

Numerical Verification of Bridge Screening Technology based on Vehicle Vibration

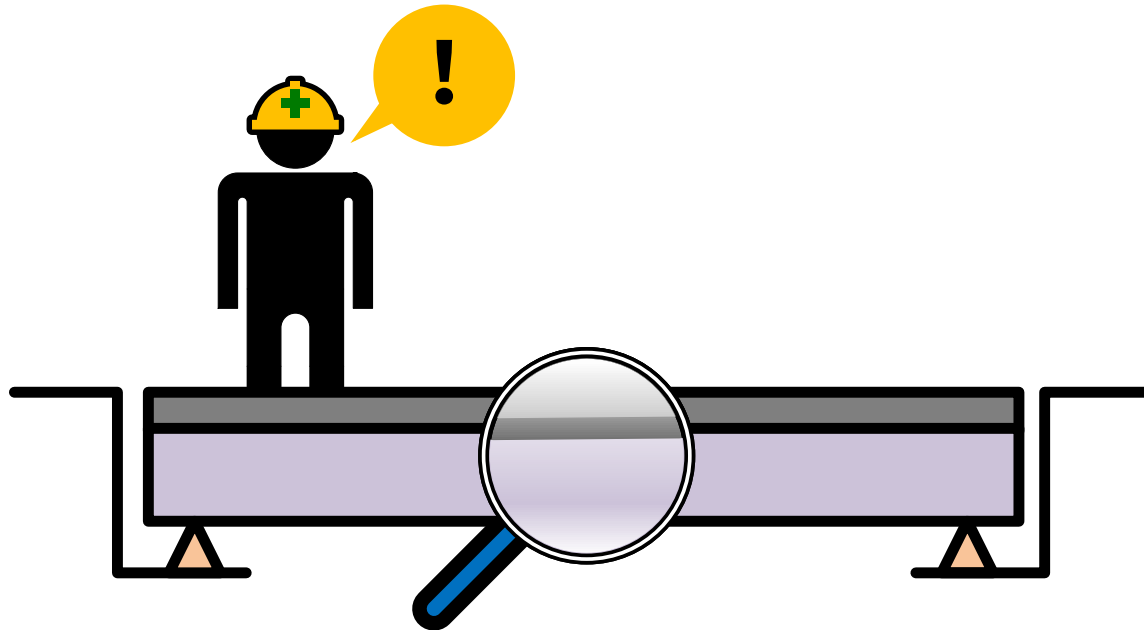
University of Tsukuba



Kyosuke Yamamoto
Assistant Professor

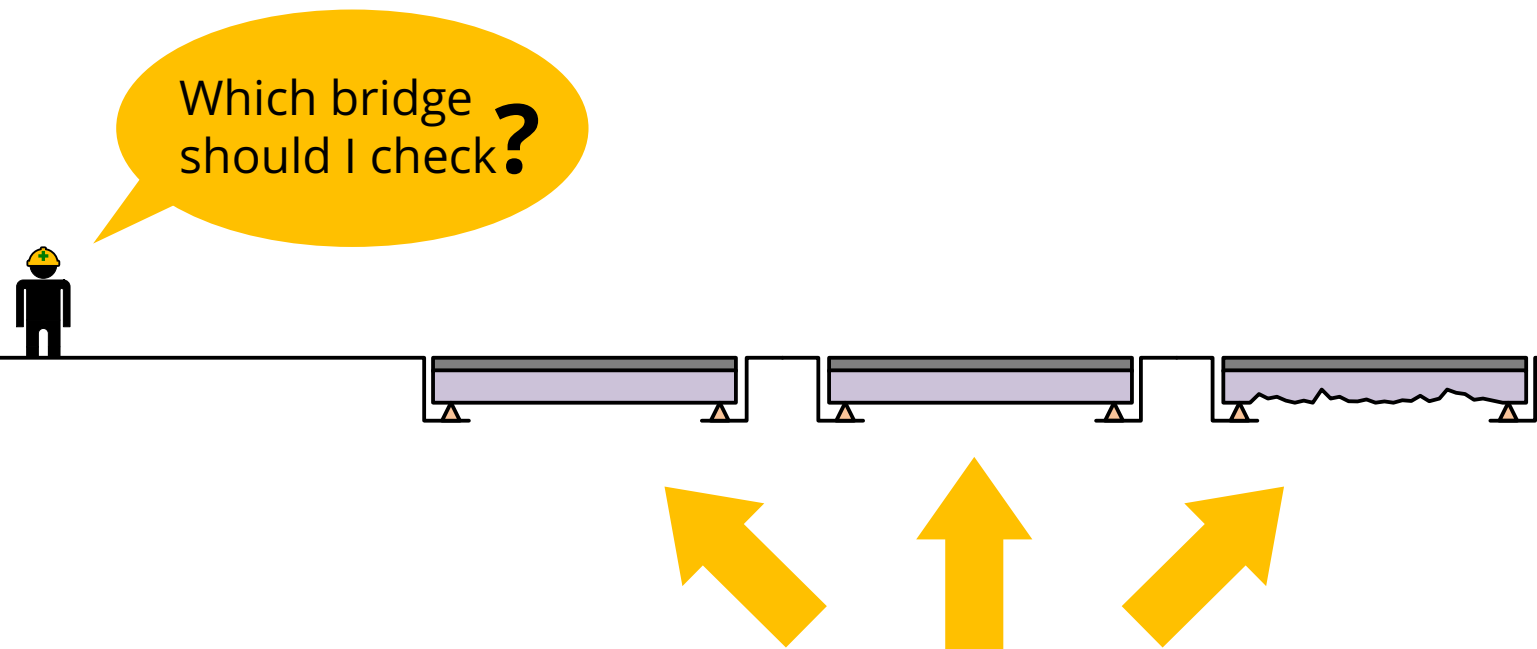
Background:

Bridge Inspections based on **Visual Check** by **Veteran Engineers**



Social Matter:

The Training of Engineers requires several years, though there is a **Large Number of Aging bridges**

