一般財団法人 首都高速道路技術センター
Shutoko Technology Center

ACECC, The 46th Executive Committee Meeting, TC 28 Seminar:
Application of Monitoring Technology for Infrastructure Maintenance
Philippine Institute of Civil Engineers, Inc.

# Phase-free Road Management with Monitoring Technology

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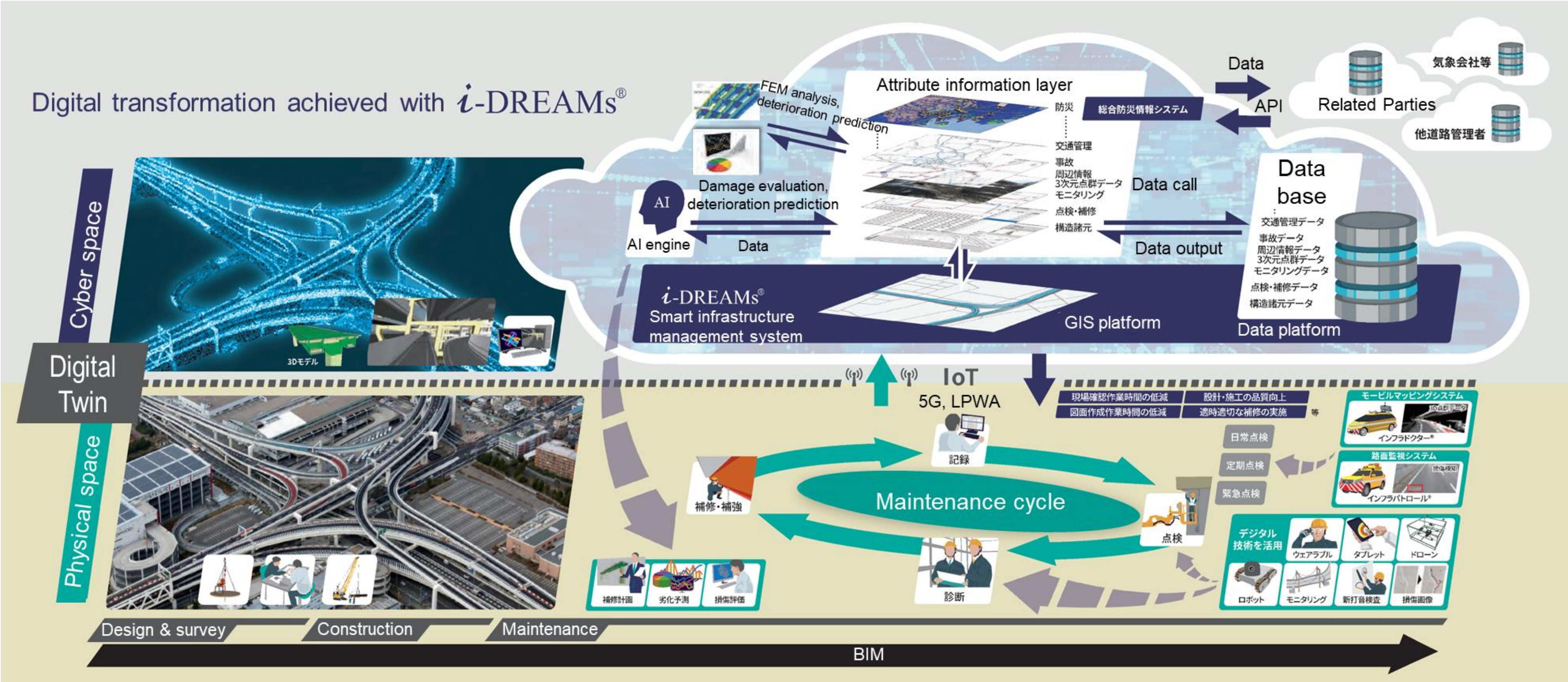
# Contents

# 1. Implementation of Digital Twin with Data Platform

- **Collecting online sensor data from physical space , are integrated and stored into a GIS platform.**
- These big data are analyzed by AI and simulation, and the solutions are fed back to the infrastructures in the physical space.
- **We could realize more efficient and advanced infrastructure management through a digital twin that seamlessly integrates and utilizes data throughout the lifecycle from survey, design, and construction to maintenance and management.**



# Development and Integration of Advanced Technologies to Realize Digital Twin

- To visualize the site conditions based on obtained data and information

Keywords and key technologies:

1) **Remote**: remote monitoring, remote diagnosis, remote control technology(robotics)
2) **Non-contact, non-destructive**: sensing technology (sensor, image, laser, radar), satellites, UAV, etc.
3) **Online and real-time**: high-speed communications (5G/6G), IoT, cloud

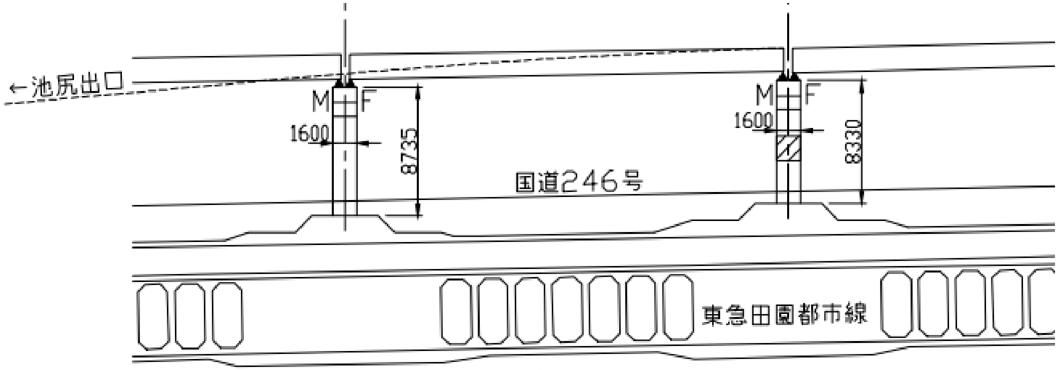
# 2. Application of Monitoring to Infrastructure Management

- Inspection and diagnosis of road structures is basically conducted through periodic inspections by close visual inspection every five years in Japan.
- However, there are issues with the adequacy, cost, and efficiency of the diagnosis, such as the fact that the person conducting the inspection changes each time, there is a risk that the results may differ depending on the skill of the inspector, close visual inspections are very expensive, and similar inspections are performed on apparently sound areas.
- Therefore, with the recent development of sensor technology, data analysis and analysis technology, and communication technology, an environment has been developed in which highly accurate information can be easily obtained, and we believe that introducing monitoring into the current maintenance and management operations will help solve some of the inspection and diagnosis issues.

Objectives of the Study :

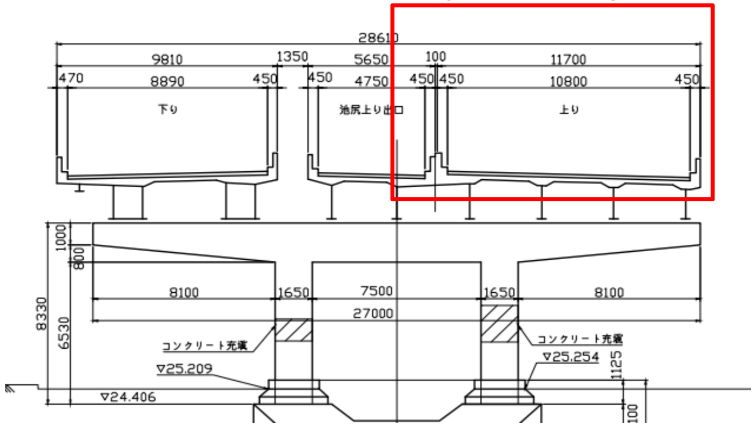
Monitoring and fatigue analysis of the existing RC slab of the Tokyo Metropolitan Expressway, where many cracks were found, **to predict its service life**.

