Development of the Damage Level Sensor System for RC Railway Rigid-frame Viaduct

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Introduction

- After an earthquake ⇒ Detection of damage to RC railway rigid frame viaducts is normally carried out by visual inspection.

↓ However

- The number of viaducts with retrofitted columns using steel-Jackets increased in recent years to protect against earthquake.

↓ Making it

- Difficult to check for damage using visual inspection.

RC viaducts : possible inspection

increased

Retrofitted columns : impossible inspection

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Introduction

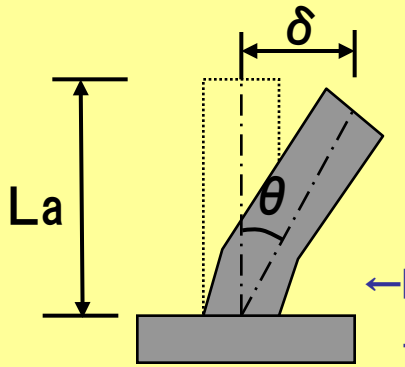
・The relationship between the maximum response member angle occurring at the end of a column and the level of damage in a viaduct is generally known.

＊ “Design Standard for Railway Structure (Seismic Designs)”

Therefore

・If it were possible to measure accurately and efficiently the maximum response member angle, it would be possible to rapidly determine the damage state of viaduct, and it is expected that this would result in accurate safety assessment during recovery operations after an earthquake.

The maximum response member angle



$$\tan\theta = \frac{\delta}{La}$$

←RC railway rigid frame viaduct

Relationship

The damage state of viaduct

Damage Level
1
2
3
4

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Introduction

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The damage state of viaduct

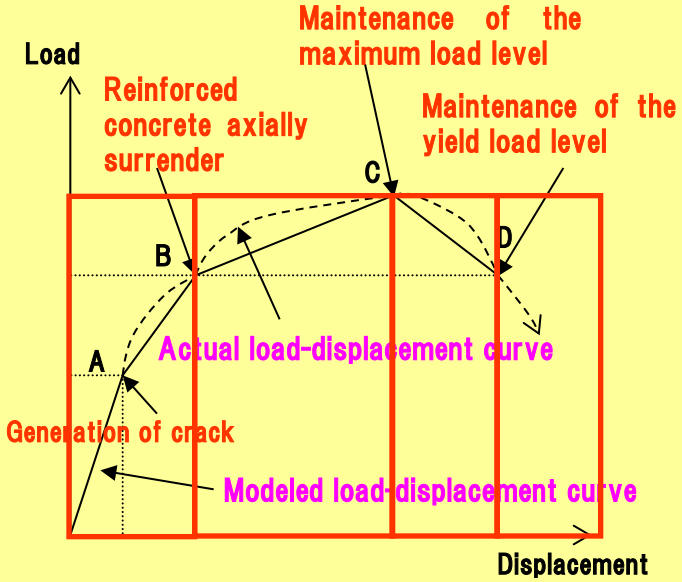

Fig. Envelope curve of reinforced concrete member’s load-displacement curve

Damage Level	The damage state of viaduct
1	No damages
2	Damage for which repair is necessary depending on the case.
3	Damage for which repair is necessary
4	Damage for which repair is necessary. Damage for which the material substitution is necessary depending on the case