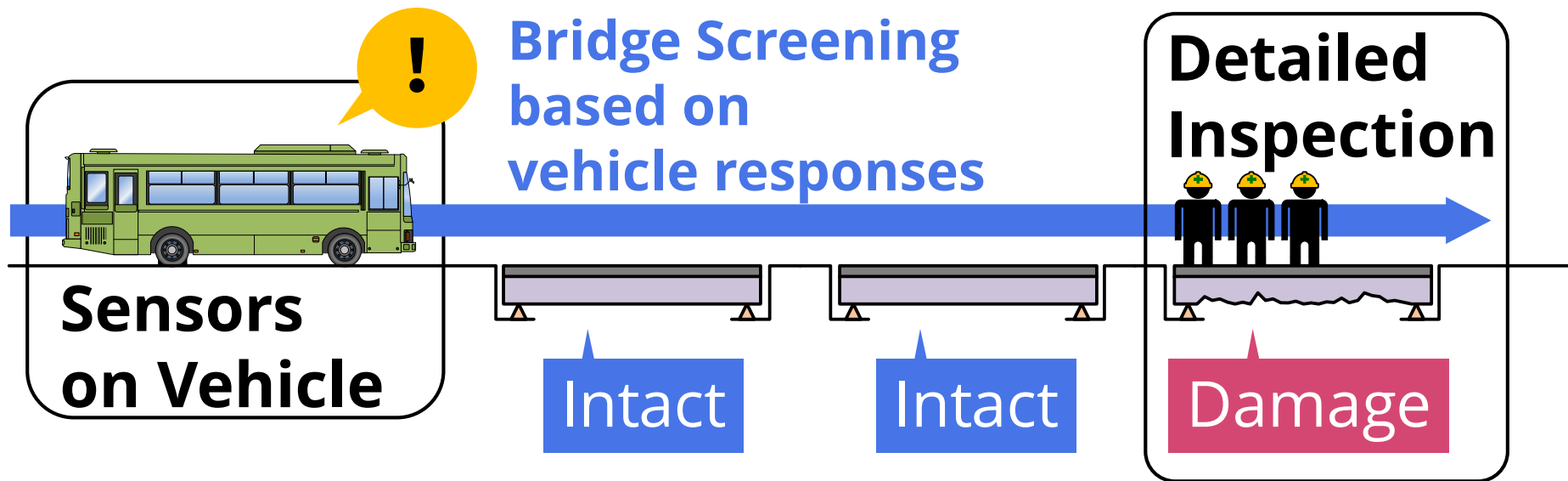


Which bridge should I check?

To implement the priorities of bridges we need to know the soundness before the inspections!?

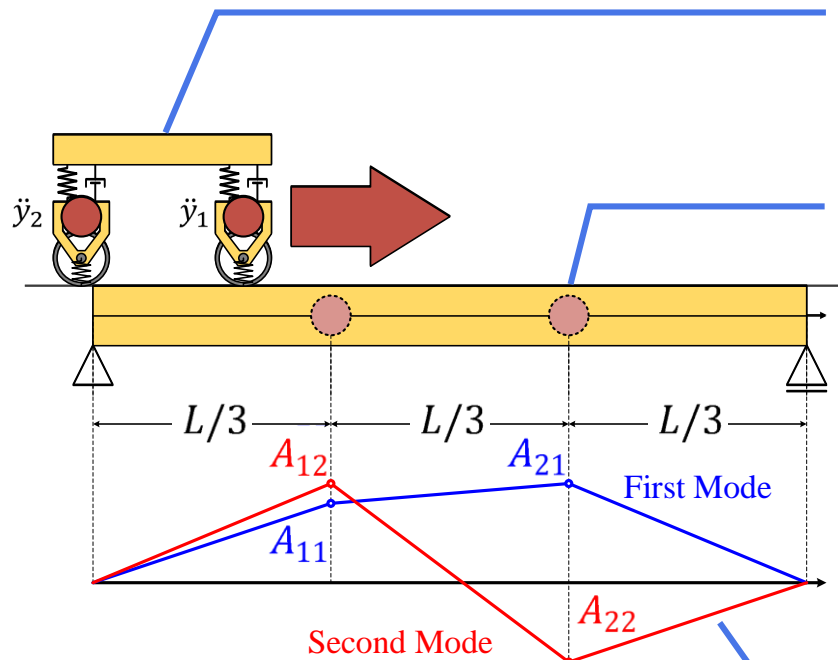
Solutions:

Bridge Screening (Roughly Quick Inspection)
enables **Strategic Allocation of Resources**



Technical issue:

How to estimate the **bridge status** only by using **vehicle vibrations**?



1 To measure the vibrations of the **passing vehicle**

2 To transform them to vibrations at the **fixed points**

3 To estimate the **mode shapes** of the bridge

Spatial Singular Mode Angle:

$$\theta = \tan^{-1} \left(\frac{A_{21}}{A_{11}} \right) = \tan^{-1} \left(-\frac{A_{12}}{A_{22}} \right)$$

The Purpose:

To examine the applicability of SSMA to the Bridge Screening

Bridge Vibration

$$y(t) = Aq(t)$$

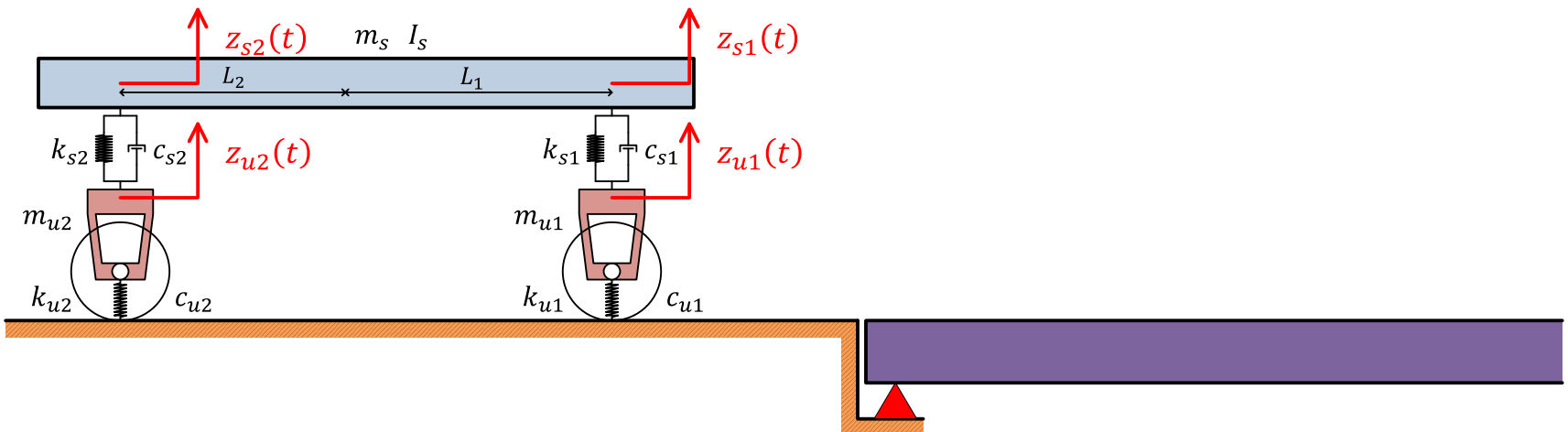
Bridge Vibrations measured at Moving Positions

$$N(t)^{-1} \tilde{y}(t) = Aq(t)$$

Vehicle Vibrations

- (1) Bridge vibrations
- (2) Road Roughness
- (3) Vehicle Body vibrations

$$N(t)^{-1} \ddot{z}(t) = A\sigma(t)$$



The Proposed Method:

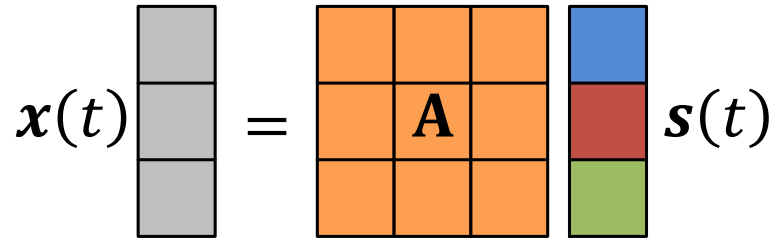
Application of **SVD** method to the spatially corrected vibration data

Measured
Vehicle
Vibrations

$\ddot{z}(t)$

$N(t)^{-1}\ddot{z}(t)$

SVD: Singular Value Decomposition

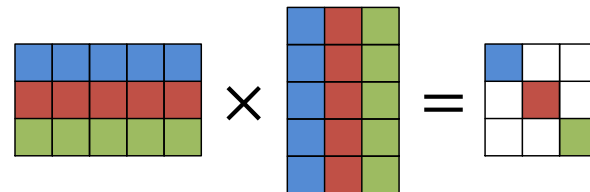


The diagram shows the SVD decomposition equation: $x(t) = A s(t)$. On the left, $x(t)$ is represented by a vertical grey bar with three segments. In the middle is an equals sign. To the right of the equals sign is a 3x3 orange grid labeled **A**. To the right of **A** is a vertical bar labeled $s(t)$ with three colored segments: blue (top), red (middle), and green (bottom).

Spatially Corrected Vibrations
at assumed fixed points

Estimated Mode Shapes

Estimated Basis Coordinates
SVD assumes their non-correlation



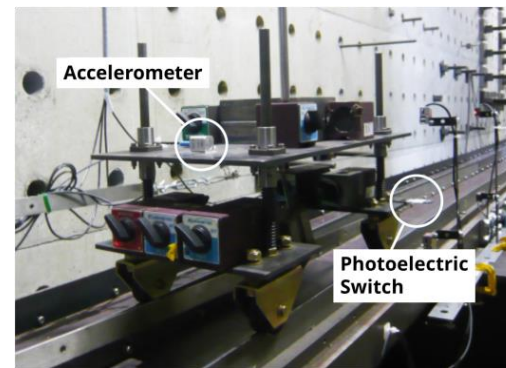
The diagram illustrates matrix multiplication. On the left is a 3x4 grid with rows of blue, red, and green. This is multiplied by a 4x3 grid with columns of blue, red, and green. An equals sign follows, leading to a 3x3 grid with a blue top-left cell, a red middle-middle cell, and a green bottom-right cell, with all other cells being white.

The Methodology: Experimental & Numerical Verification

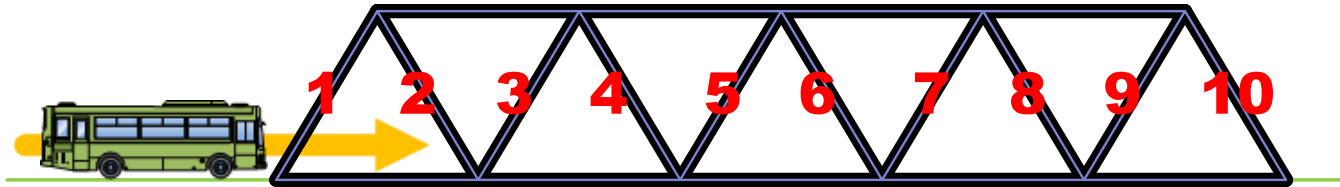
Data Acquisition

Application of
the proposed method

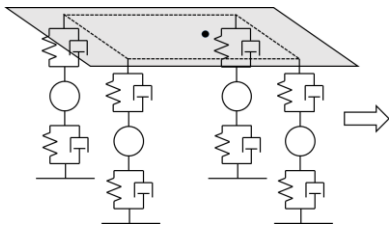
Numerical Simulation
Field Experiment
Laboratory Experiment



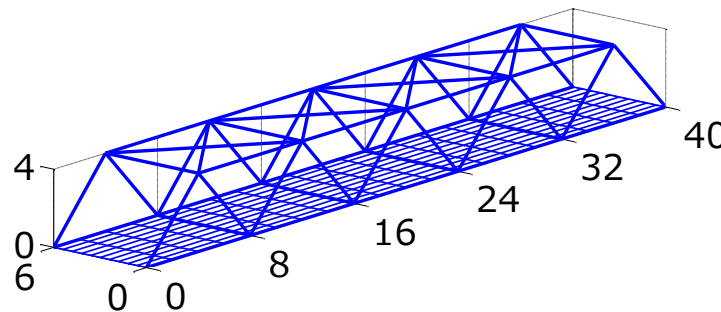
The Numerical Simulation: RBSM Vehicle & FEM Bridge



