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Relationship between Spatial Singular Mode Angle and vehicle run speed

UNIVERSITY OF TSUKUBA

Kyosuke Yamamoto
Mikio Ishikawa

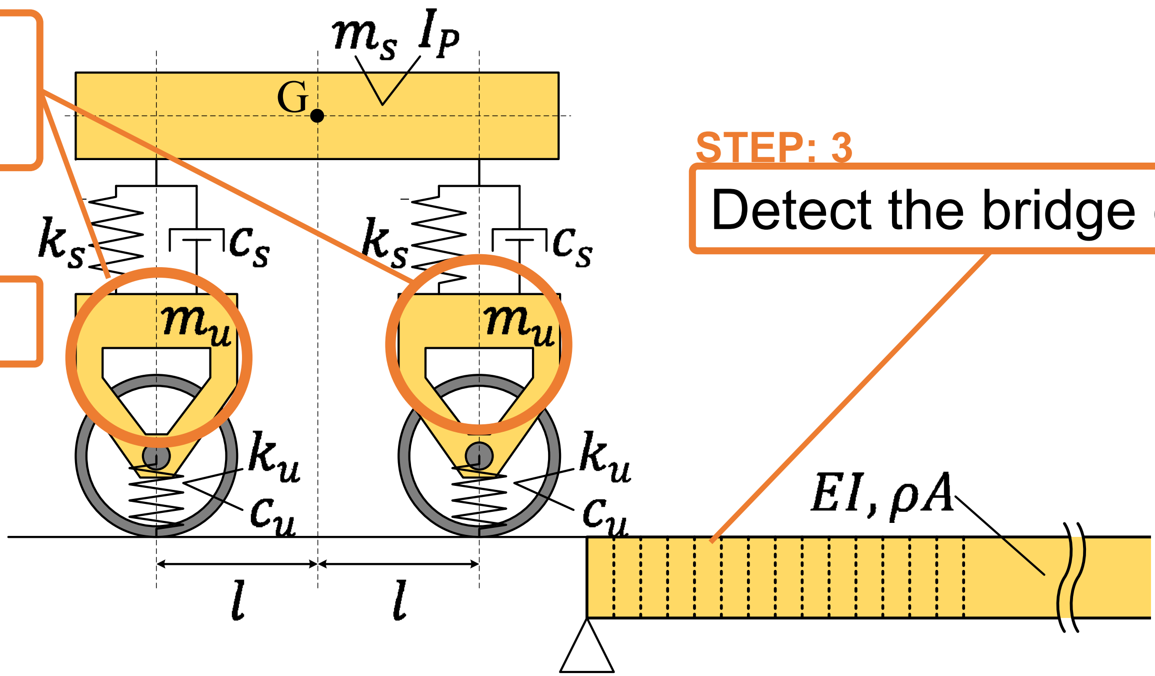
Introduction

Indirect Approach (Vehicle Response Analysis) proposed by Yang et al. (2004)
Bridge health estimation by only using acceleration on the vehicle