Target bridges


side view

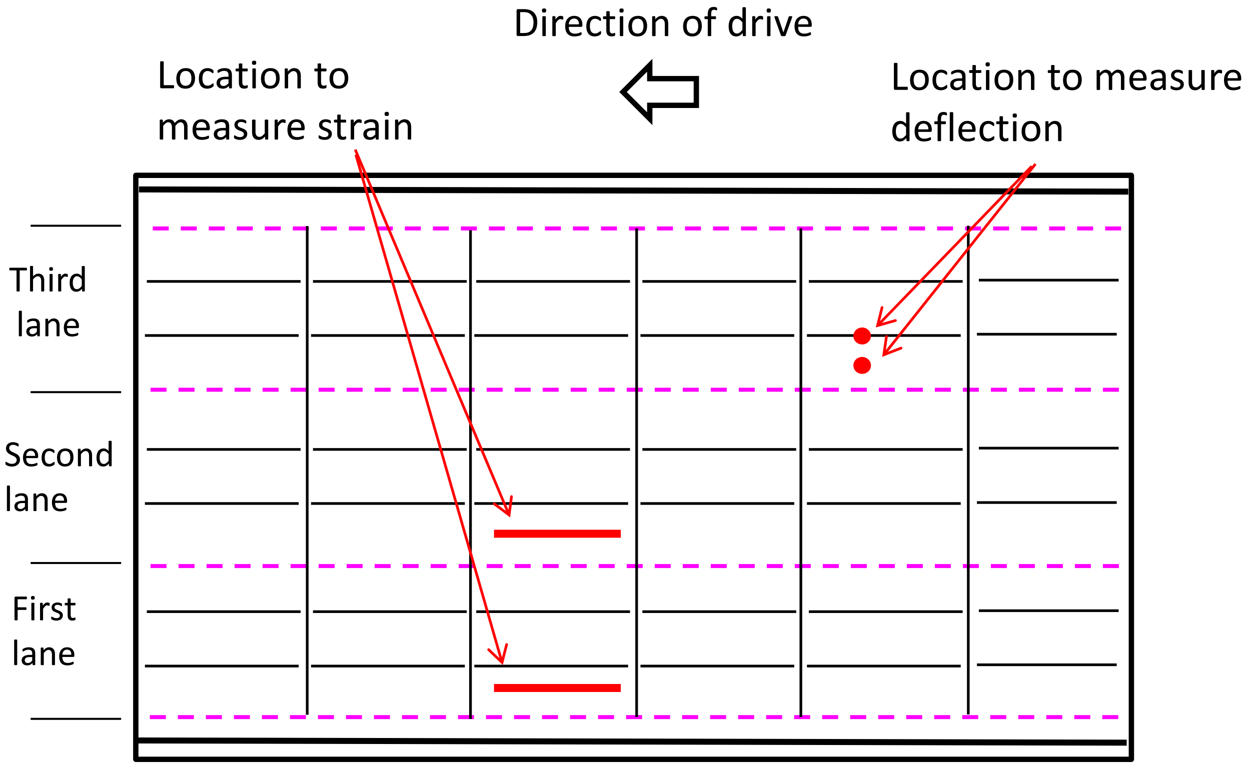
Scope of Objectives




Cross section

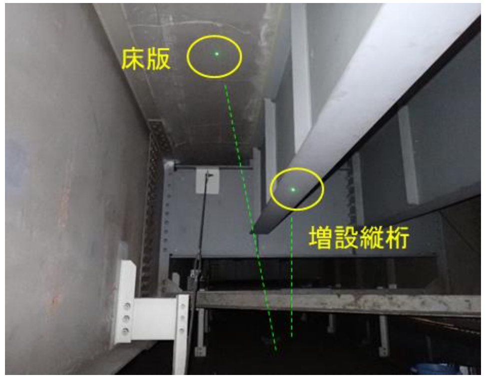
# In-site Measurements to Determine the Deterioration of Bridges in Service

- A 25-ton truck and a 12-ton truck were driven to measure the deflection and strain of the RC slab to determine the deteriorated condition of the bridge in service.
- <u>Verification of in-situ measurement results by wheel load running test and laser doppler/optical fiber</u>




(July 31, 2023)

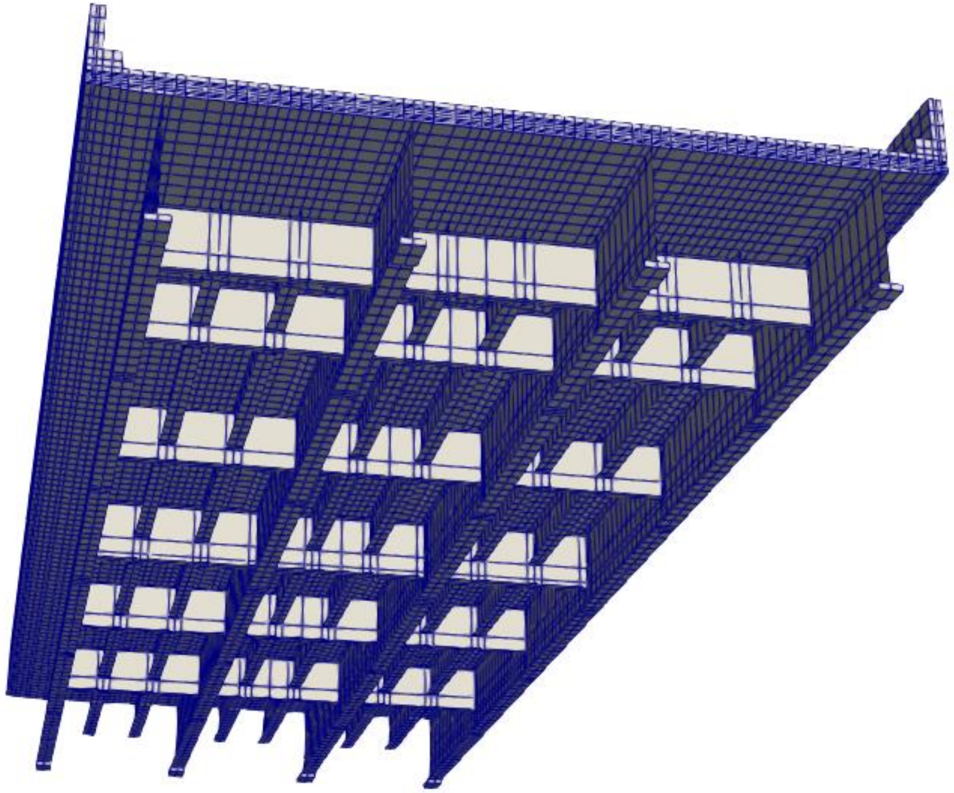

Measuring Strain with Fiber-Optic Sensors




Measurement of deflection by laser Doppler

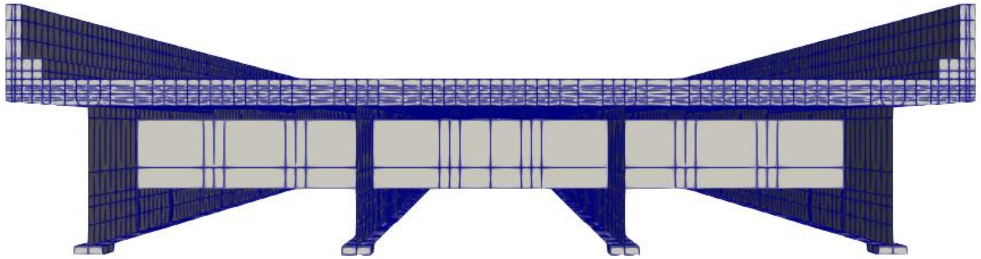
# Analytical Model of the Reinforced Concrete Slab

| Structural specification of RC slab | |
|---|---|
| Strength of Concrete | 35 $N/mm^2$ |
| Main rebar (upper edge, bottom edge) | D16@220mm |
| Rebar in transverse direction (upper edge) | D16@280mm |
| Rebar in transverse direction (lower edge) | D16@140mm |



