experiment



## FEM Analysis



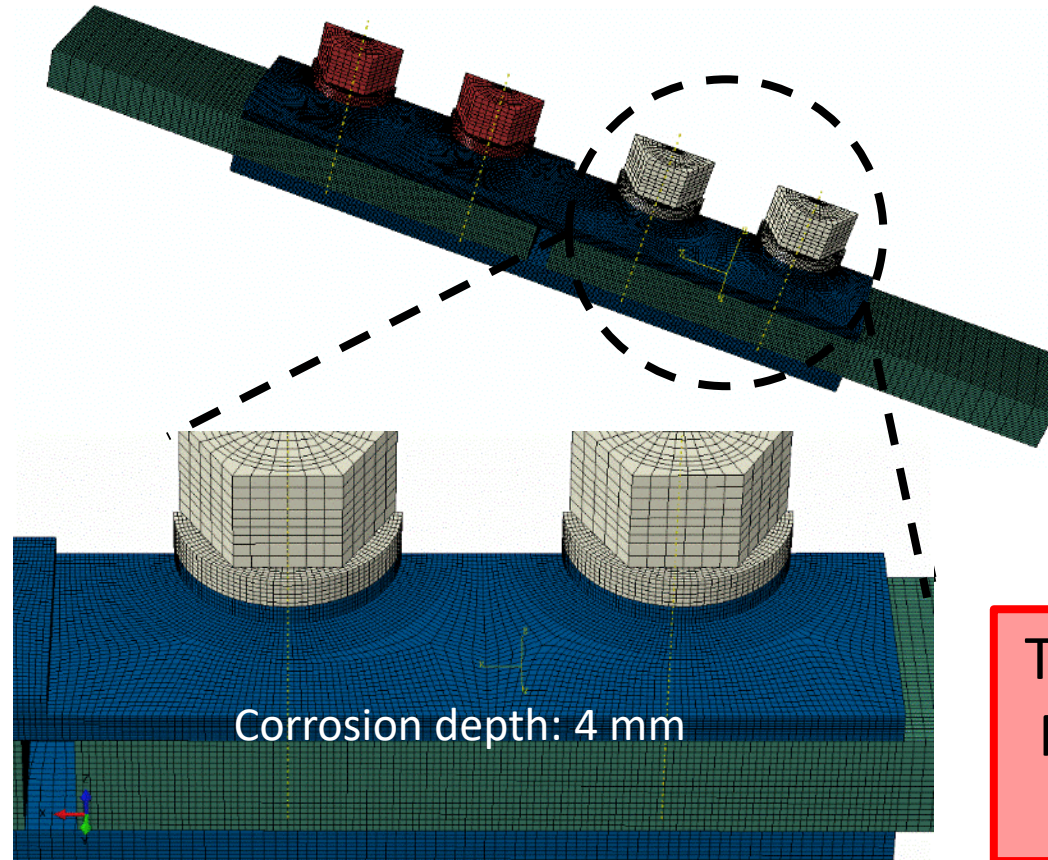
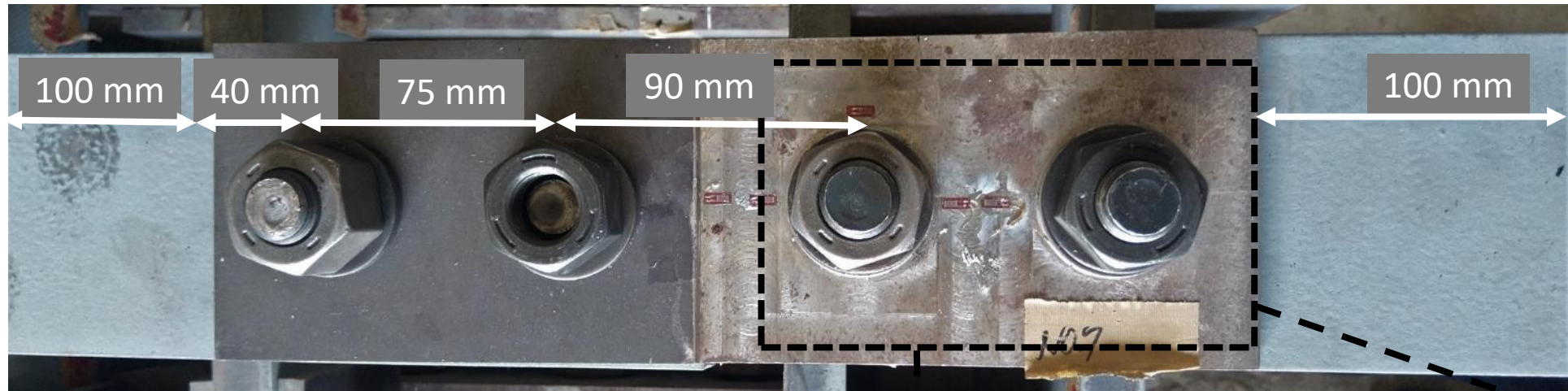
## Establish evaluation method