STEP: 1
Measure the acceleration on the vehicle

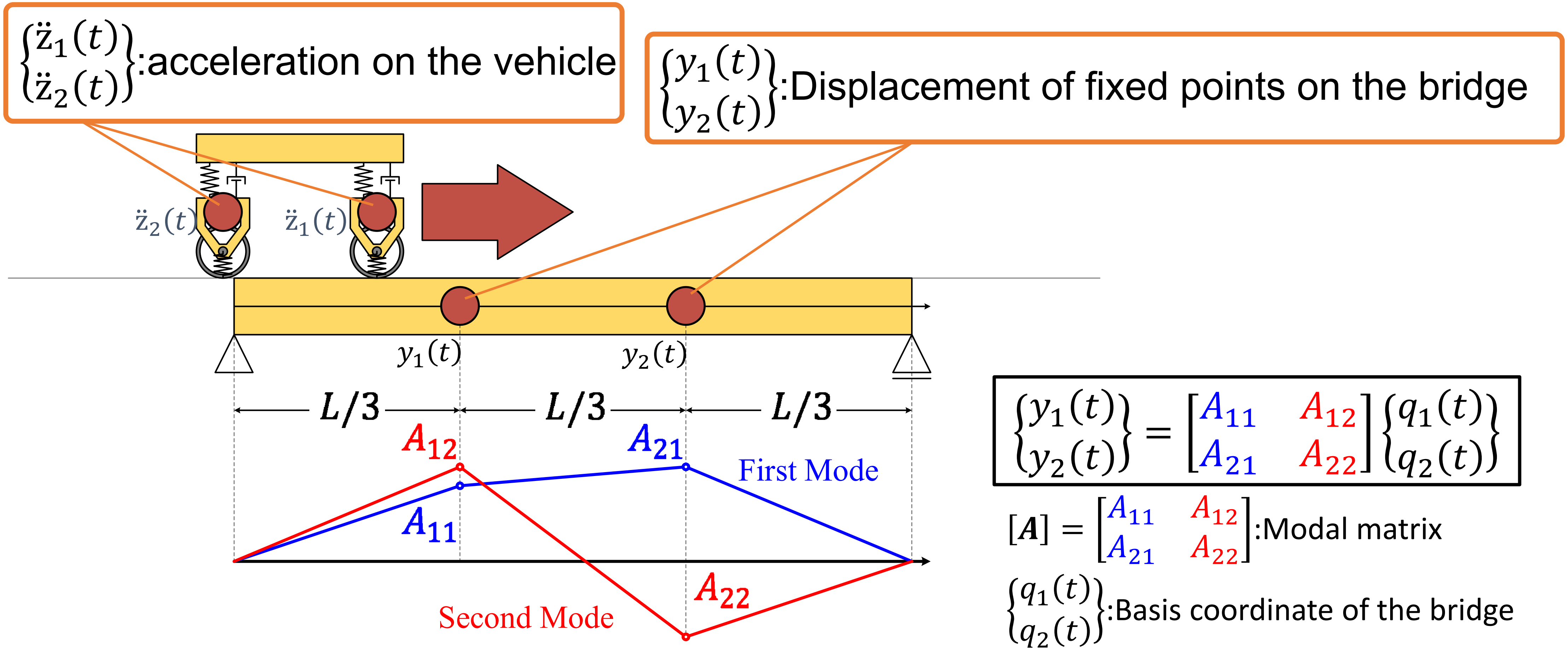
STEP: 2
Estimate the bridge vibration

STEP: 3
Detect the bridge damage



Use Spatial Singular Mode Angle for damage detection index

How to estimate SSMA



$$\begin{Bmatrix} y_1(t) \\ y_2(t) \end{Bmatrix} = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} \begin{Bmatrix} q_1(t) \\ q_2(t) \end{Bmatrix}$$

$[\boldsymbol{A}] = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix}$:Modal matrix

$\begin{Bmatrix} q_1(t) \\ q_2(t) \end{Bmatrix}$:Basis coordinate of the bridge

How to estimate SSMA

Spatial Singular Mode (Vehicle Vibration)

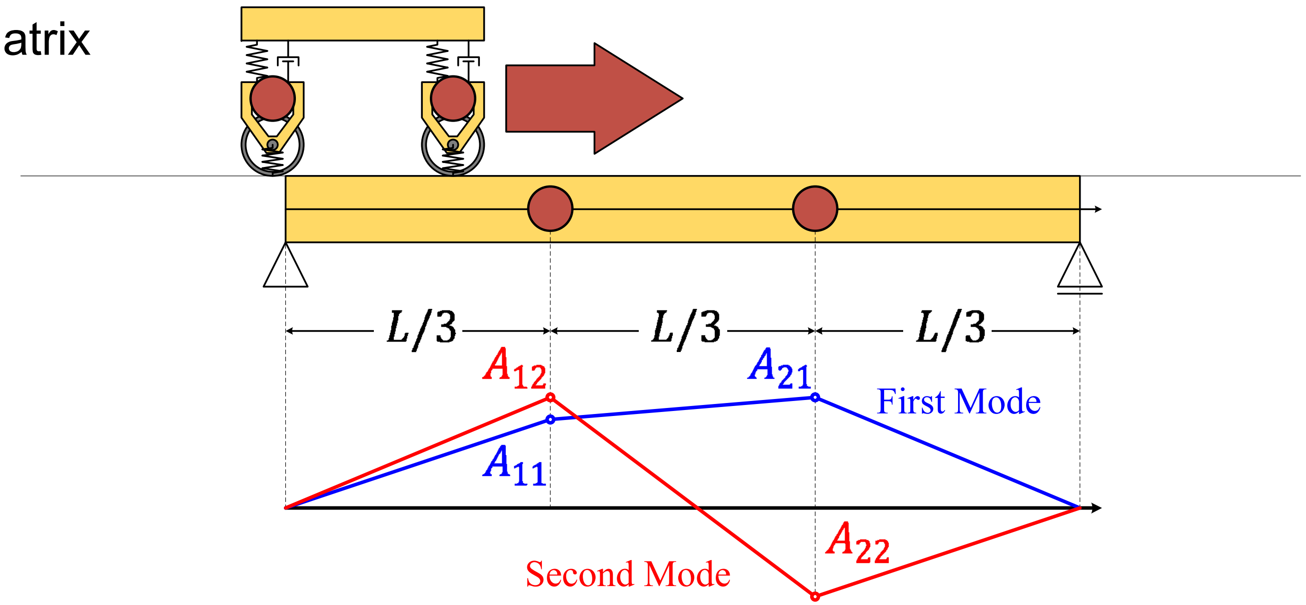
$$\begin{bmatrix} N_{11}(t) & N_{12}(t) \\ N_{21}(t) & N_{22}(t) \end{bmatrix}^{-1} \begin{Bmatrix} \ddot{z}_1(t) \\ \ddot{z}_2(t) \end{Bmatrix} = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} \begin{Bmatrix} \sigma_1(t) \\ \sigma_2(t) \end{Bmatrix}$$