Thickness of slab: 200mm

Thickness of pavement: 80mm



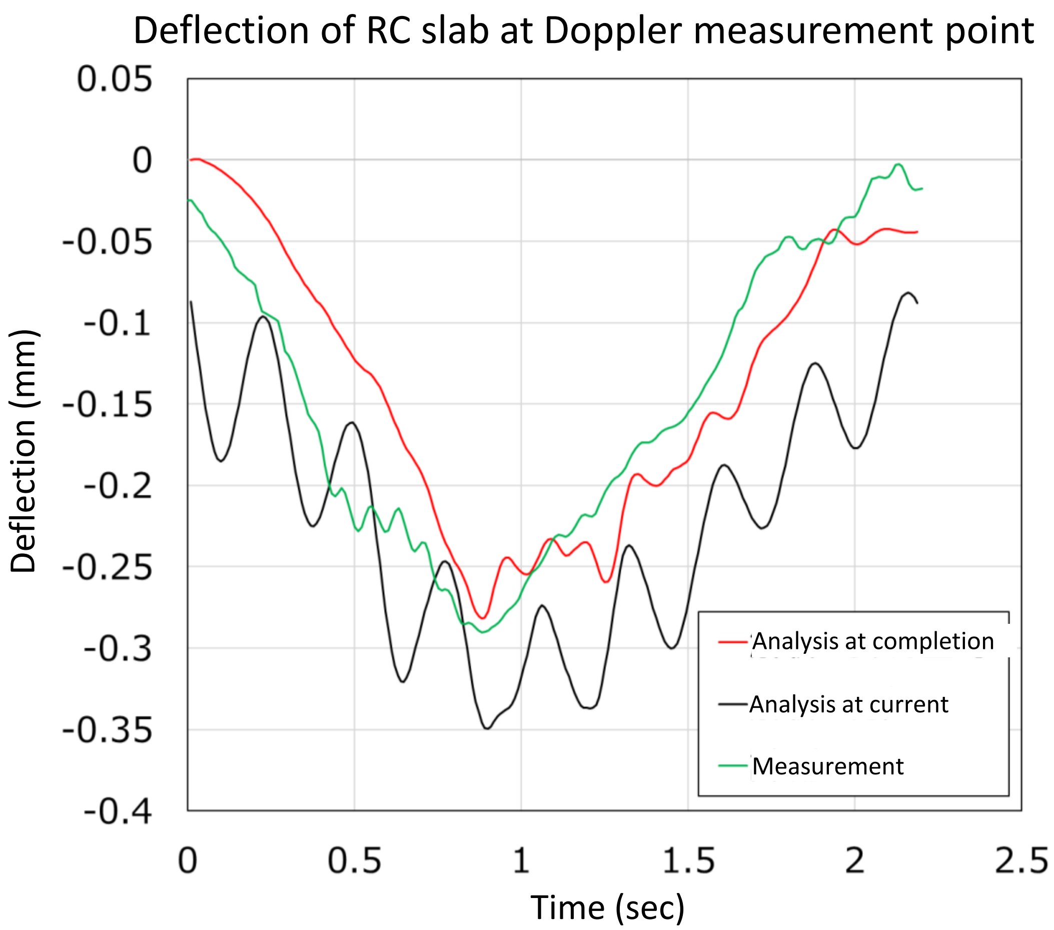
Reinforcements:

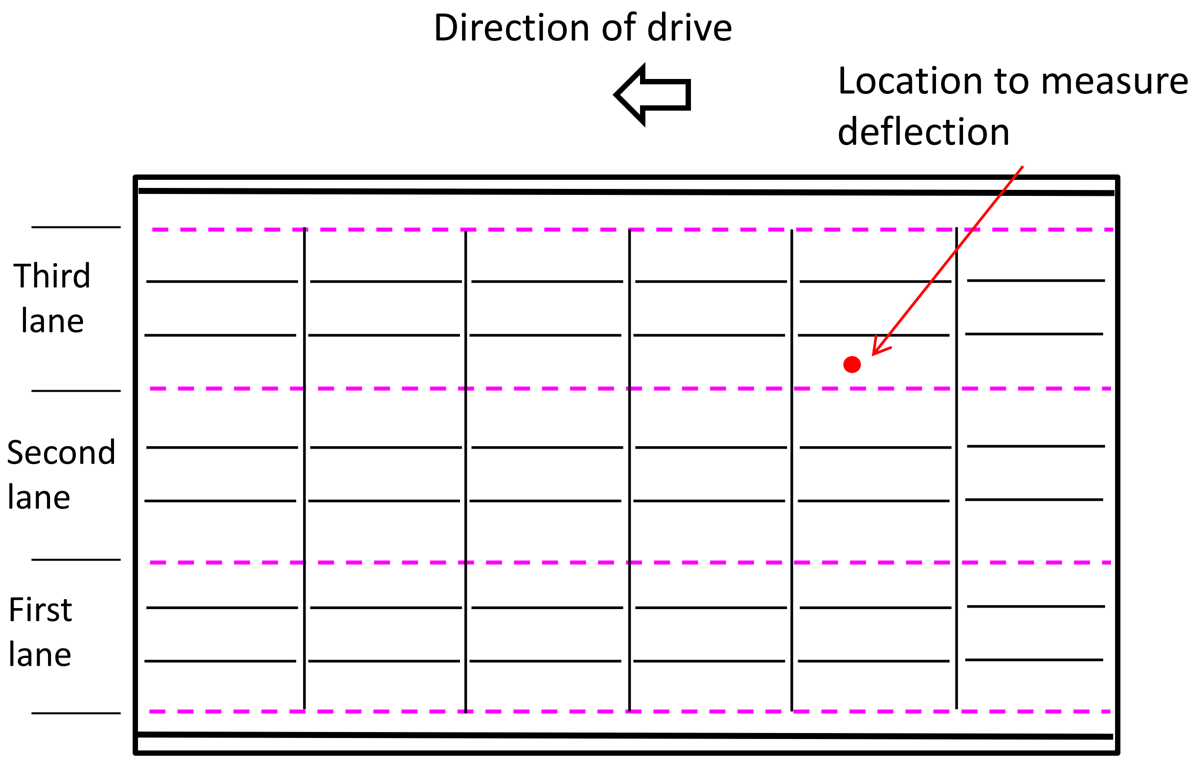
・4-main girder + 6-additional girder
・1- transverse girder + 5-additional transverse girder
・ Reinforced with steel plates at the edge of the RC slab

# Comparison of Analysis and Measurement Results

## Validation of the model through field measurements and analytical results

- Deflection of RC slab when one 25-ton vehicle is driven in the second lane after 52 years of heavy-duty driving
- Measurement data and analysis results were in close agreement.



# Comparison of Wheel Load Running Test and Analysis Results by COM3

■ The results of wheel load running tests of the slab constructed in 1964 will be compared with the results of the analysis by COM3.

**Test**

Wheel load running test
Specimen (dry)

Modeling →

**Analysis**

COM3 model

**Wheel load test**

- Strain Amplitude (Optical Fiber)
- Live load deflection

Comparison of results ⟷

**Fatigue Analysis**

- Strain amplitude (Average strain per meter)
- Live load deflection

# Wheel Load Running Test

- Wheel load running tests were conducted using fiber-optic sensors mounted on the underside of the floor slab.
- To measure strain response to fatigue progression