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

## Change Parameters

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

# Experiment samples and analysis models

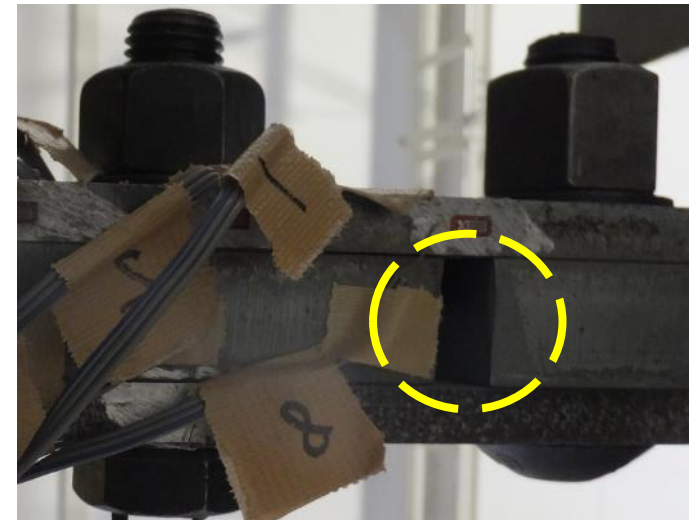
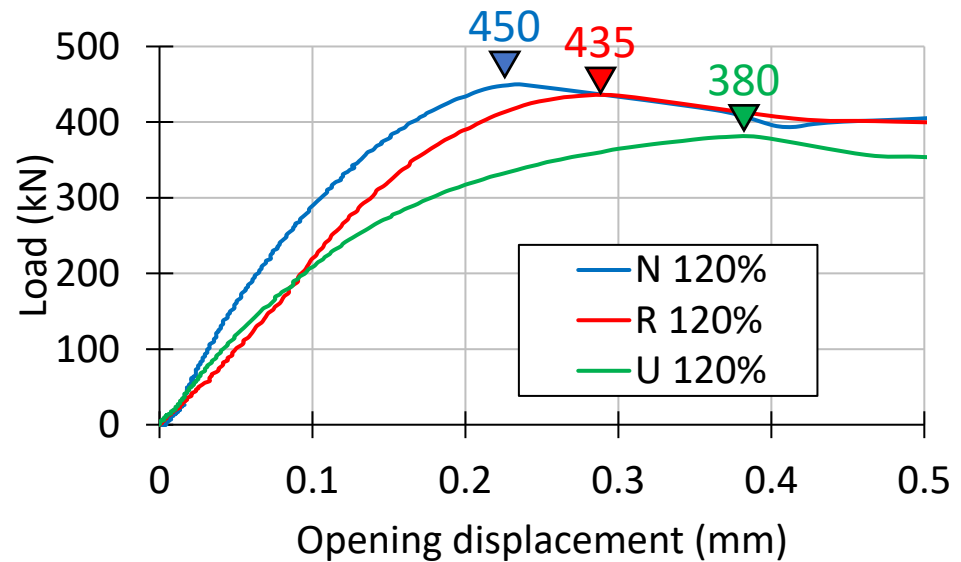
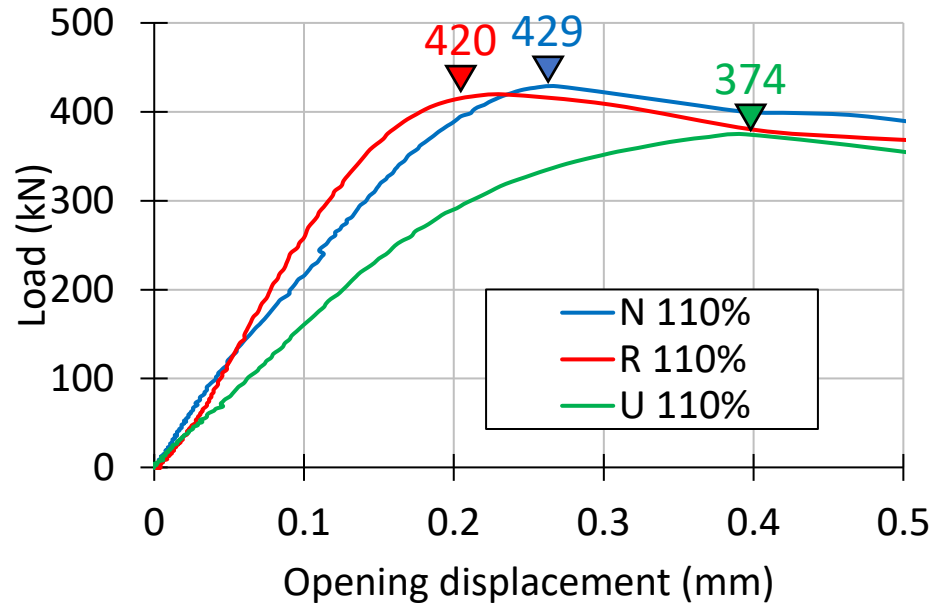
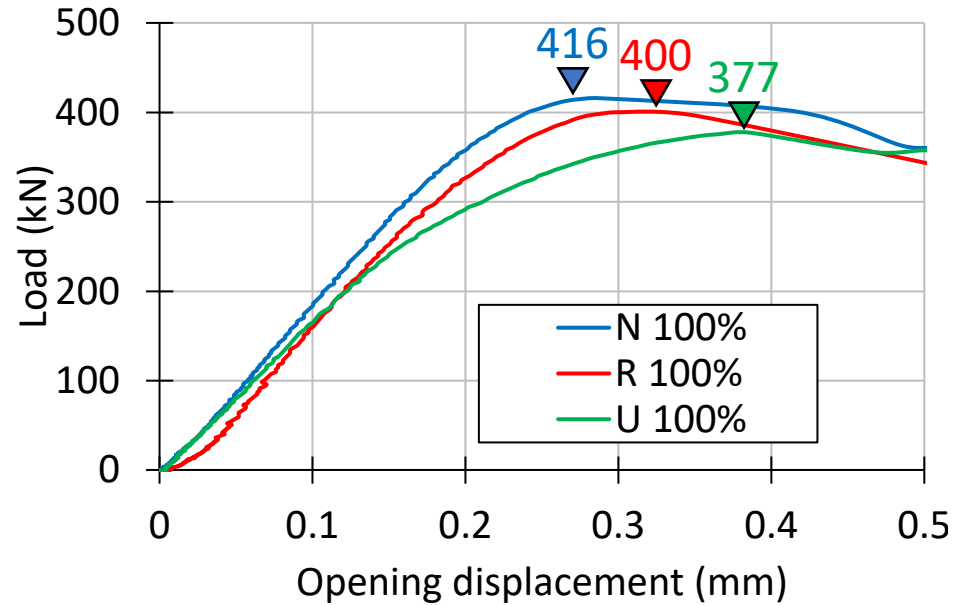