1) To correct **vehicle vibration** by the interpolation based on the vehicle position
2) To apply **SVD** (**S**ingular **V**alue **D**ecomposition) to the corrected vibration data
3) **Spatial Singular Mode** is **Singular Mode** of the corrected data

$$[\boldsymbol{N}] = \begin{bmatrix} N_{11}(t) & N_{12}(t) \\ N_{21}(t) & N_{22}(t) \end{bmatrix}$$:Shape function matrix

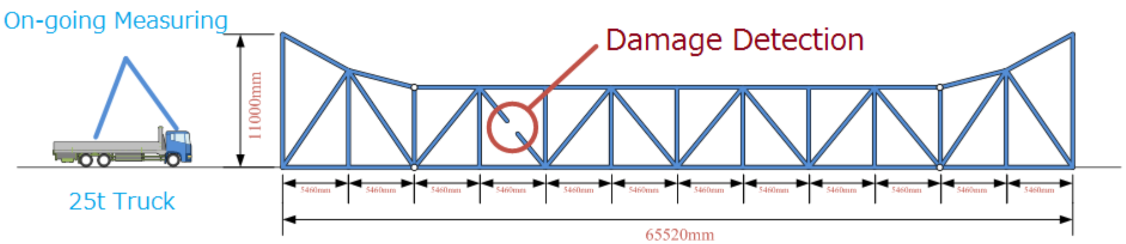
$$\begin{Bmatrix} \sigma_1(t) \\ \sigma_2(t) \end{Bmatrix} = c_u \begin{Bmatrix} \dot{q}_1(t) \\ \dot{q}_2(t) \end{Bmatrix} + k_u \begin{Bmatrix} q_1(t) \\ q_2(t) \end{Bmatrix} + \epsilon$$