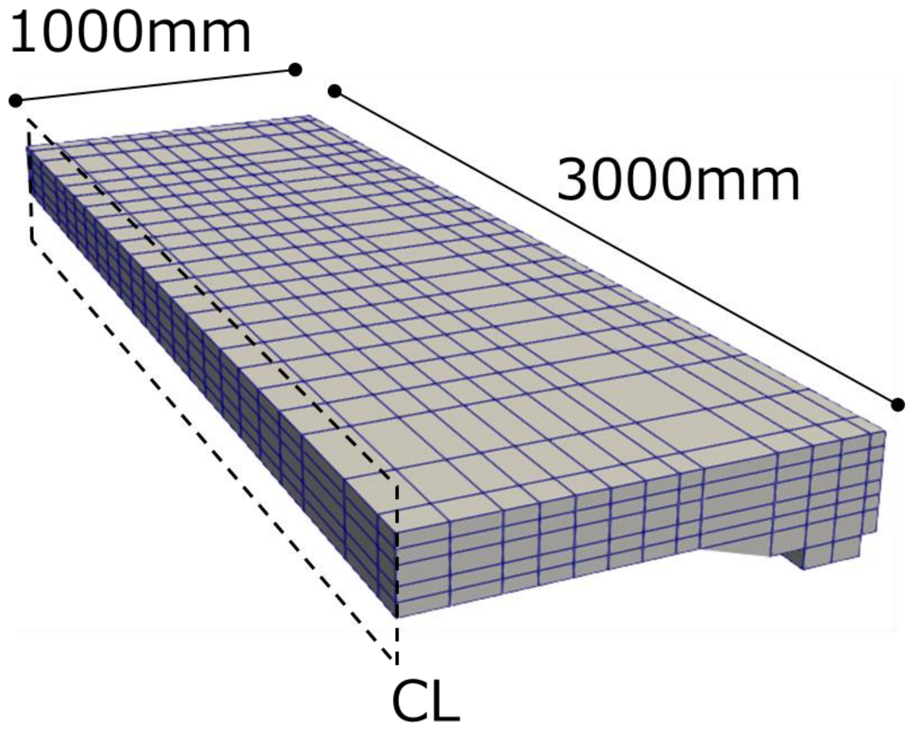
Wheel Load Running Test Equipment

Optical Fiber sensor

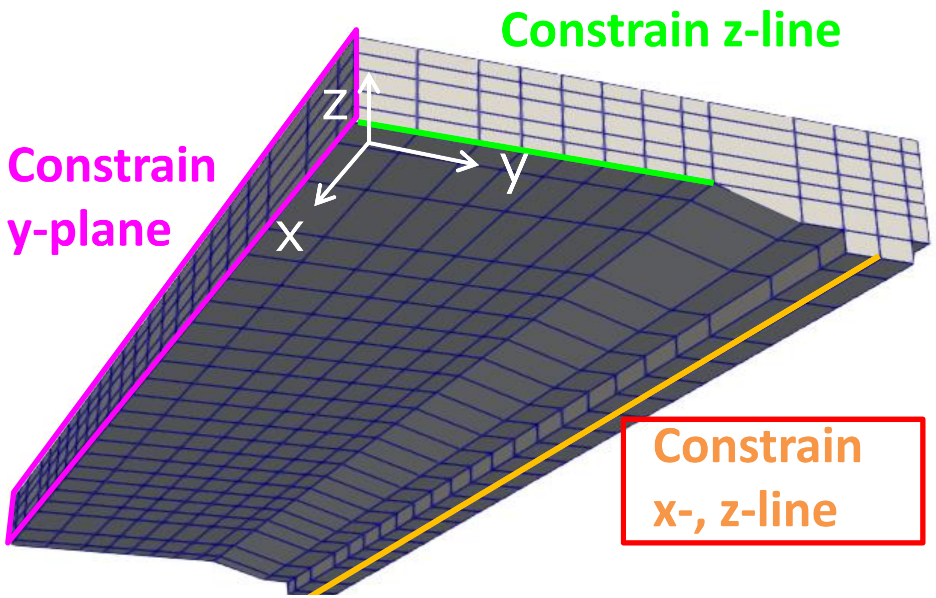
# Analysis Model with Changed Conditions

Load condition: 98kN x 1.1

| | |
|---|---|
| Compressive strength of concrete | 30 ($N/mm^2$) |
| Tensile strength of concrete | 2.22 ($N/mm^2$) |
| Young's modulus of concrete | $2.8 \times 10^4$ ($N/mm^2$) |
| Yield Strength of reinforcement | 345 ($N/mm^2$) |
| Young's modulus of reinforcement | $2.0 \times 10^5$ ($N/mm^2$) |



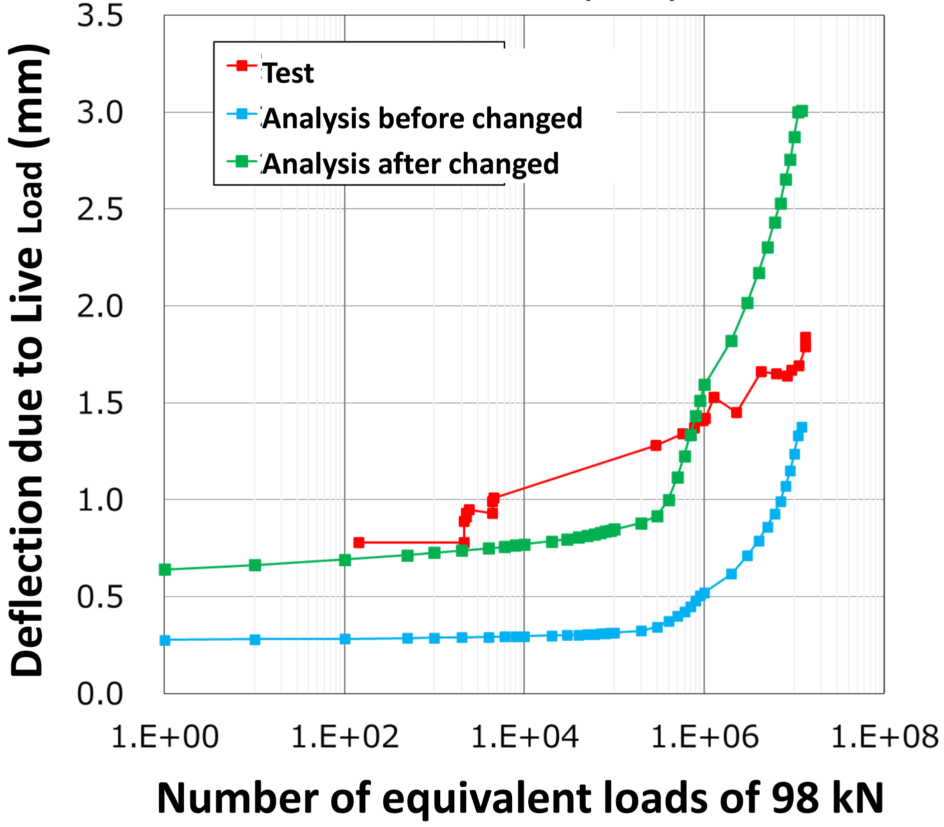

1/2 model of the specimen




Boundary condition

# Deflection due to Live Load with Dry Condition

- After changing the conditions of the model, the initial deflection is in general agreement between analysis and experiment.
- The number of loadings at which deflection increases rapidly differs between experiment and analysis.



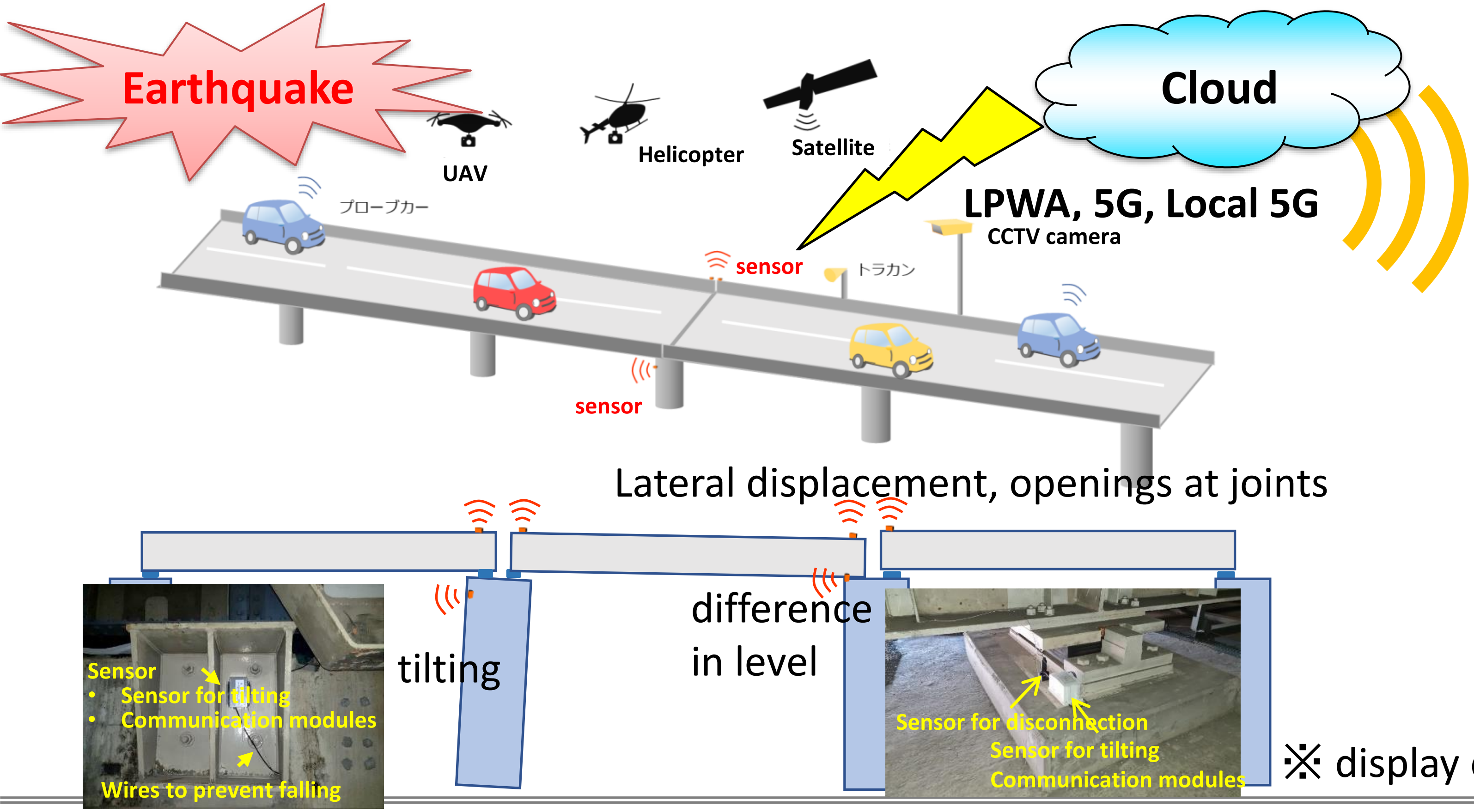

- It is expected to predict deterioration damage of RC slab by analysis based on in-site measurement results
- Then, timely and appropriate repair and reinforcement of structures could be determined