Uniform corrosion case: ***U***

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

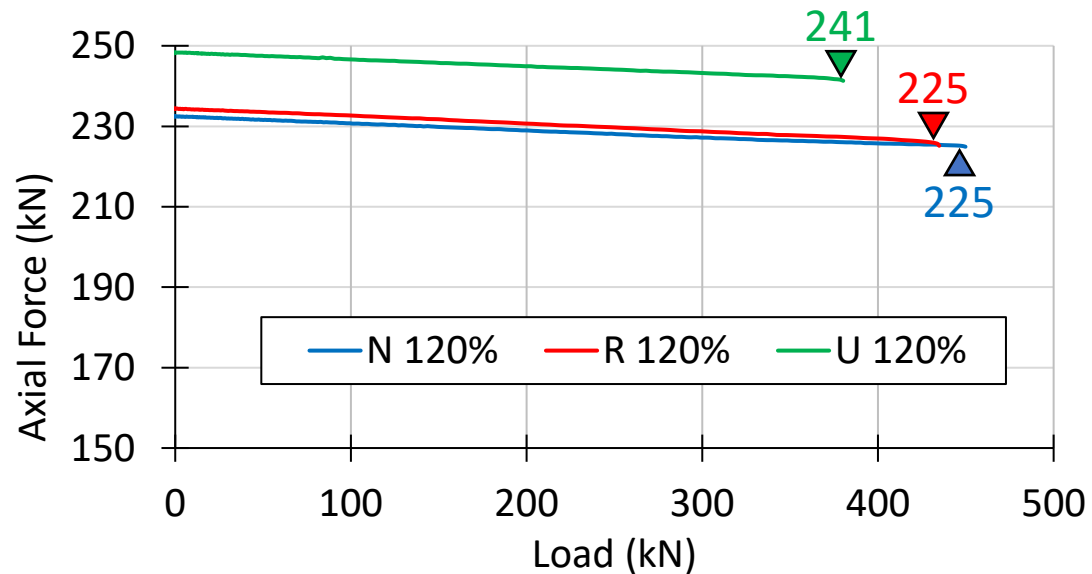
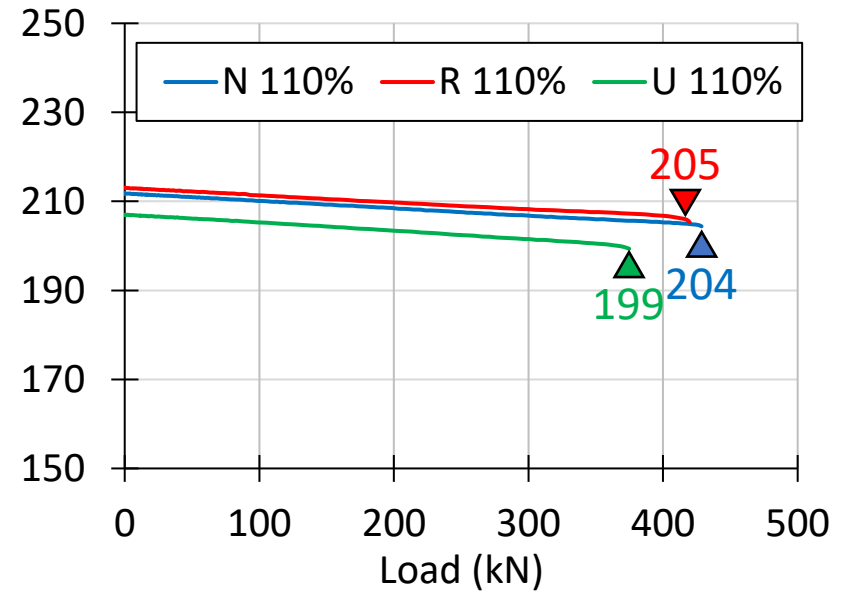
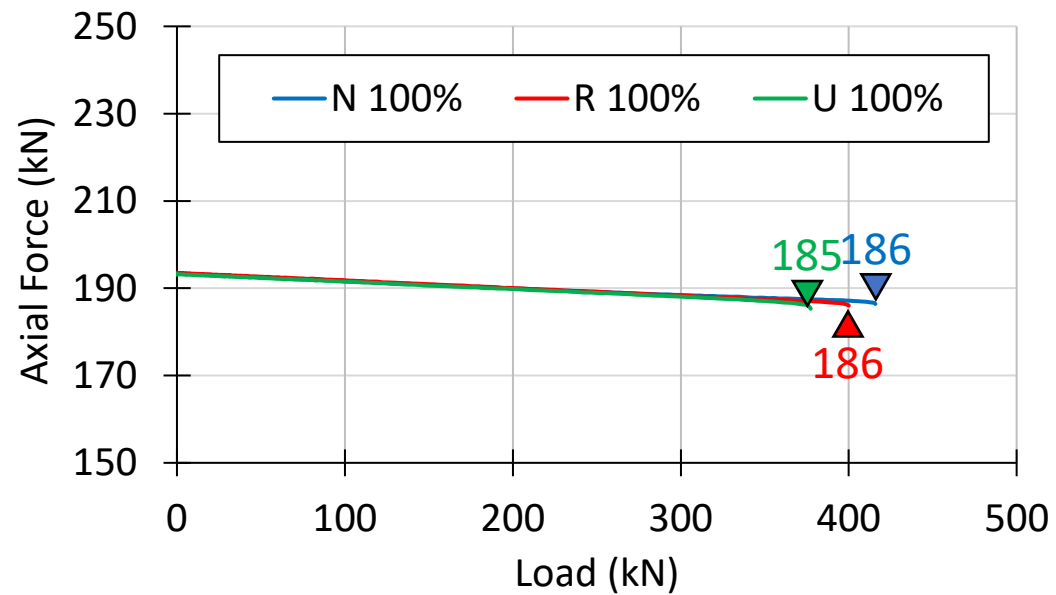