Outline of the maximum response member angle measurement device

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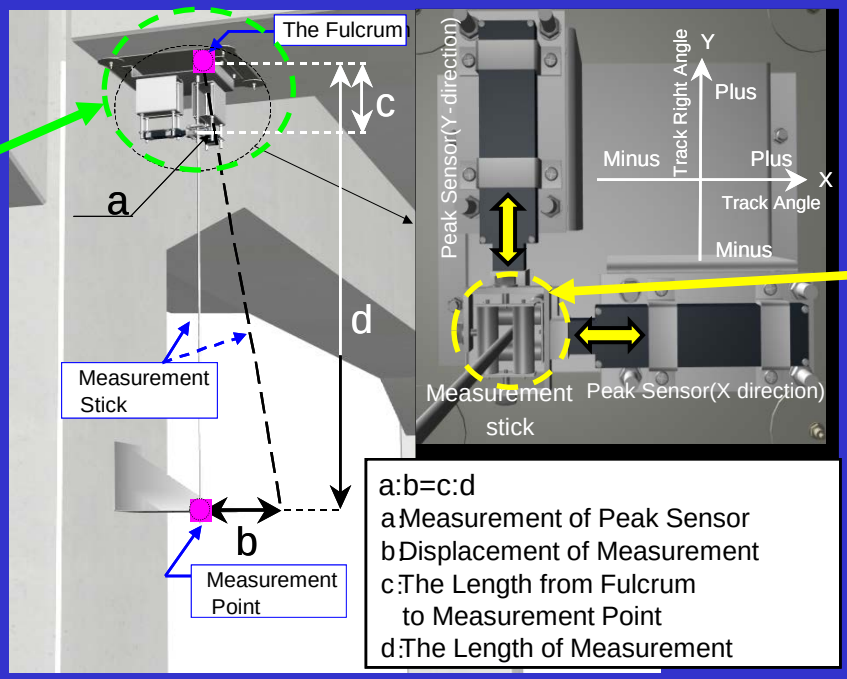
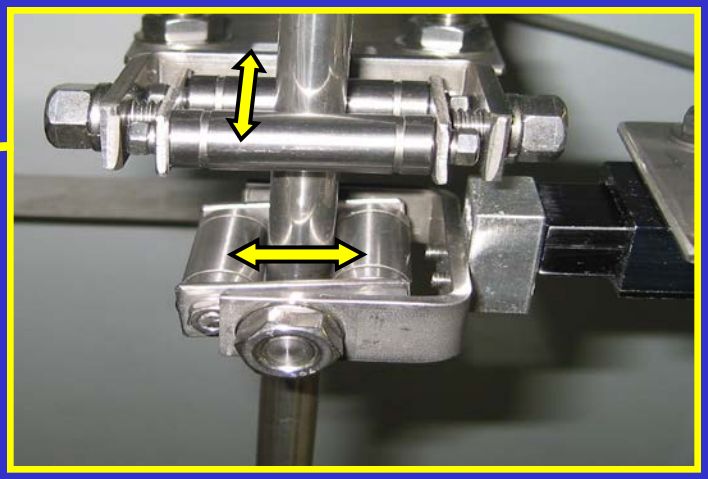
corner part



a:b=c:d
a:Measurement of Peak Sensor
b:Displacement of Measurement
c:The Length from Fulcrum to Measurement Point
d:The Length of Measurement



The maximum response member angle measurement device

- The column's angle of inclination ⇒Measurement Stick
- The device uses the geometrically similar relationship.
- The device measures the maximum response member angle. (θ max)
- The device can measure two directions on both the X-direction and the Y-direction in a single device.

Outline of the maximum response member angle measurement device

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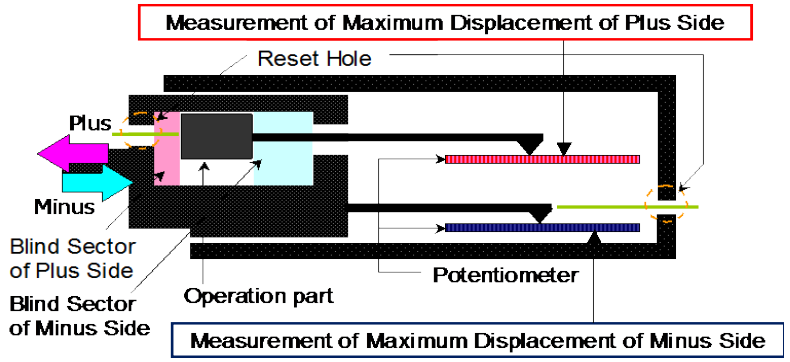
Peak Sensor



Peak sensor specification

Item	Value
Dimensions	127×18×32mm
Weight	155g
Measurement Range	±10mm
Resolution	2μm

Peak sensor

- The peak sensor can measure and record the maximum displacement on both the positive and negative side in a single sensor.
- It is not necessary to always supply electrical power to the sensor, but a weak power supply is used only when measuring in order to measure voltage changes due to the movement of a potentiometer.
- The peak sensor has reset function.

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Laboratory accuracy confirmation tests

Accuracy confirmation test arrangement

Test cases

CASE	Postulated RC railway rigid-frame viaduct	Input earthquake wave	Measurement direction
0-1	-	Sin wave	L angle
0-2			C angle
1-1	Height of column 12m (1 layer)	L1G3 wave	L angle
1-2			C angle
2-1	Height of column 7m (1 layer)	L2G3 wave	L angle
2-2			C angle