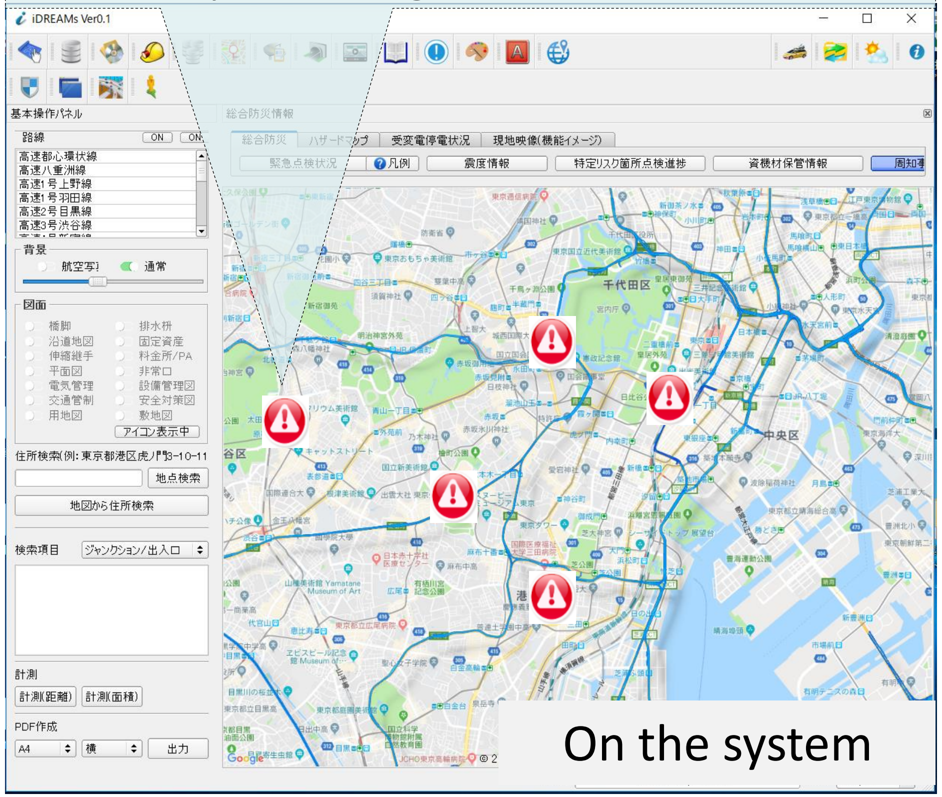
# 2) Seismic Diagnosis System with Monitoring System

Sensor-based monitoring detects damage to bridges and assists in making decisions on early opening of bridges.

- Detection of tilt angle of piers by inclinometer
- Detection of damage to bearings
- Detection of joint level, joint openings, and lateral displacement

Information obtained from sensors can be displayed in real time and combined with UAV and CCTV image data to quickly collect information on traffic accessibility and damage.




※ display damages within 30 minutes after the earthquake

# Research Topics

■ Five technologies to help achieve the objectives of the BCP

**Technologies**

1. Trigger sensor
2. GNSS sensor using satellite positioning technology
3. Inclinometer
4. Using pier inclination to quickly assess the post-earthquake performance of a bridge
5. A low-cost and easy-to-install retrofit method to prevent severe damage to the bearings in a major earthquake

Technologies 1–3 → To speed up the inspection

Technology 4 → To evaluate the seismic performance

Technology 5 → To prevent severe damage to the bearing

**Objectives of the BCP**

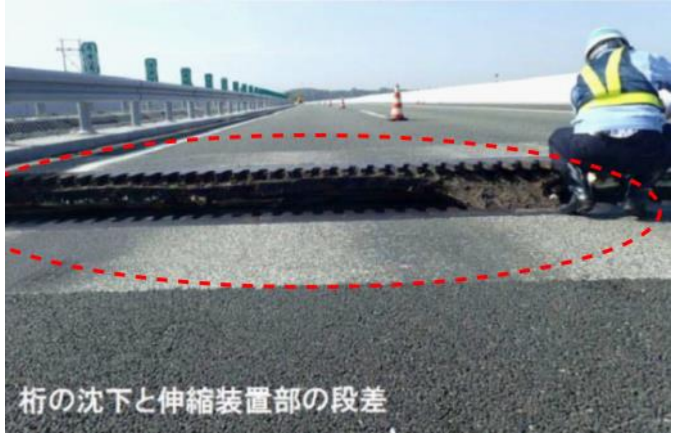
- ☐ Complete the post-earthquake inspection for high priority routes (101km) within 3 hours
- ☐ Reopen at least one route within 24 hours

# Targeted Earthquake Damages

## Targeted Earthquake Damages

- Damages to the expansion joints
- Pier inclination

⇨ May obstruct the passage of the emergency vehicles




Difference in level

Gap in longitudinal direction

Gap in transverse direction

Pier inclination

For the differences in level and the gaps:

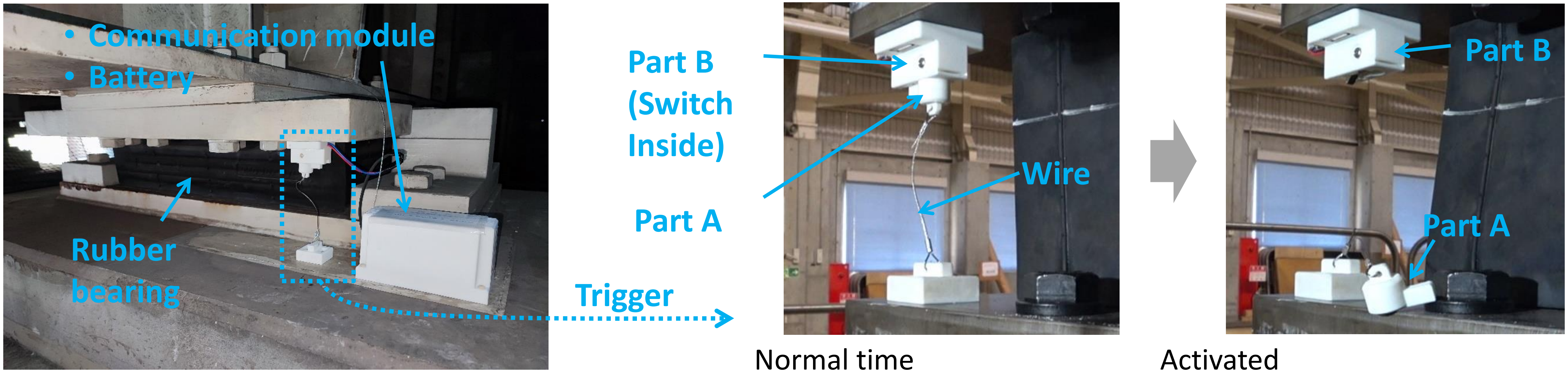
- Trigger sensor
- GNSS sensor

For pier inclination:

- Inclinometer

# 1) Trigger Sensor

- Component: a trigger, a wireless communication module and a battery
- Install the trigger between the girder and the pier, or on each side of the joint on the road
- The trigger is activated when the **relative displacement of the two ends of the trigger exceeds the threshold** (the length of the wire) → Damage information is transmitted to the cloud via wireless data communication