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

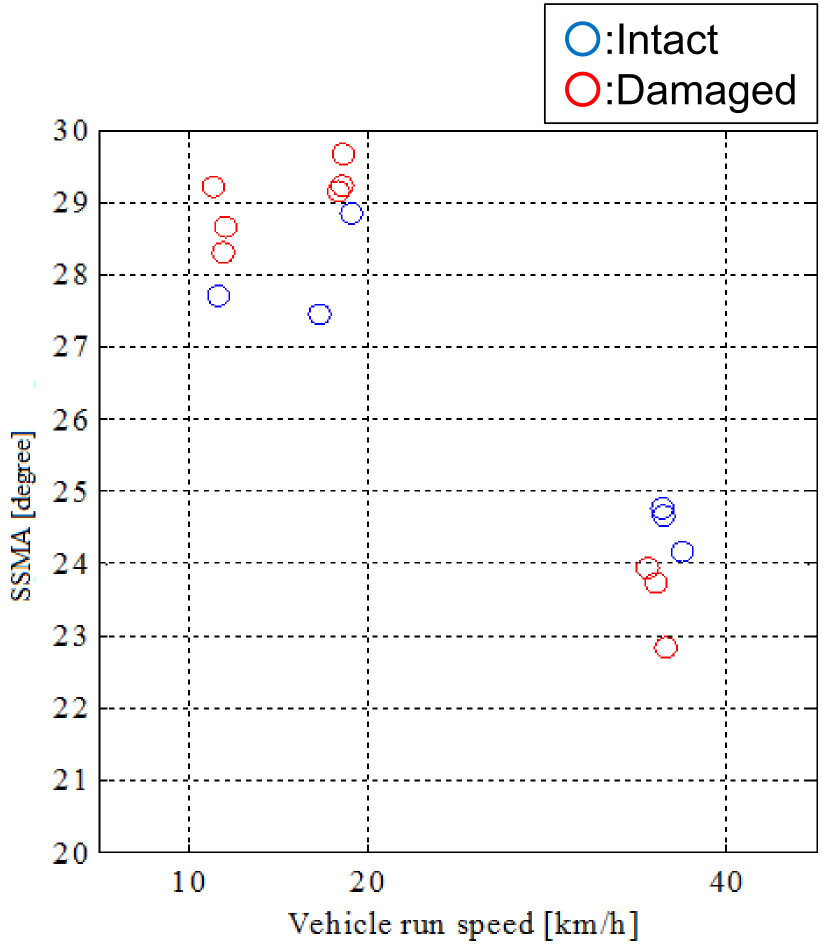


Background

Previous experiment on the real truss bridge



One scene of the experiment



Purpose

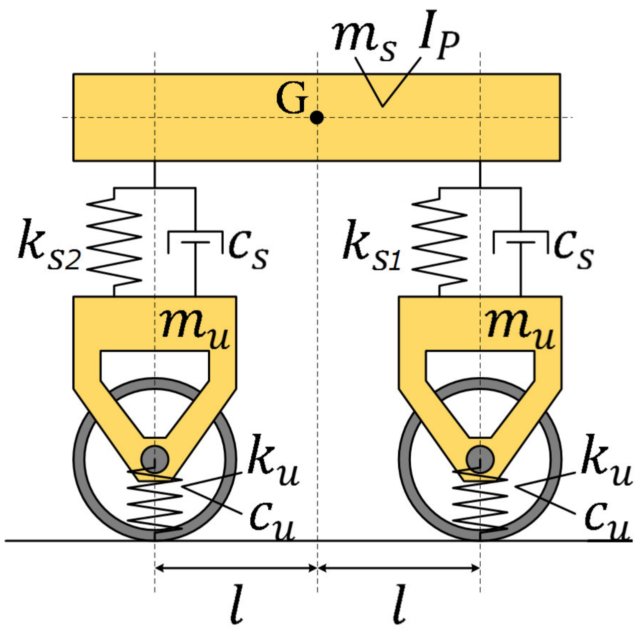
Check the applicability of SSMA to detect damage of the bridge

1. when the vehicle including sensors changes
2. when vehicle speed varies gradually