# Experiment results



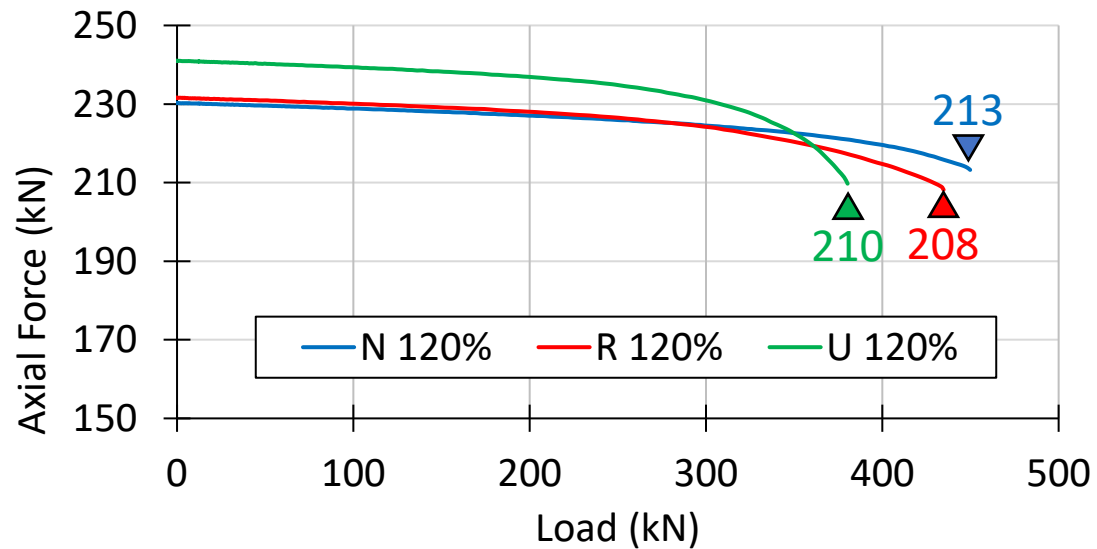
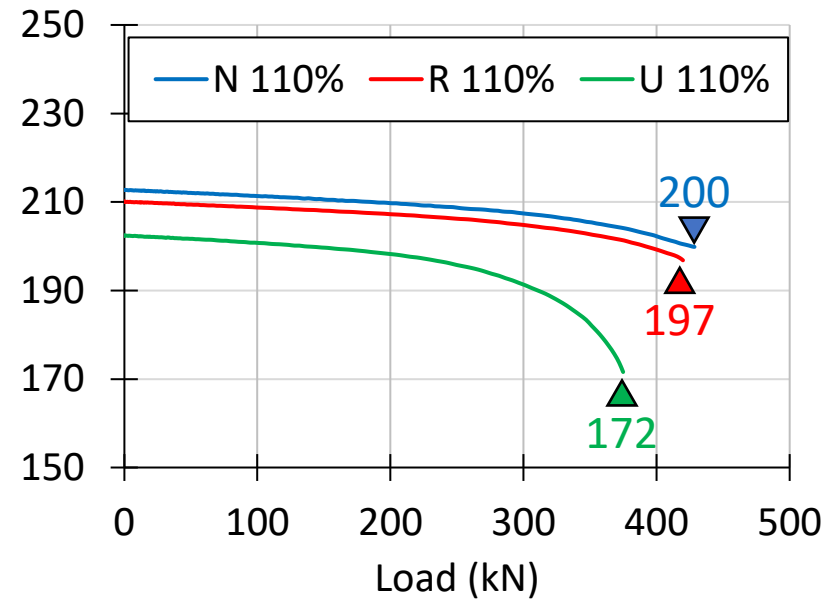
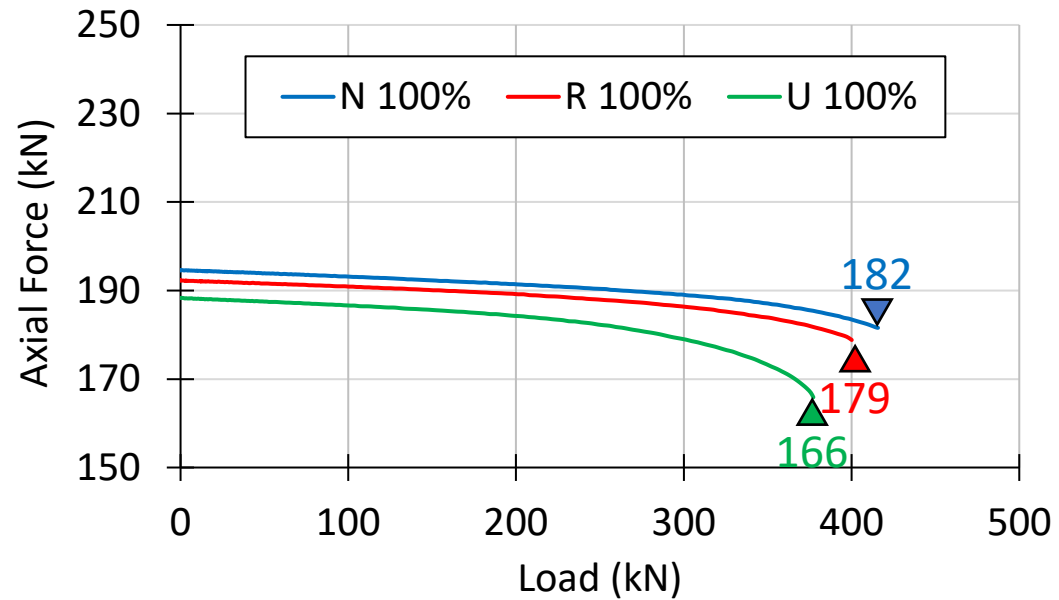
Cases with corrosion have larger opening displacements.