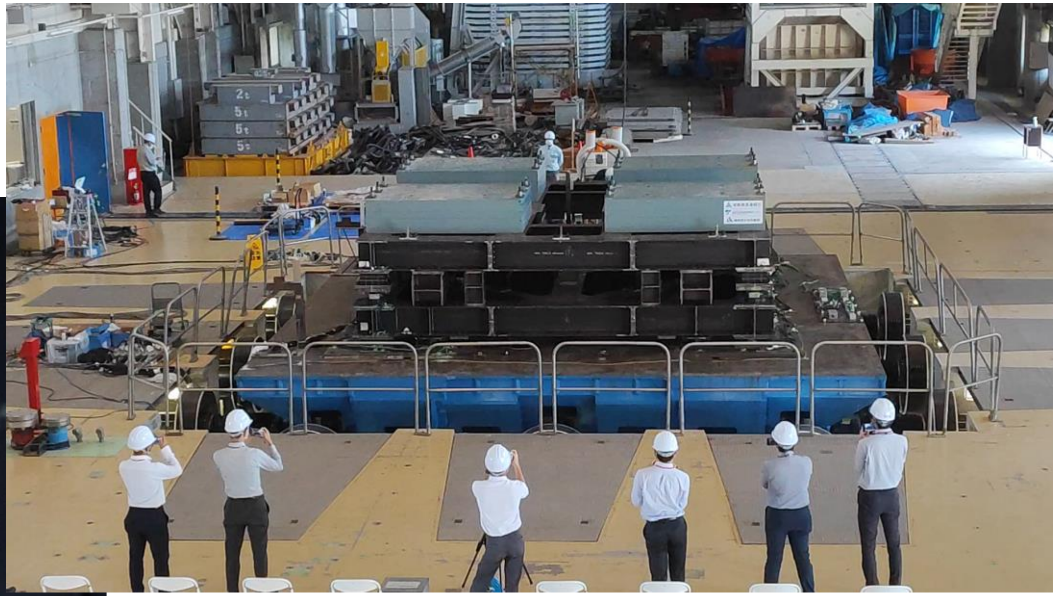

Trigger sensor installed between the girder and the pier

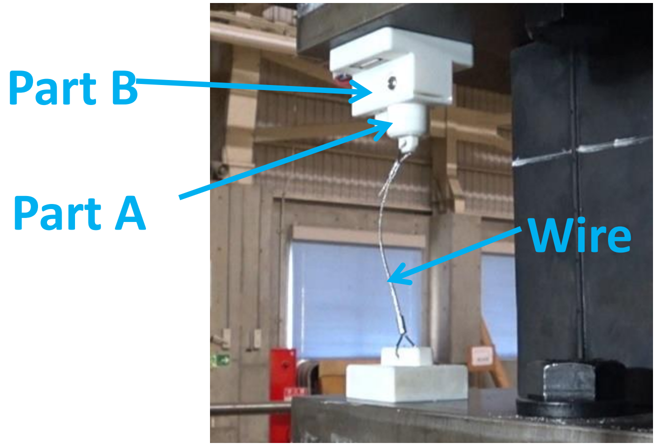
Normal time
- Part A contacts to part B by magnetic force

Activated
- Part A separated from part B
- Switch on

# 1) Trigger Sensor

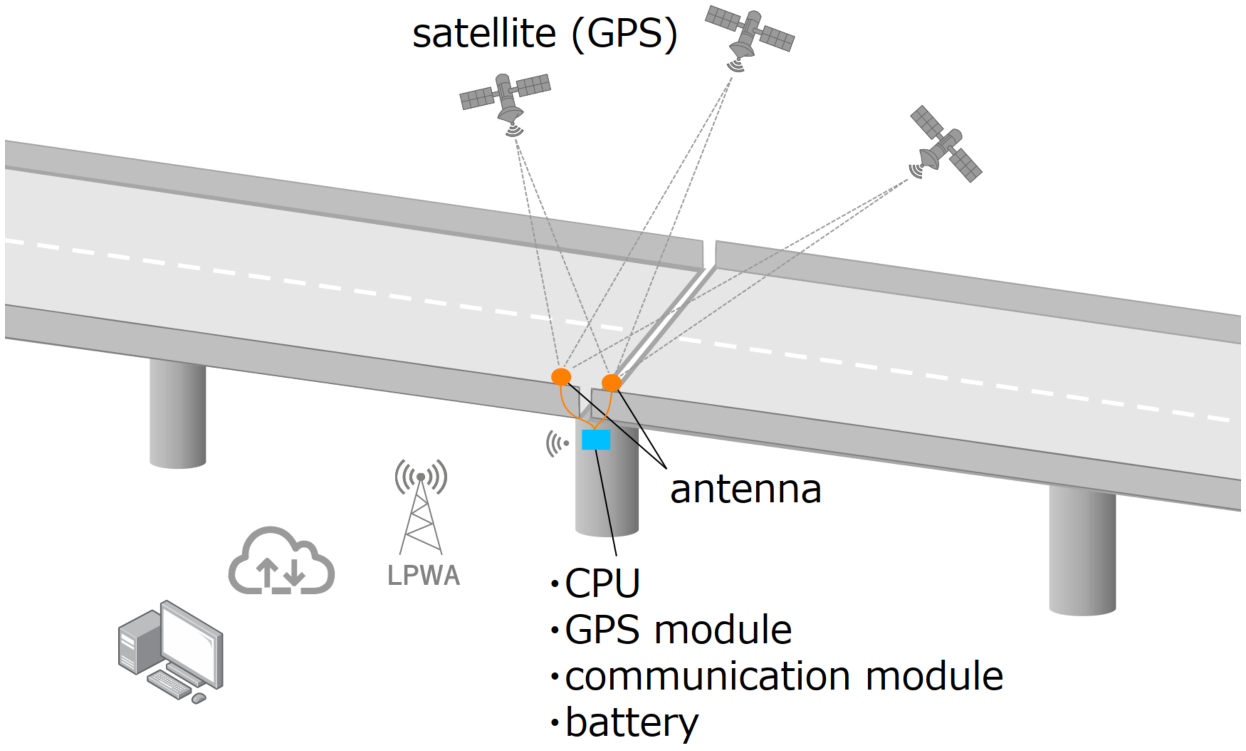
- Verified the effectiveness of the trigger sensor in a large shaking table experiment
- Part A separated from part B → the trigger activated



# 2) GNSS (Global Navigation Satellite System) Sensor

- Consists of a pair of antennas, a CPU, GPS and wireless communication modules, and a battery
- Install two antennas on each side of the joint
- Detect the damage by the **relative displacement of the two antennas**