by numerical simulation

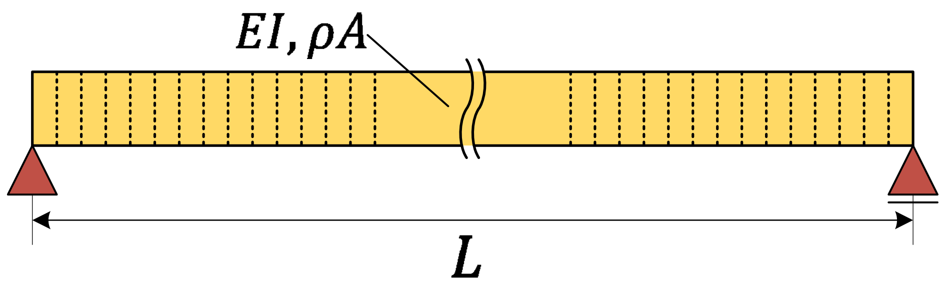
Parameters of the Vehicles

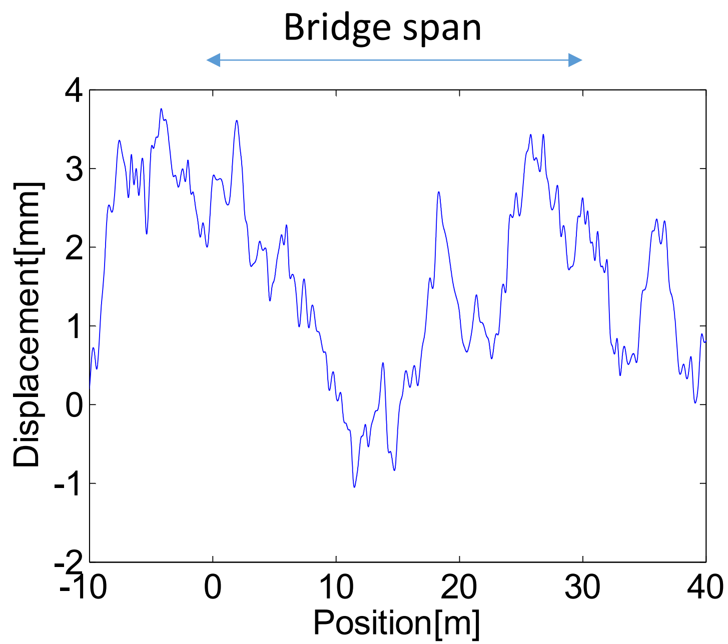
Vehicle Parameters				Vehicle1	Vehicle2
Sprung-	Mass	m_s	[kg]	18,000	
	Stiffness (Front)	k_{s1}	[kg/s²]	1.0×10^6	
	Stiffness (Rear)	k_{s2}	[kg/s²]	1.0×10^6	2.0×10^6
	Damping	c_s	[kg/s]	1.0×10^4	
	Inertia	I_P	[kg m²]	64958	
	Distance	l	[m]	1.875	
Unsprung-	Mass	m_u	[kg]	1,100	
	Stiffness	k_u	[kg/s²]	3.5×10^6	
	Damping	c_u	[kg/s]	3.0×10^4	



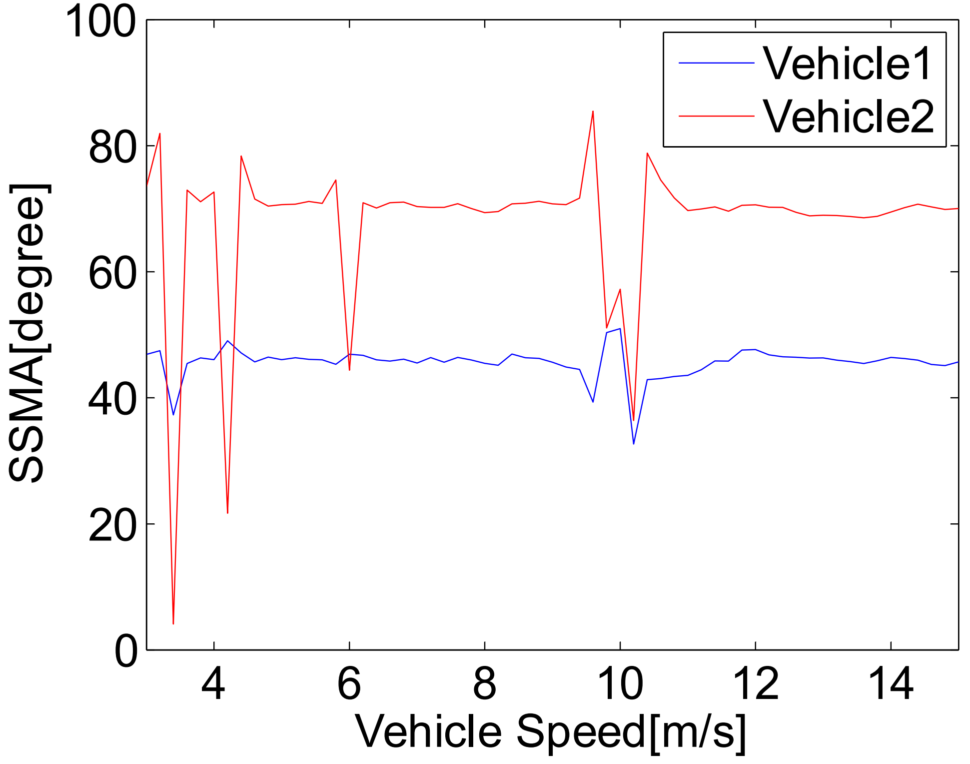
Parameters of the Bridges

BRIDGE PARAMETERS			
Span length	L	[m]	30
Mass	M	[kg]	18000
Flexural stiffness	EI	[kg/s]	1.56×10^{10}
Mass per unit length	ρA	[kg/m]	3000
Rayleigh coefficient	α β		0.238 0.000
FEM PARAMETERS			
Element number			300
DAMAGE OF BRIDGE			
Damaged area		[m]	20~30
Stiffness decreasing		%	30
Mass decreasing		%	10