# Axial force (outside bolt)



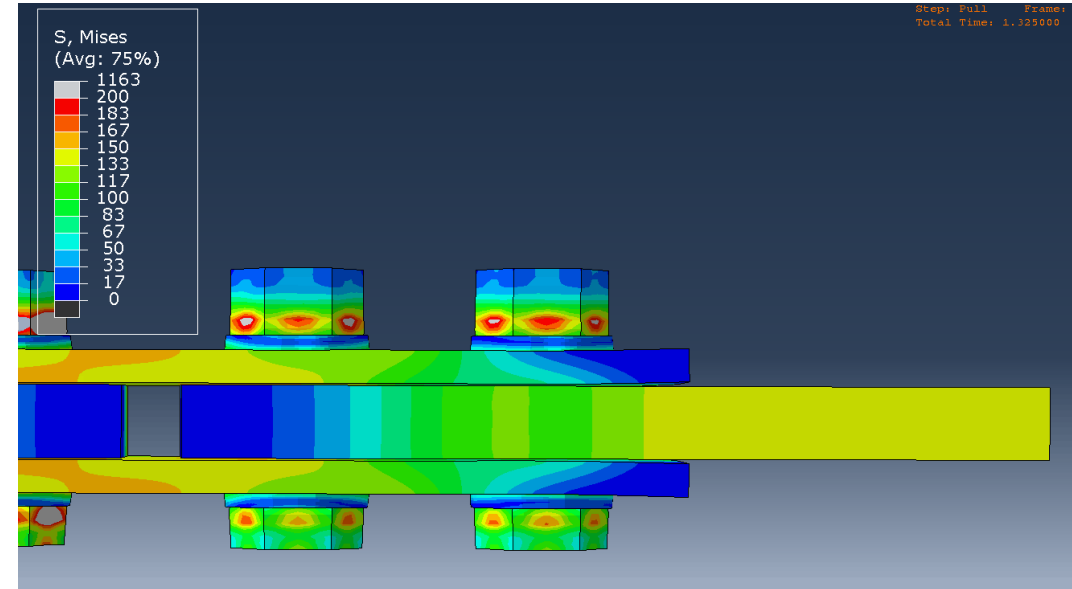
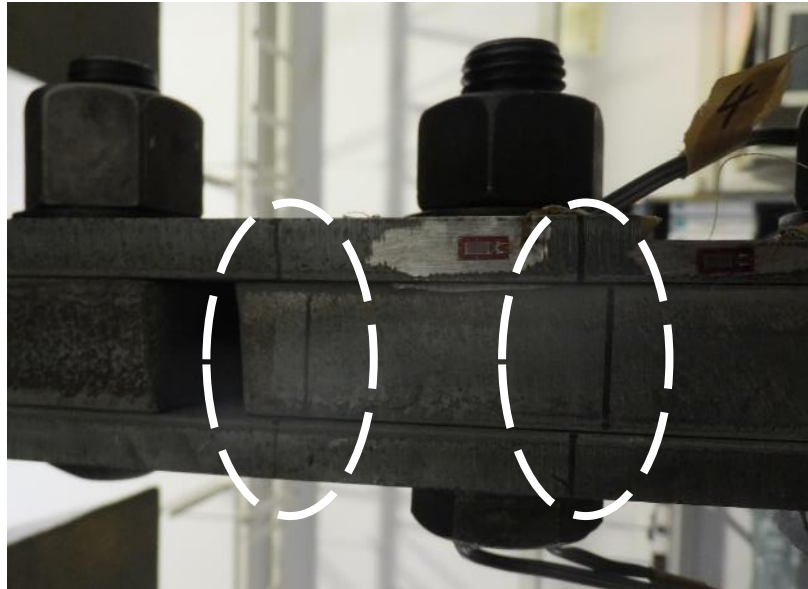
All cases have almost the same reduction.

# Axial force (inside bolt)



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

# Experiment and analysis results



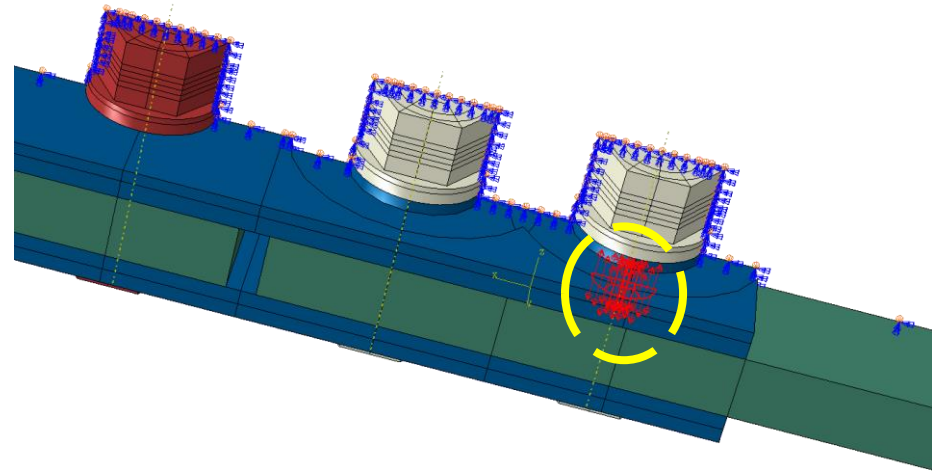
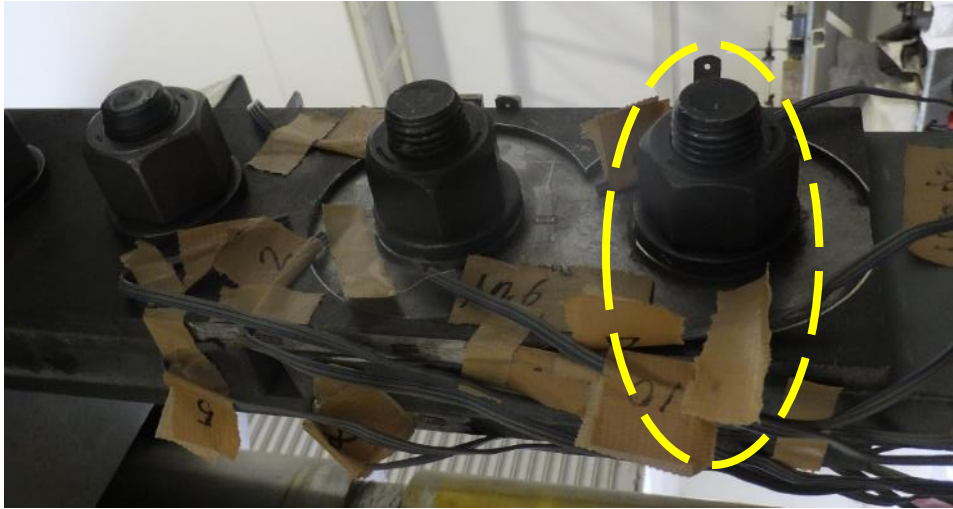
Case	Slip strength (kN)		
	100% AF	110% AF	120% AF
<b>N</b>	416	426	450
<b>R</b>	400	420	435
<b>U</b>	377	375	380