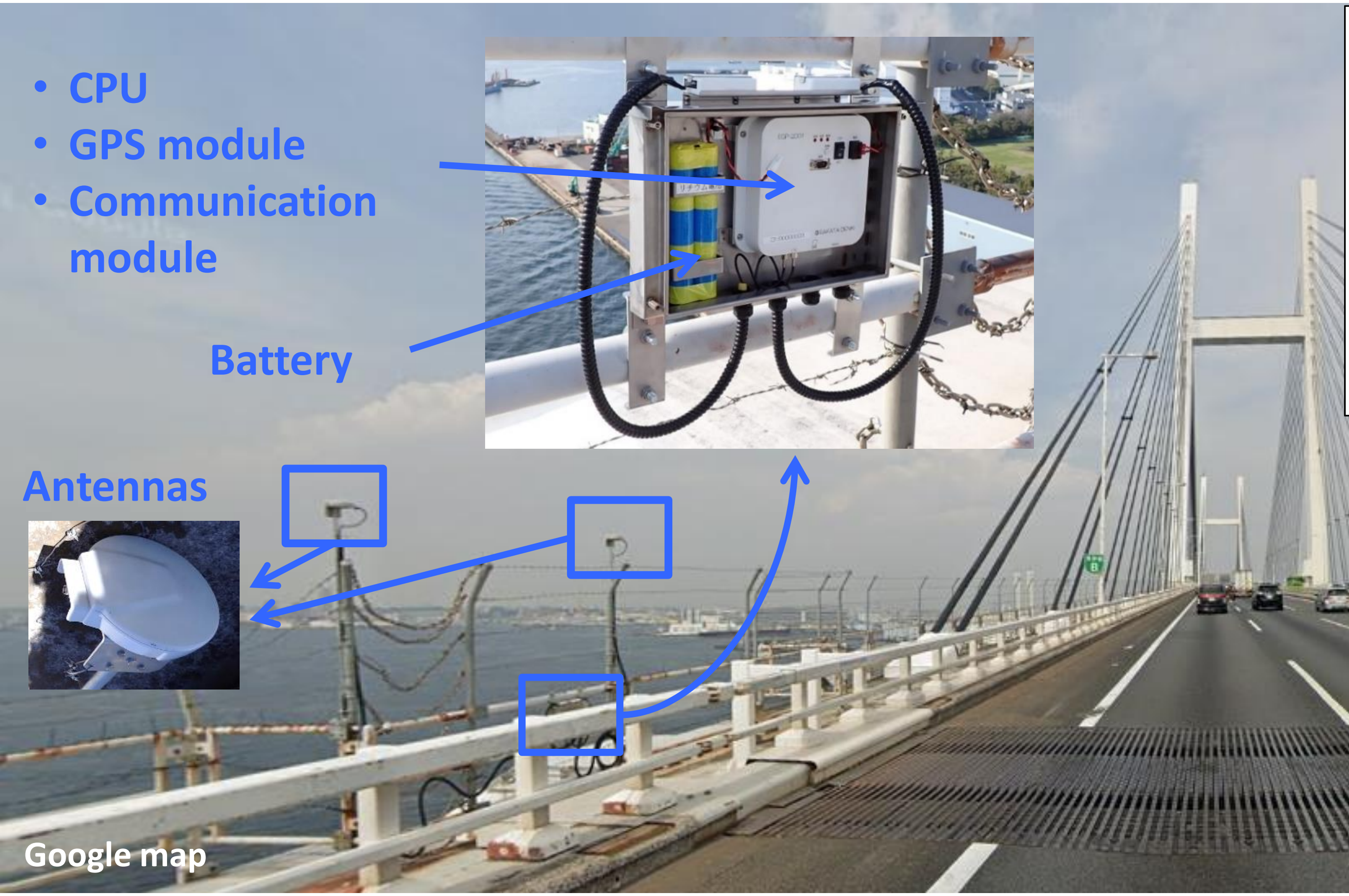

Relative displacement is calculated from the coordinates of the two antennas based on the satellite positioning technology


High precision (expensive) Low precision (cheap)

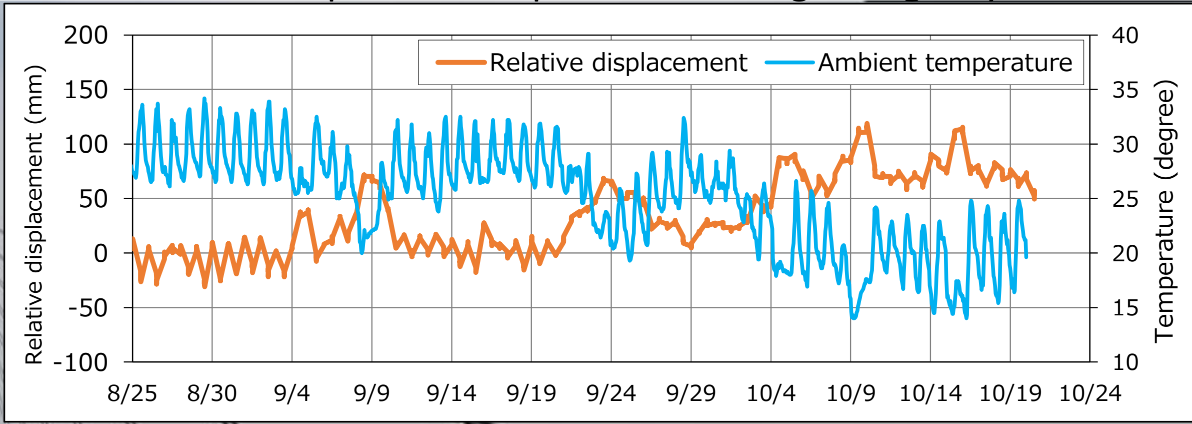
Antennas used for GNSS sensor

# 2) GNSS Sensor

- Field test on the Honmoku side of the Yokohama Bay Bridge
- Record data twice a day from August 25th, 2023
- Thermal expansion and contraction of the girder can be detected with a good accuracy




Ambient temperature: Japan Meteorological Agency data



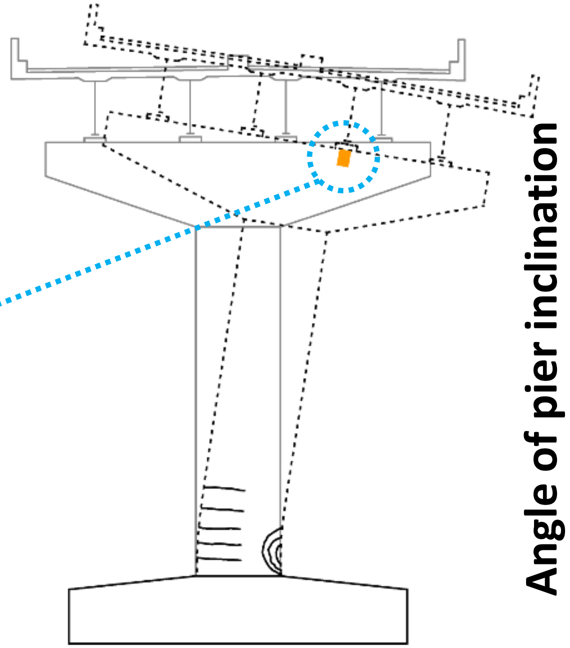
# 3) Inclinometer

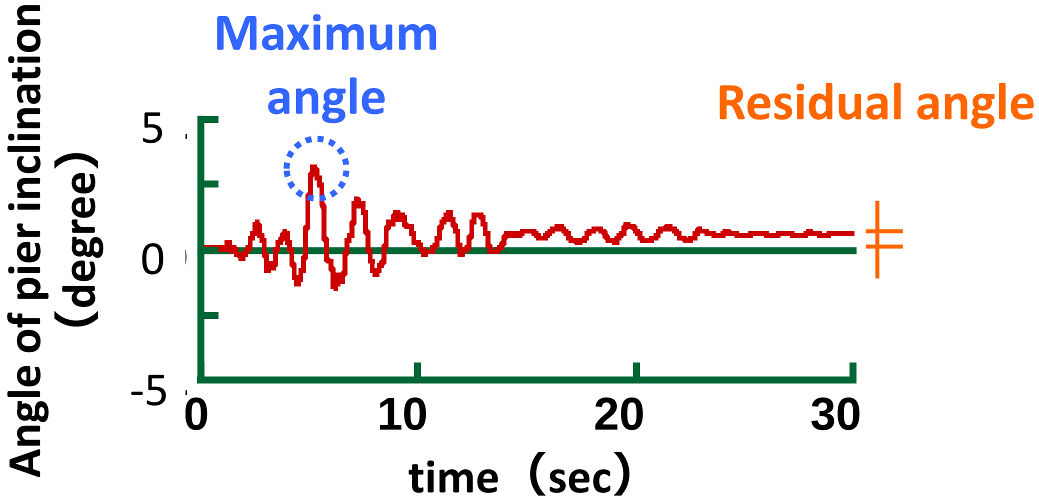
- Consists of an inclinometer, a wireless communication module and a battery
- Current stage:

  detect the inclination of a pier in a static state → **residual angle**
- Next stage:

  detect the inclination of a pier in a dynamic state → **maximum angle** (under development)

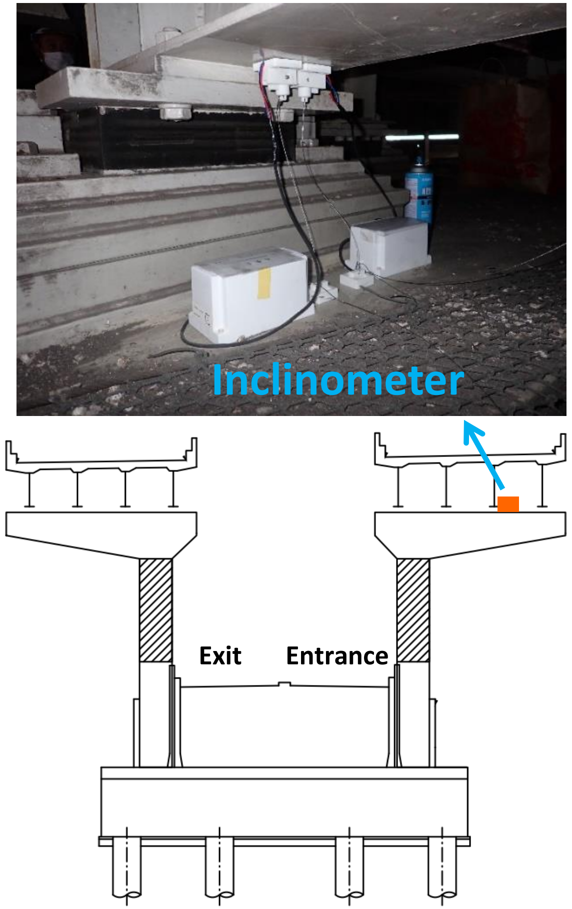
- Inclinometer
- Communication module
- Battery