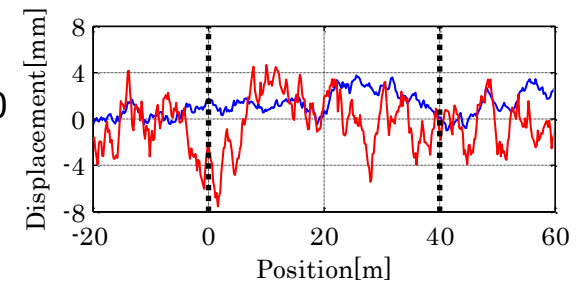
20t (=200kN)
Vehicle Model



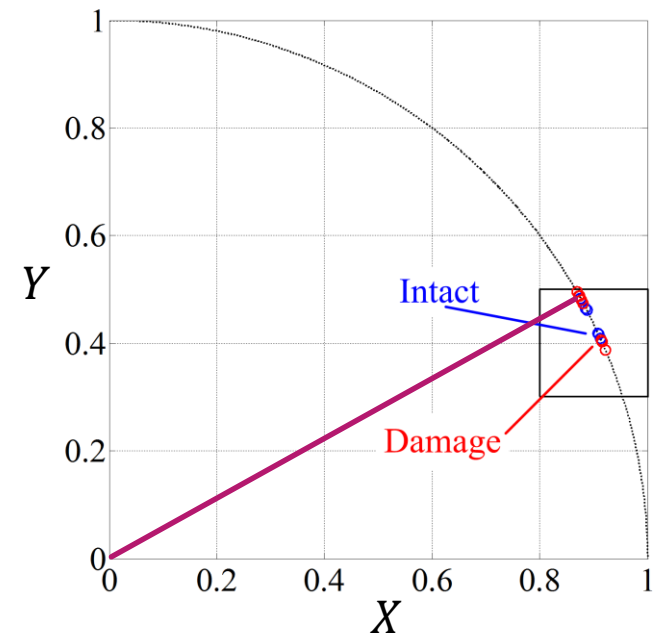
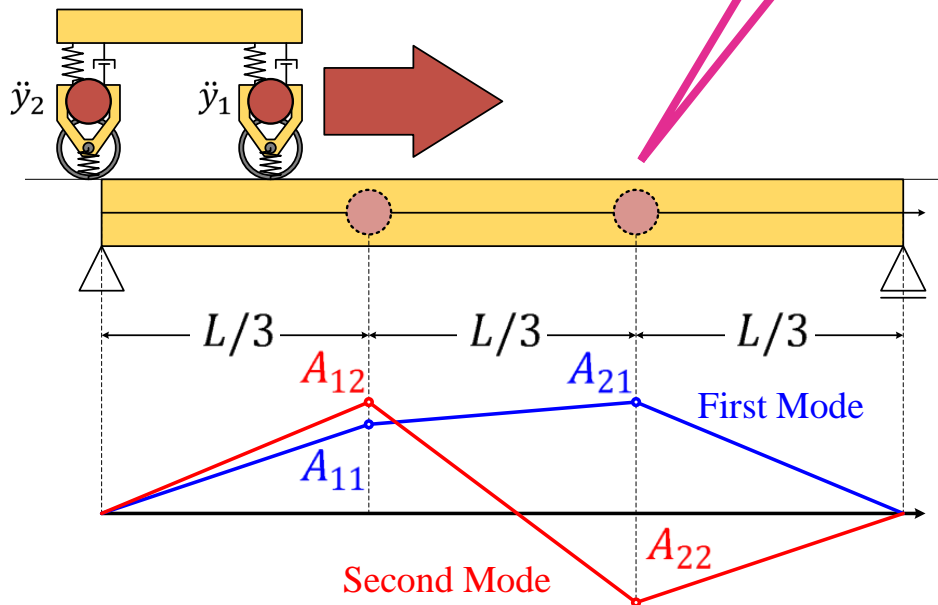
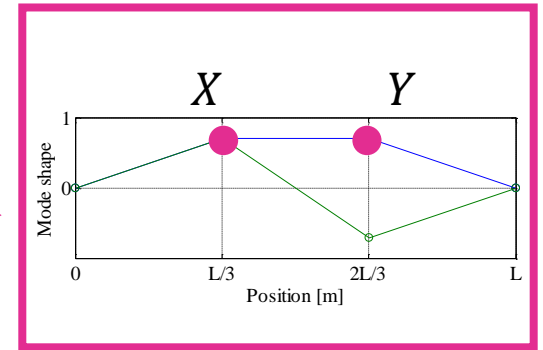
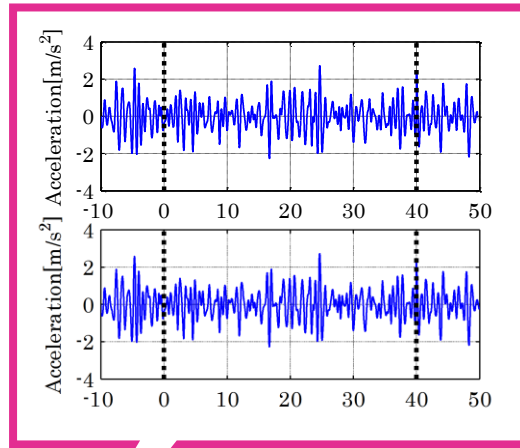
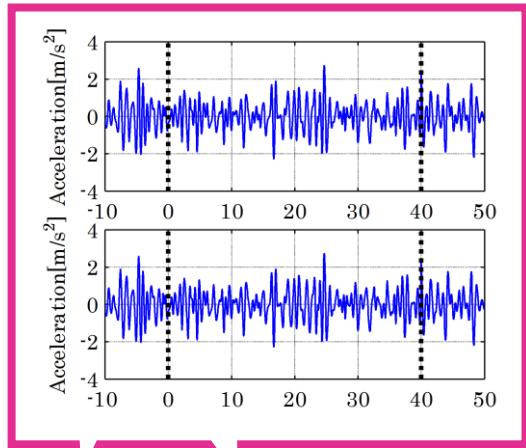
40m span Steel Truss Bridge



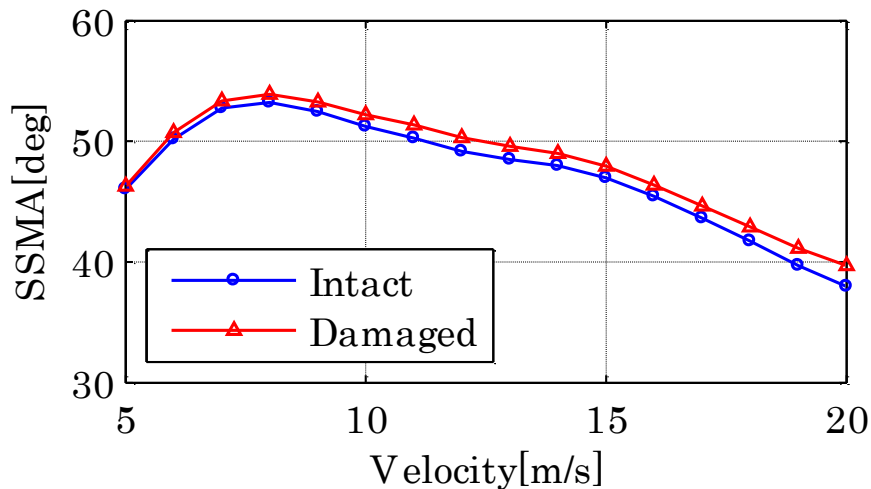
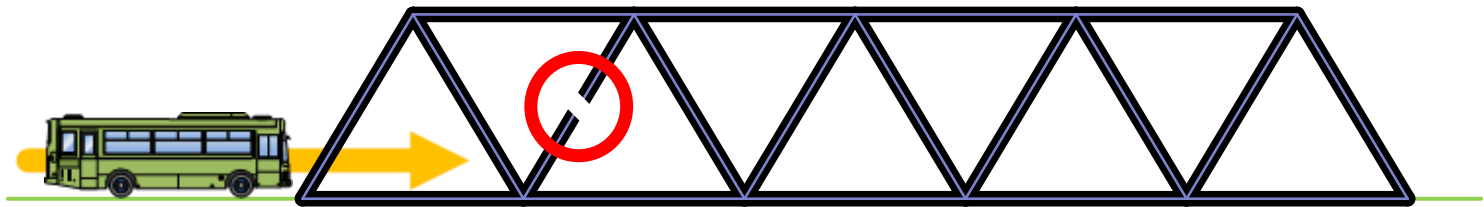
Road Unevenness



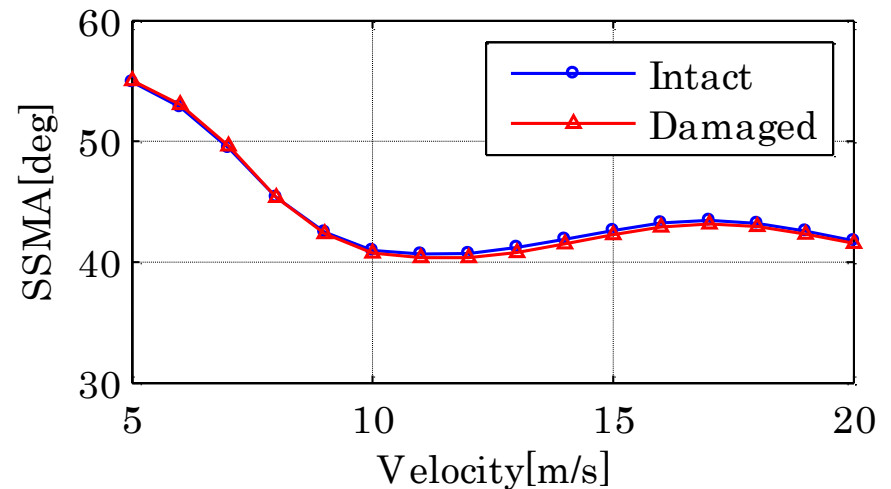
The Procedure to calculate SSMA: Spatial Correction & Mode Decomposition