Case	Slip strength (kN)			Accuracy
	100% AF	110% AF	120% AF	
<b>N</b>	415	429	448	99.54%
<b>R</b>	395	411	433	98.72%
<b>U</b>	380	383	380	99.02%

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



# Axial force (outside bolt)

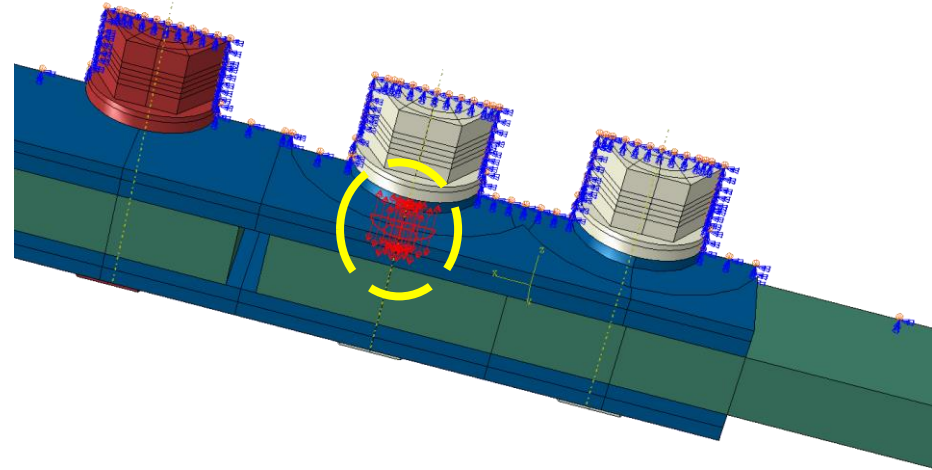


Case	Axial force during slip (kN)		
	100% AF	110% AF	120% AF
<i>N</i>	186	204	225
<i>R</i>	186	205	225
<i>U</i>	185	199	241

Case	Axial force during slip (kN)			Accuracy
	100% AF	110% AF	120% AF	
<i>N</i>	185	203	222	99.21%
<i>R</i>	185	203	223	99.20%
<i>U</i>	185	198	238	99.42%