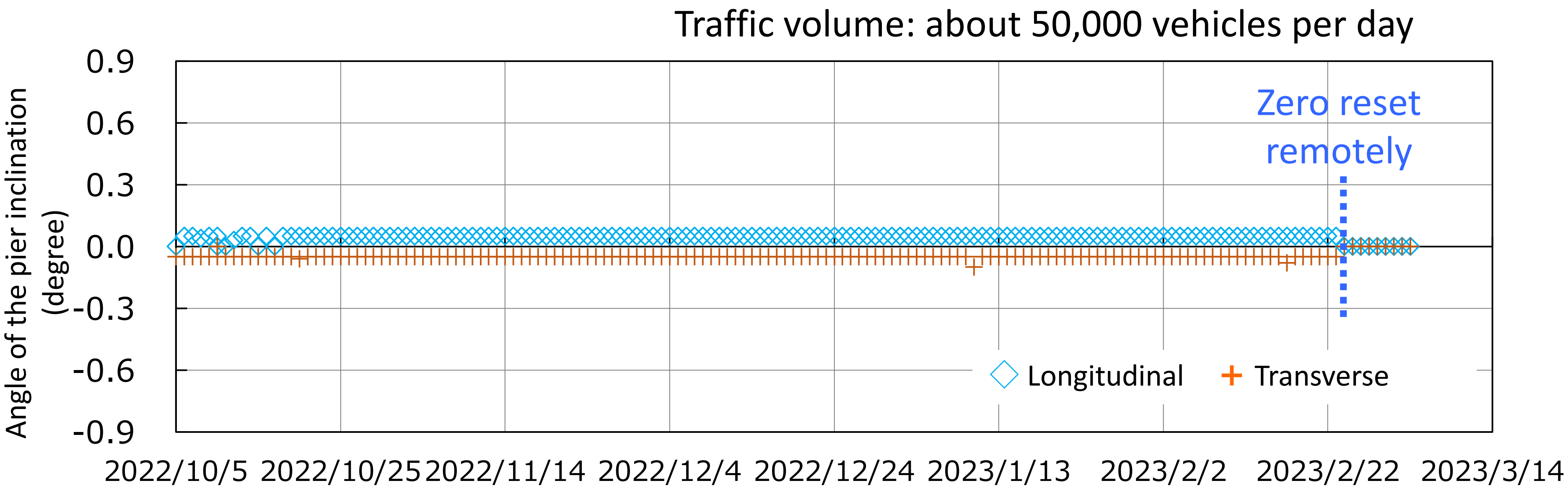


# 3) Inclinometer

- Field test on five piers of the Shinjuku Line for about half a year
- Recorded data once a day




- The variation in the results is less than 0.1 degree
- The precision is practically sufficient to detect the residual angle of pier inclination in a large earthquake




Test results of the angle of the pier inclination

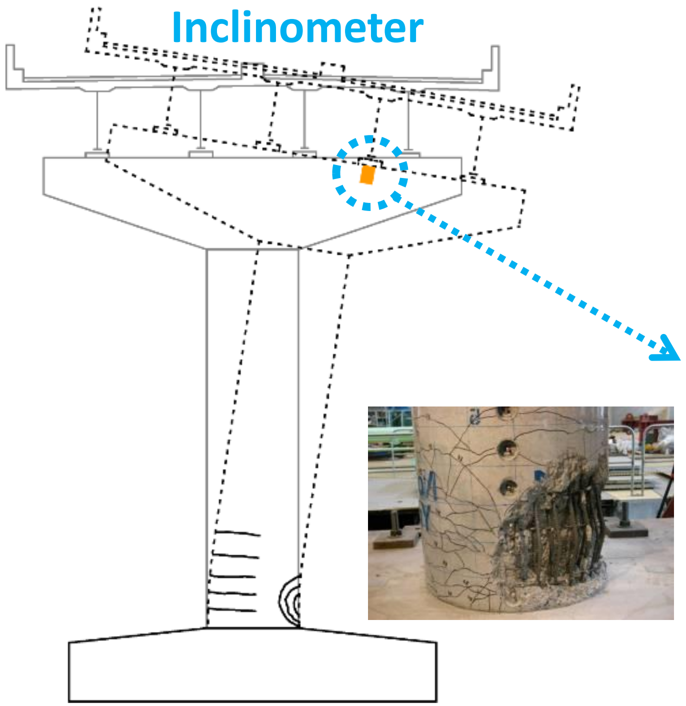
# 4) Evaluation of the Seismic Performance using Inclination of Pires

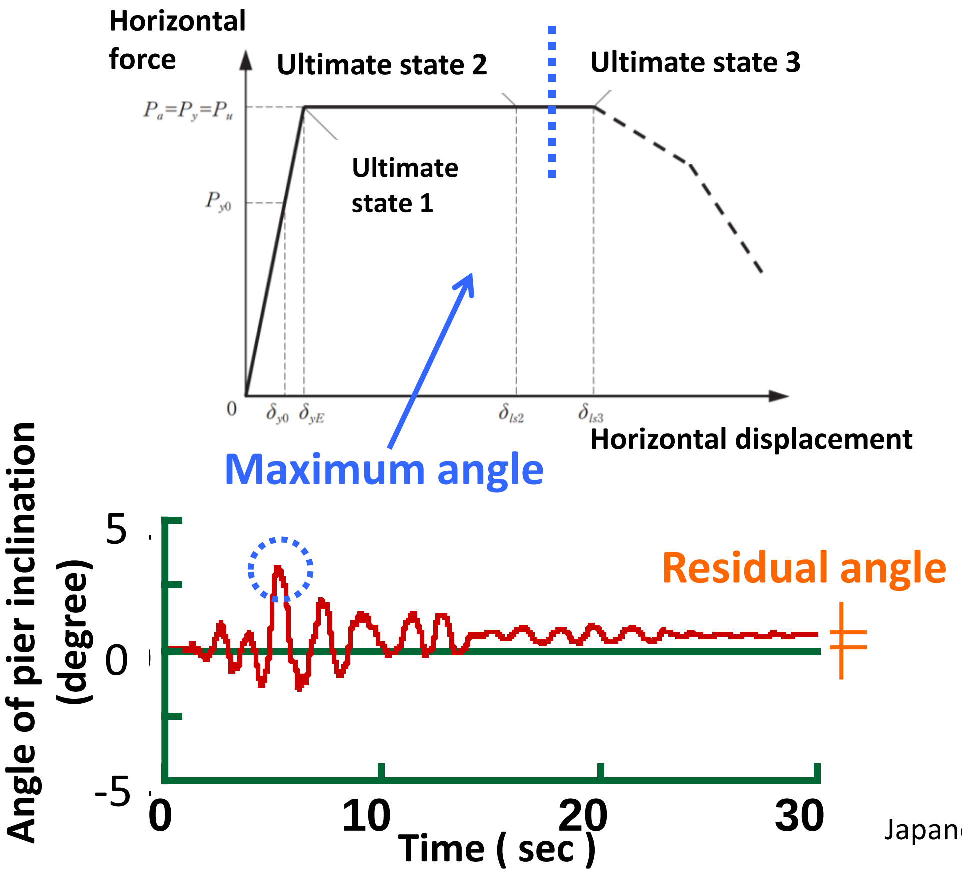
## Current Stage

- Use **angle of inclination** instead of horizontal displacement
- The residual angle of the pier inclination is used to make a **rough evaluation**

## Next Stage

- The maximum angle of the pier inclination is used to make an **appropriate and more accurate evaluation of structural performance after an earthquake**




Allowable residual displacement: 1/100 times the height from the bottom of the pier to the height of inertia force of the superstructure

Allowable residual angle of the pier inclination: **0.57 degree**

Japanese Design Specifications for Highway Part V, Seismic Design

# 3. Summary: Perspectives for the Future

- The analysis for predicting the deterioration of RC slabs and the evaluation of seismic performance of piers after earthquakes are introduced by using the monitoring
- Such a monitoring can be applied to ordinary maintenance and disaster management to enable **phase-free infrastructure management**.
- In addition, by **analyzing and evaluating** the measured and accumulated data (**displacement, tilt, vibration, images, etc.**), damage, deterioration, and deformation can be visualized and screened, and various simulations can be performed in advance to **select appropriate measures and predict future behavior**, etc. The results are then fed back into real space to realize a digital twin that highly integrates physical space and cyber space.
- By utilizing online sensor information, etc., remote monitoring, remote inspection, and remote equipment failure recovery will become possible, which will speed up decision-making and improve productivity, including infrastructure maintenance and management as well as disaster prevention measures, and realize a sustainable society through data-driven infrastructure management.