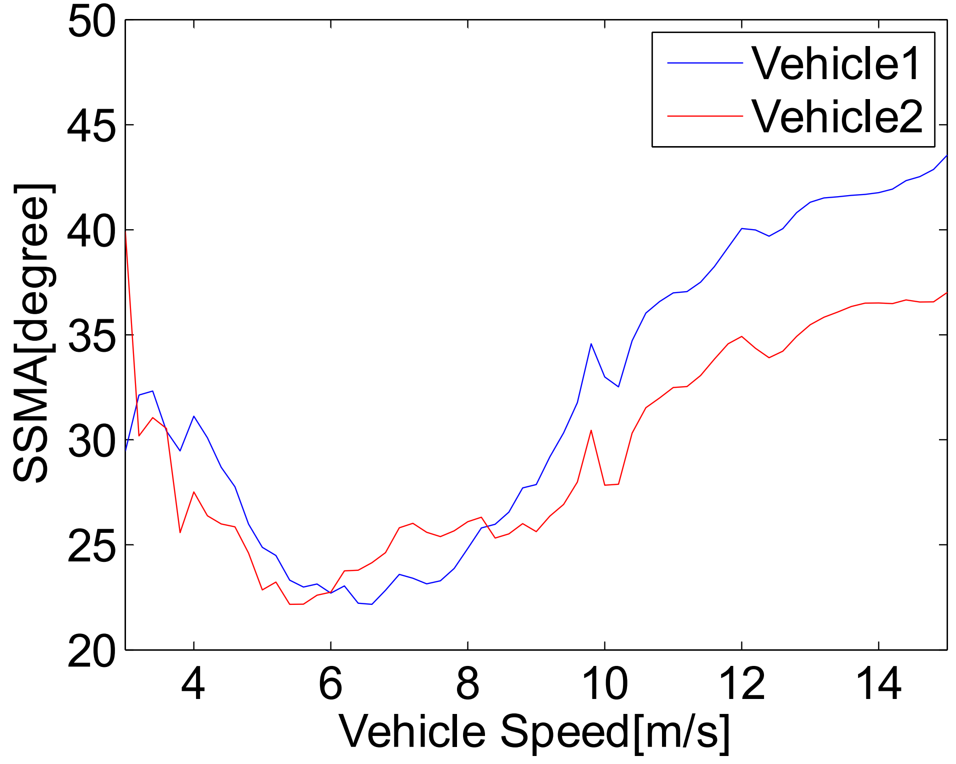




Results

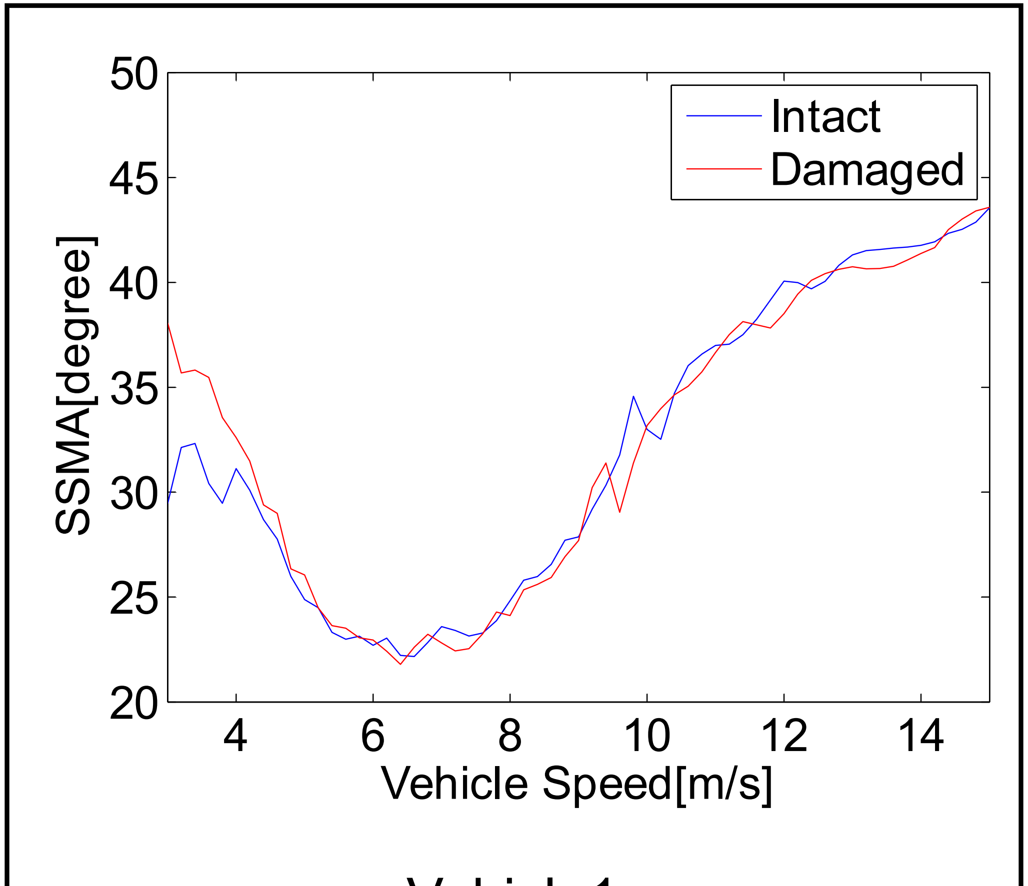


Regular road surface

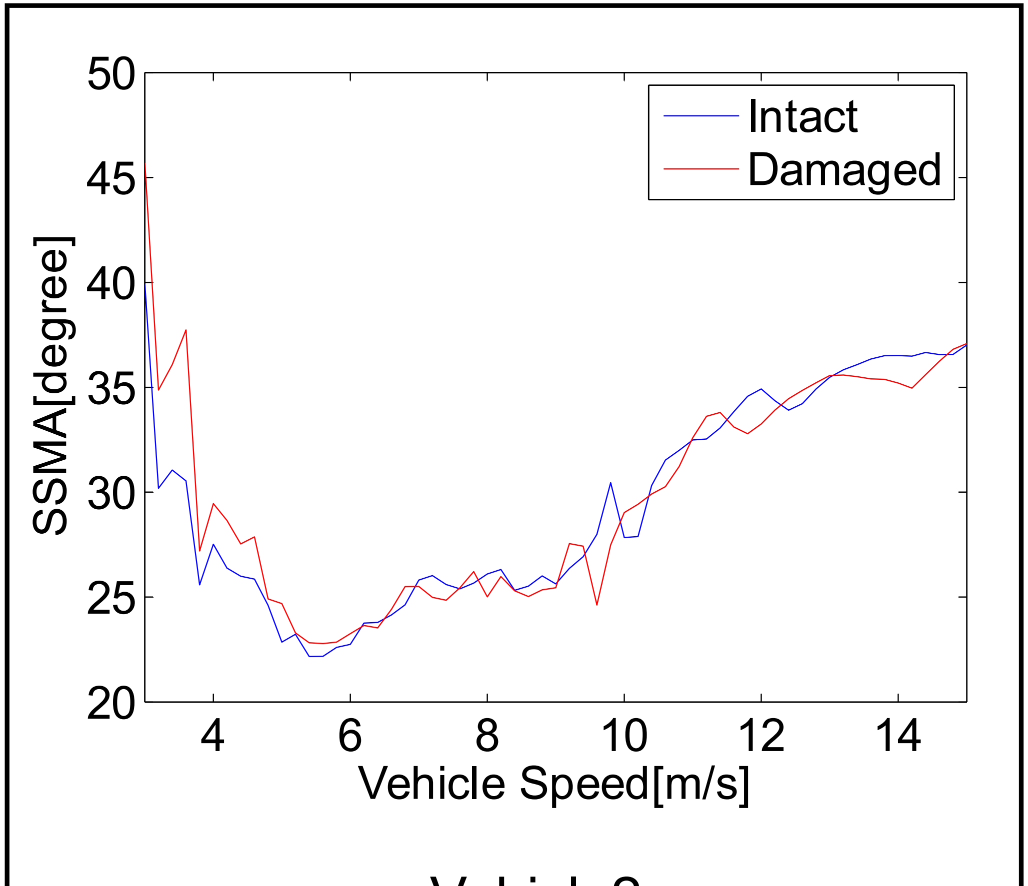


Irregular road surface

Results



Vehicle1



Vehicle2

Conclusion

- This method is affected by parameters or speed of vehicles.
- It is difficult to distinguish damaged bridges by using only existing SSMA.