The Results of Numerical Simulation: SSMA Applicability to the damage detection when varying **velocity** & **road roughness**



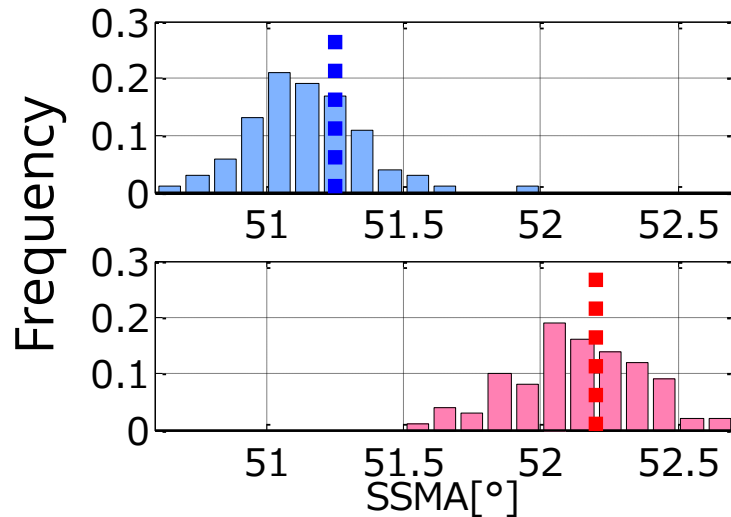
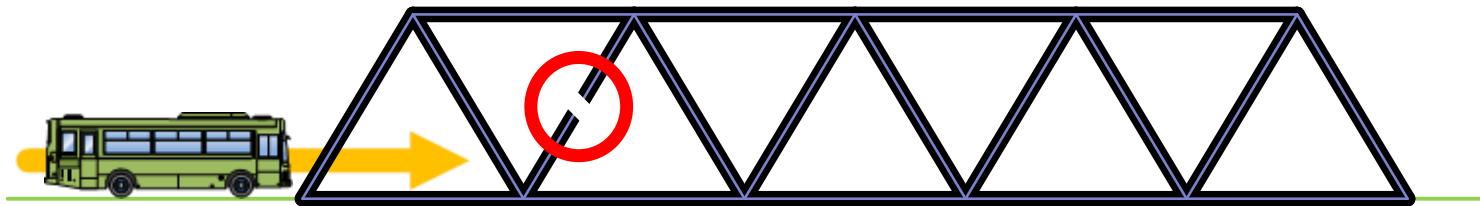
Smooth Road



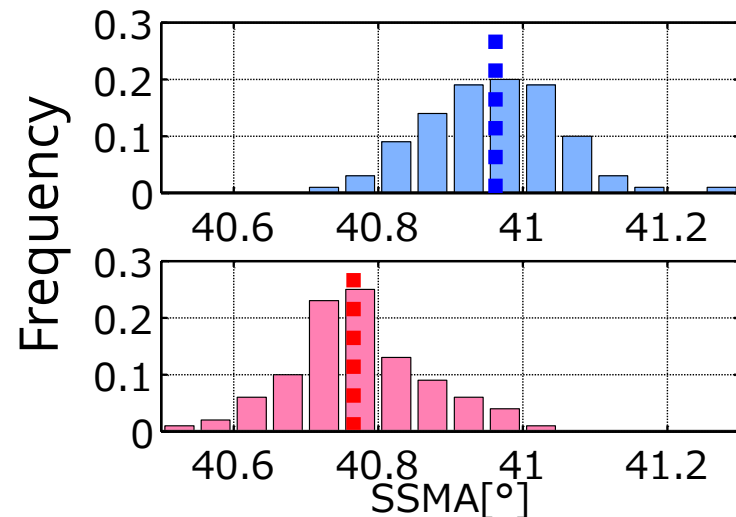
Rough Road

The Robustness:

It is found that **SSMA** has the high sensitivity to a local bridge damage

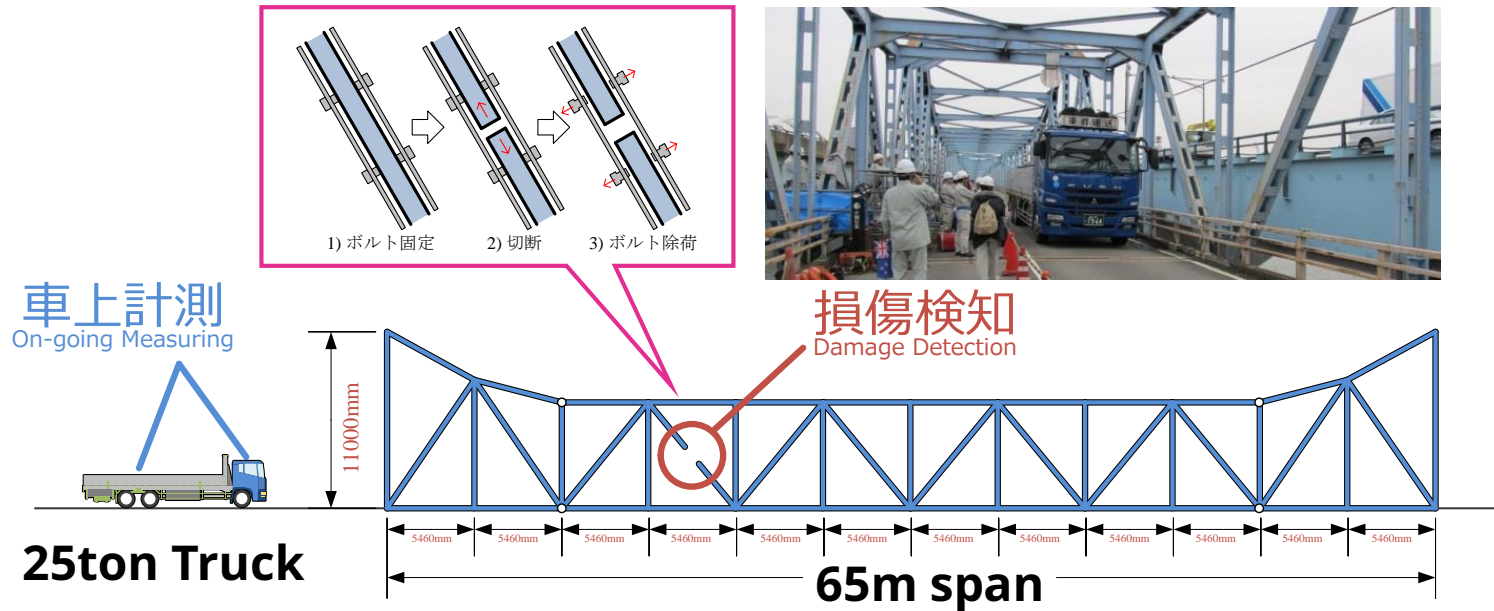


Smooth Road



Rough Road

The Field Experiment: SSMA Applicability to the damage detection on the actual steel truss bridge