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

# Axial force (inside bolt)

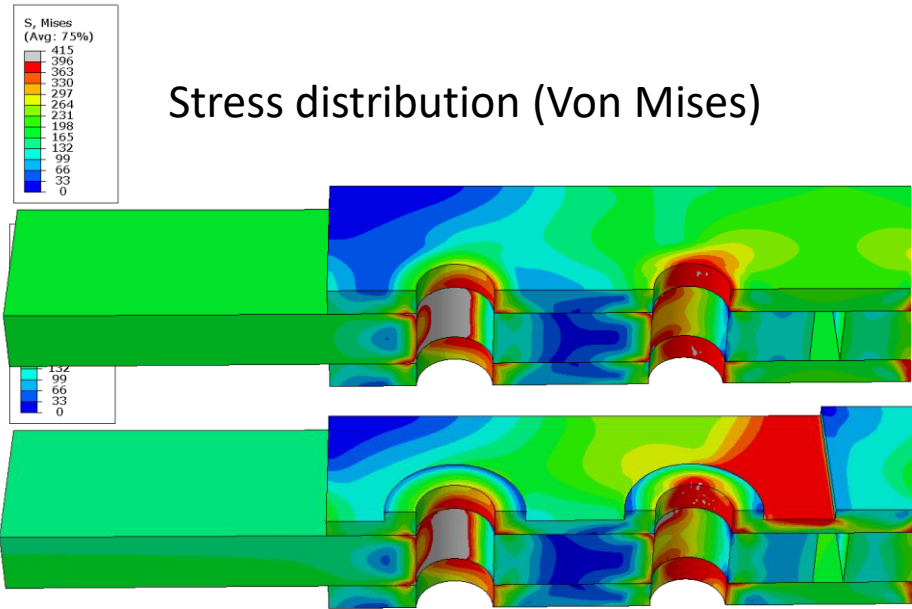
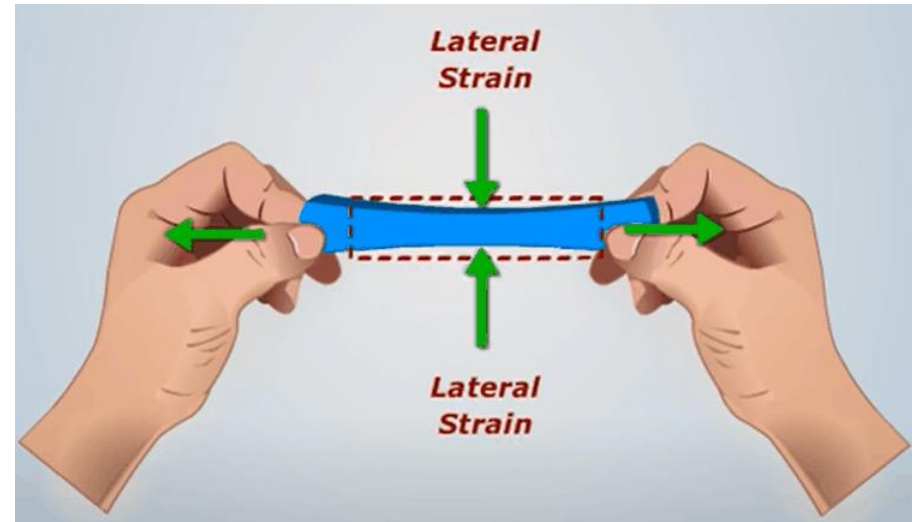
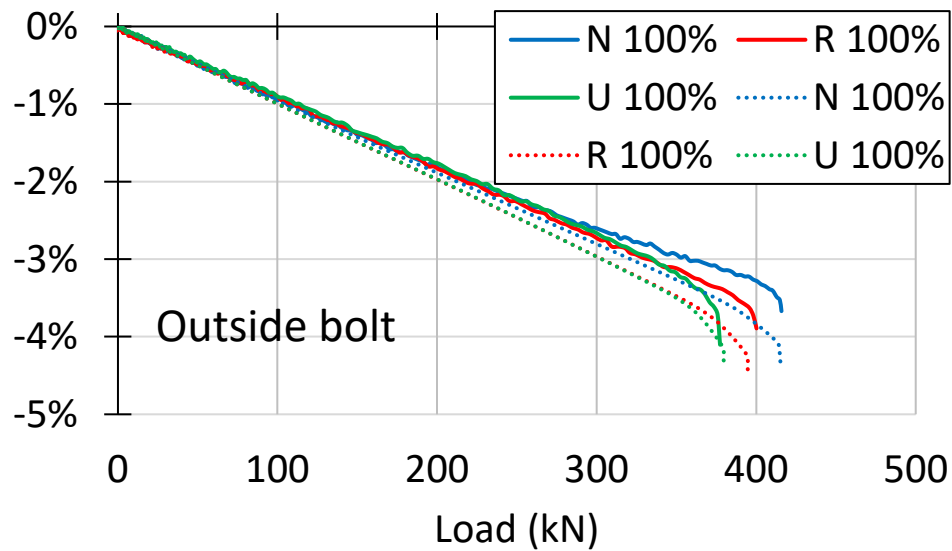
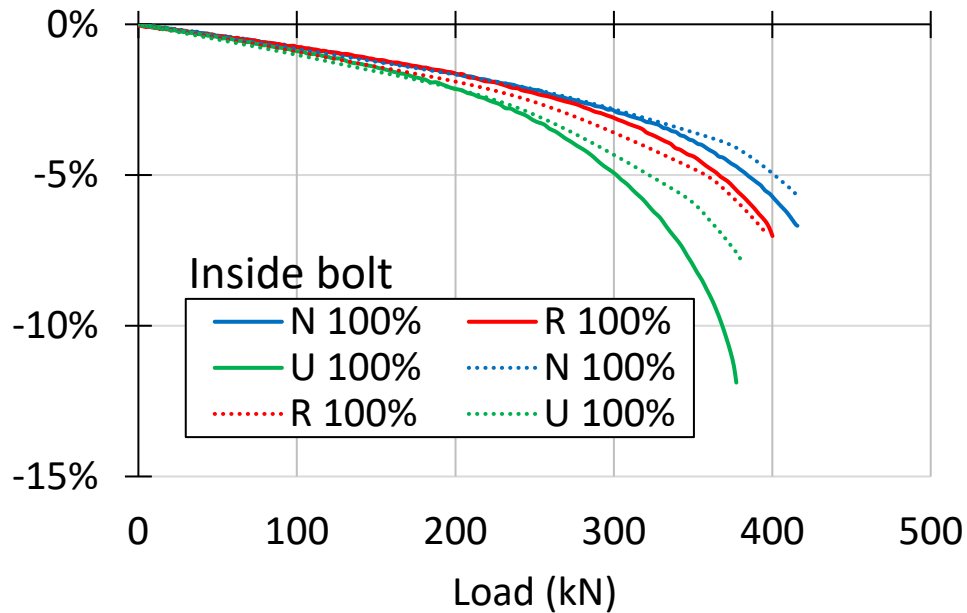


Case	Axial force during slip (kN)		
	100% AF	110% AF	120% AF
<i>N</i>	182	200	213
<i>R</i>	179	197	208
<i>U</i>	166	172	210

Case	Axial force during slip (kN)			Accuracy
	100% AF	110% AF	120% AF	
<i>N</i>	184	200	216	99.16%
<i>R</i>	179	195	213	98.86%
<i>U</i>	174	186	222	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.

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

ご清聴ありがとうございました。

Thank you for listening.