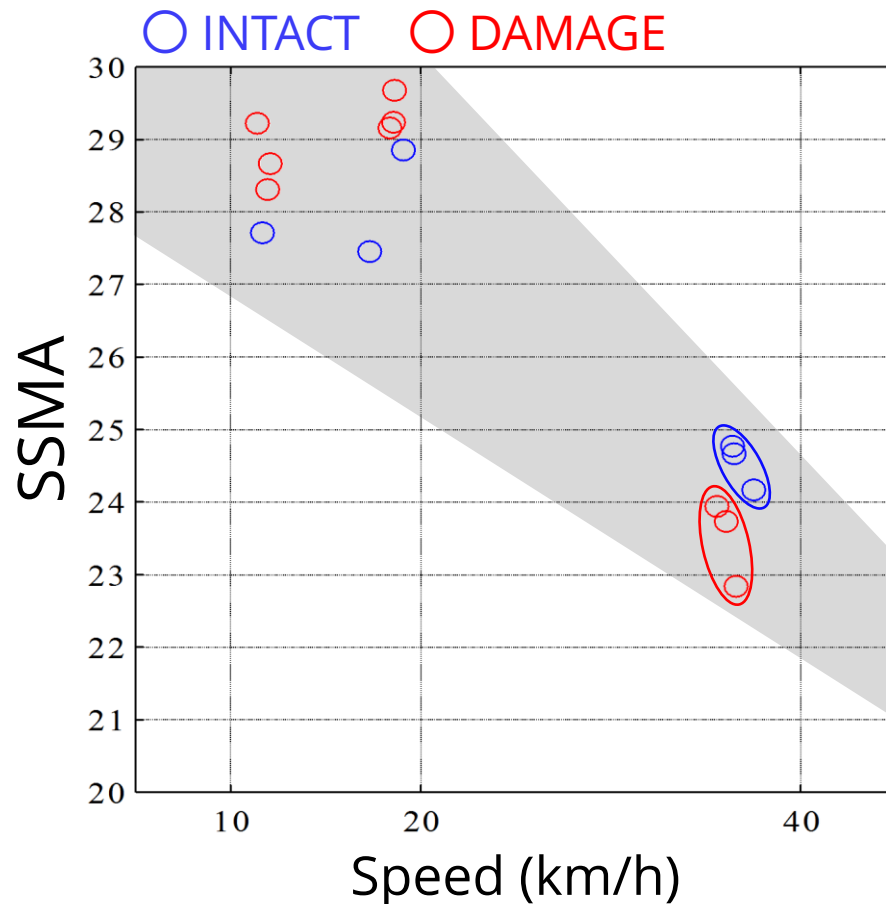


	Front (kN)	Rear (kN)	Total (kN)	INTACT			DAMAGE		
				10(km/h)	20(km/h)	40(km/h)	10(km/h)	20(km/h)	40(km/h)
First Day	87.4	165.8	253.2	First	First	First			
Second Day	87.8	170.6	258.4		Second	Second Third	First Second Third	First Second Third	First Second Third

The Results of Field Experiment:

High sensitivity to the **damage detection**

Low Accuracy to the damage identification

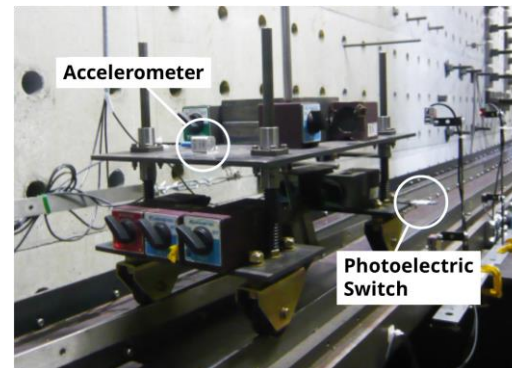
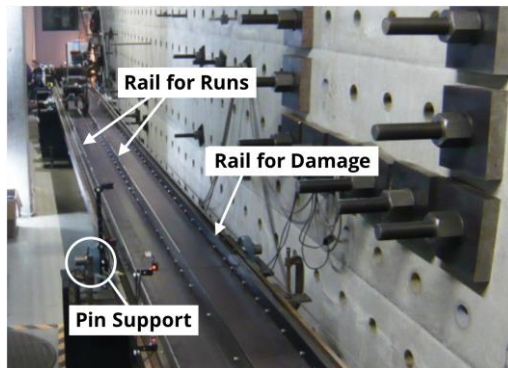
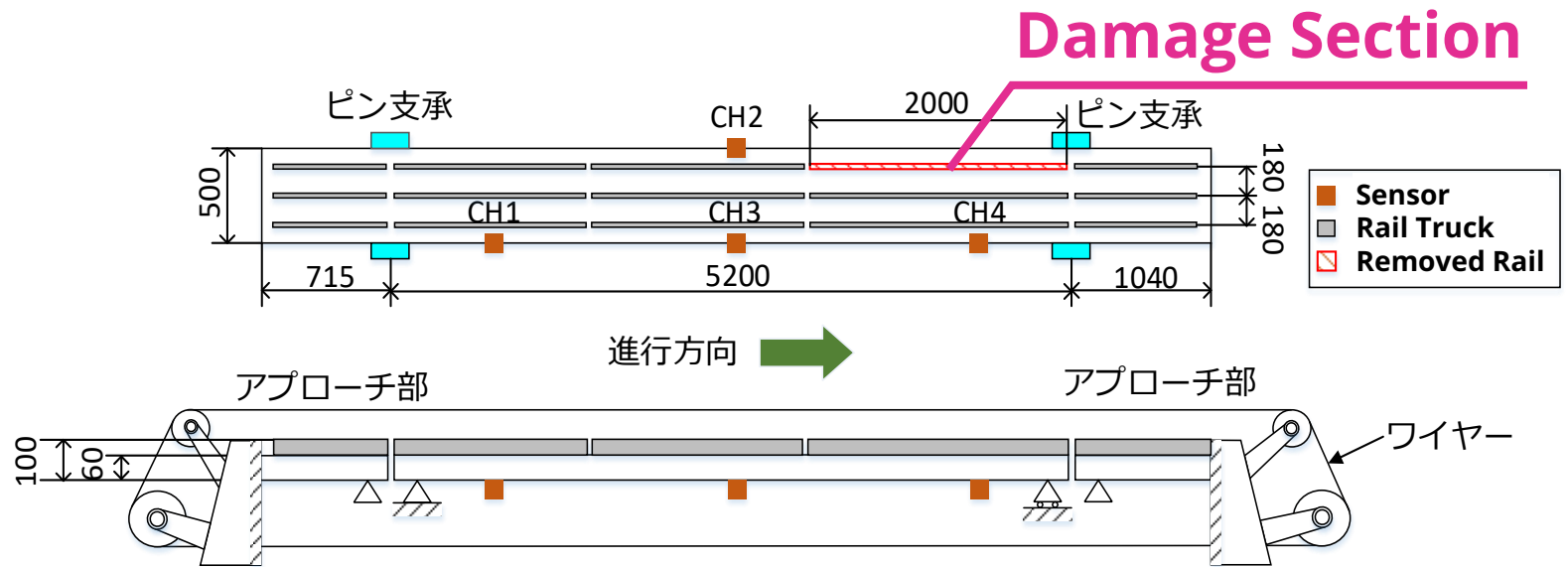


Because the mode shape is independent from the vehicle speed, it means the **low estimation accuracy** of SSMA.

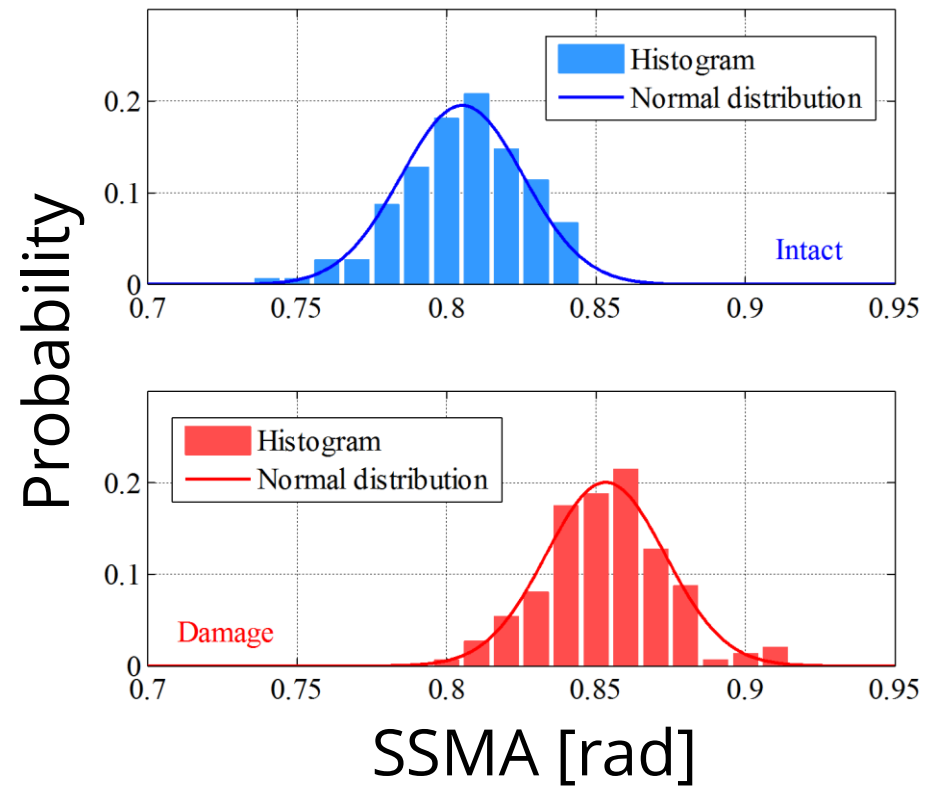
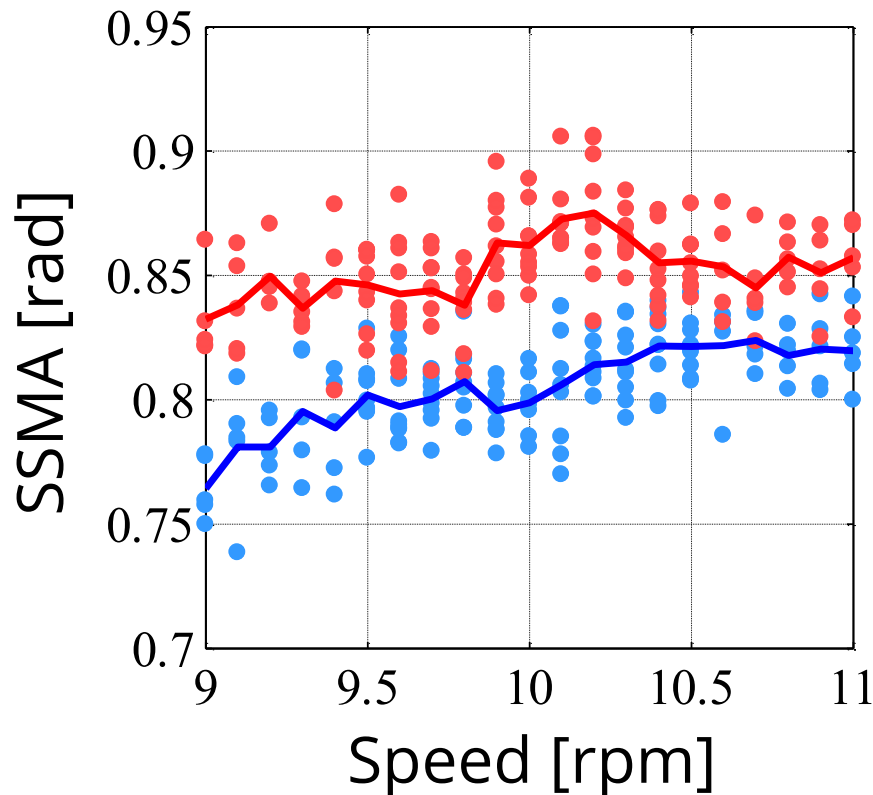
The **high sensitivity** to damage because the angle changes distinctively after damage.

The Lab. Experiment:

Statistical Validity of SSMA should be examined for Engineering application



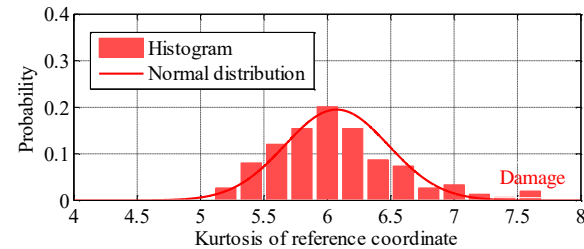
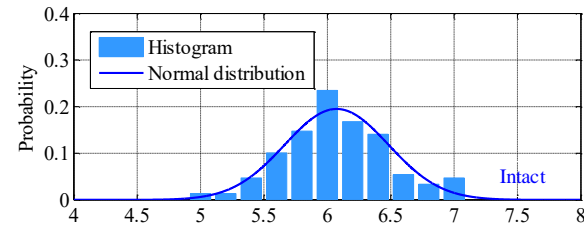
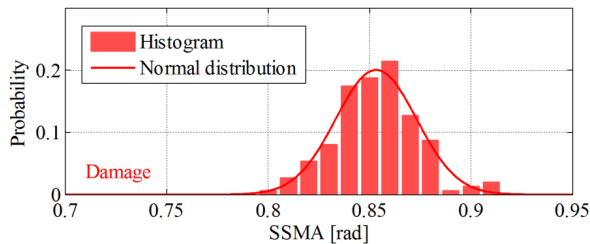
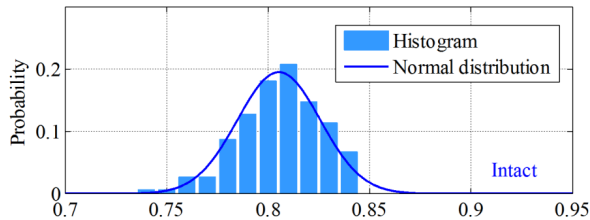
The result of the Lab. Experiment: **SSMA** probability density distribution statistically changes after the bridge damage



Discussion:

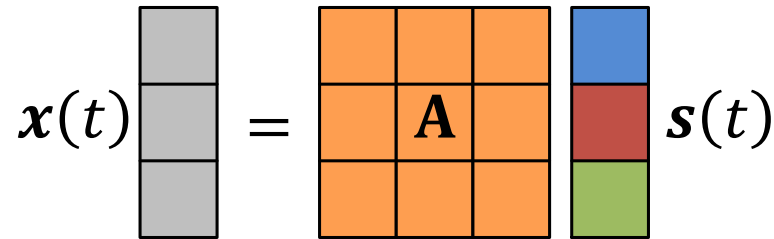
Why does **SSMA** shows the high sensitivity to the bridge damage?

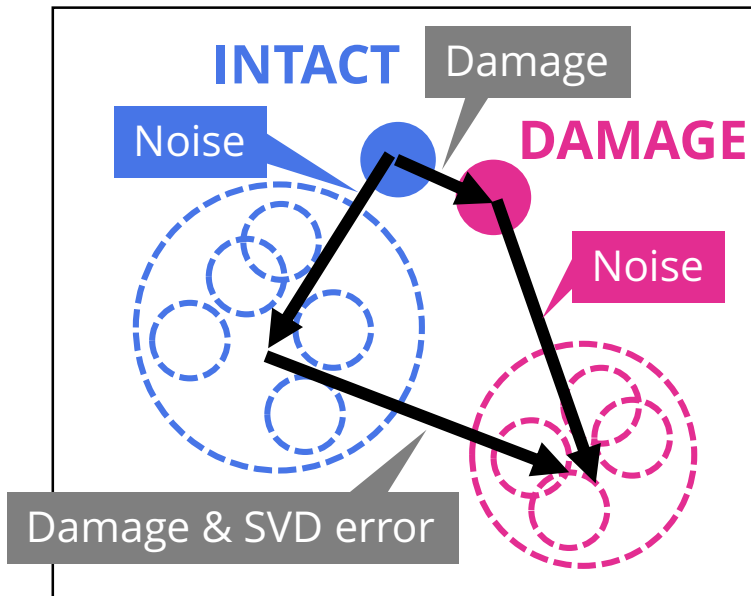
$$x(t) = A s(t)$$



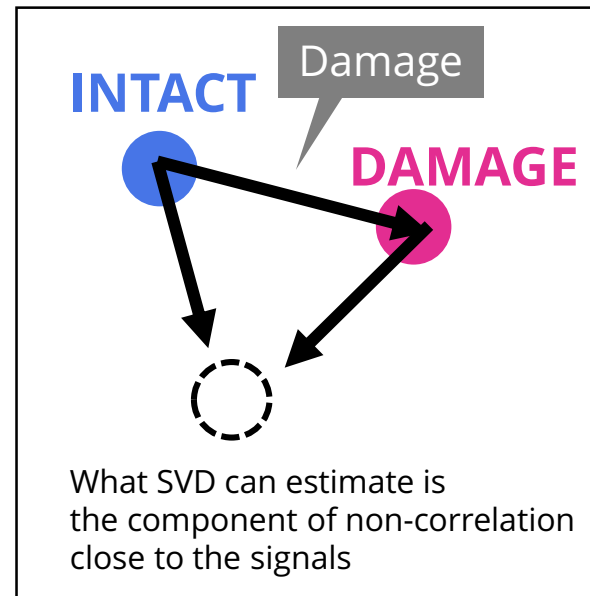
Discussion:

Why does **SSMA** shows the high sensitivity to the bridge damage?

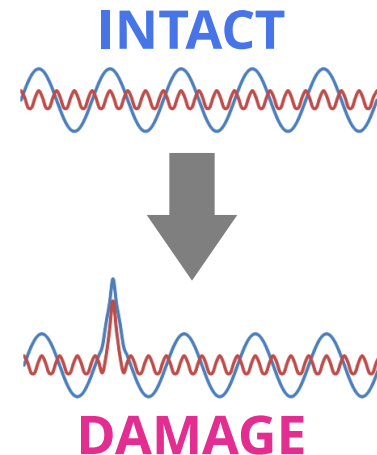
$$x(t) = A s(t)$$
A diagram illustrating the matrix equation $x(t) = A s(t)$. On the left, a vertical grey rectangle represents the vector $x(t)$. In the middle, an equals sign is followed by a 3x3 orange grid representing the matrix A . To the right of the matrix is a vertical stack of three colored rectangles (blue, red, green) representing the vector $s(t)$.



Mode Shape



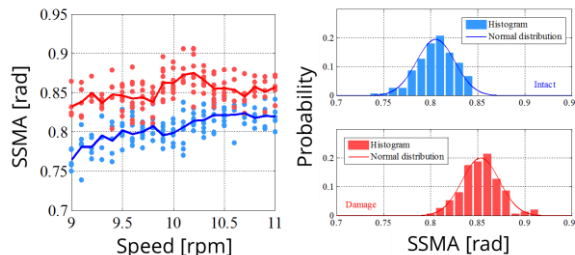
Basis Coordinate





Conclusion:

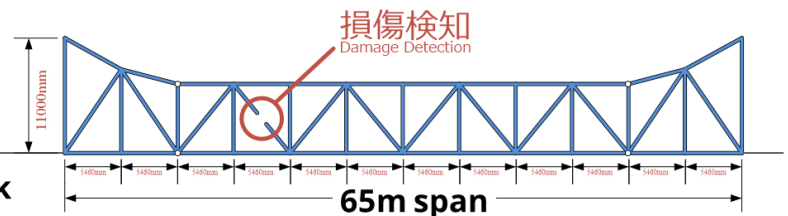
1. SSMA is the **bridge mode shape estimated** only by using the vehicle data.
2. The applicability and statistical validity is verified **numerically** and **experimentally**.
3. It is applicable to the **damage detection** because of its high sensitivity.
4. It is still difficult to apply SSMA to the **damage identification**, because of its low estimation accuracy



車上計測
On-going Measuring



25ton Truck





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