* L angle: Track angle, C direction: Track right angle

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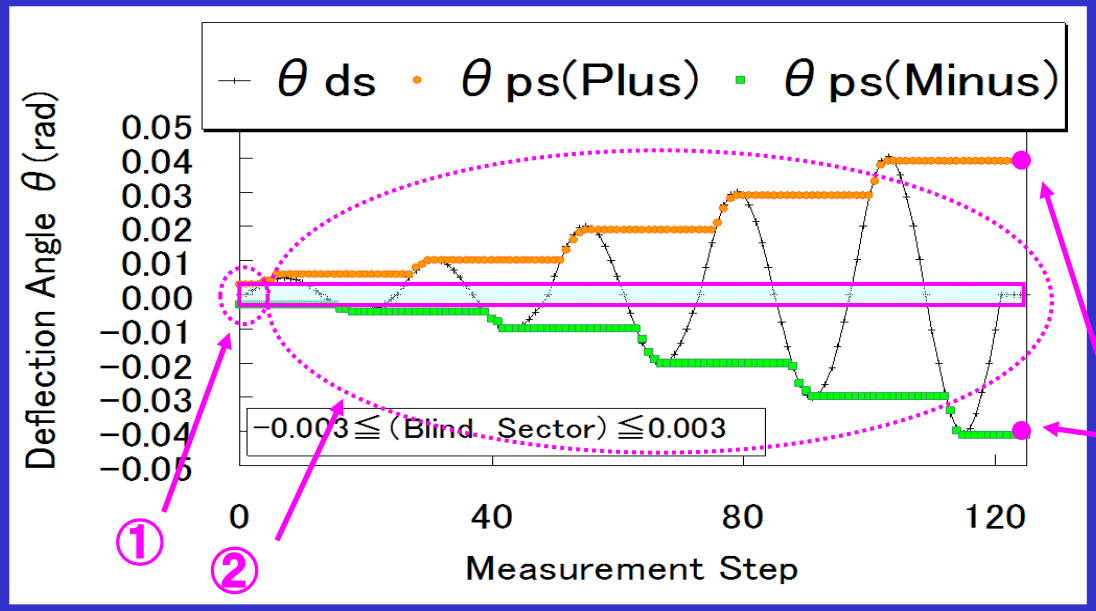
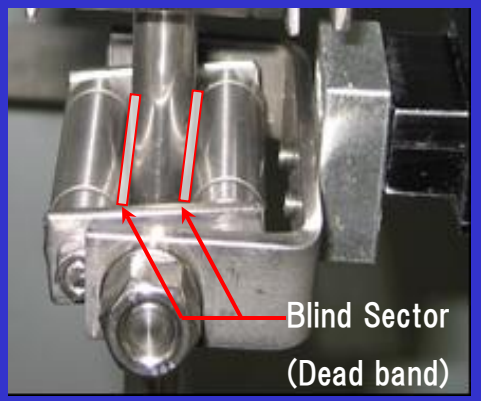
Laboratory accuracy confirmation tests



Sin wave

θ ds : input value
θ ps : measurement value of peak sensor

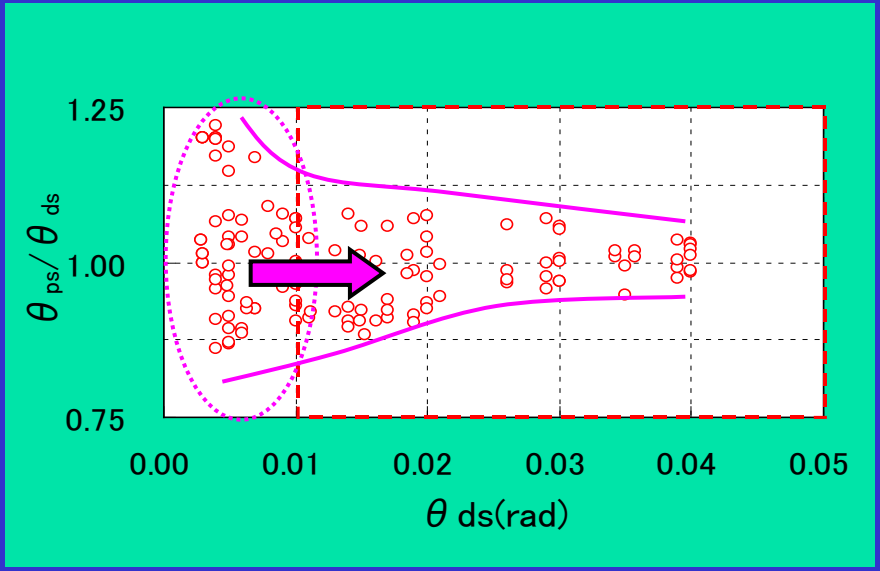


① θds : Small ⇒ cannot be measured. (Blind Sector)

② θds : Increases ⇒ can be measured.

③ θds : Final measure value.
⇒the maximum response member angle. (Peak value)

Laboratory accuracy confirmation tests



Verification of accuracy (Total case)

θds：input value
θps：measurement value of peak sensor

θps/θds
⇒measurement accuracy （%）

θds ：Small ⇒ large variation in the values can be seen.

θds ：Increases ⇒ the measurement accuracy tends to increase.

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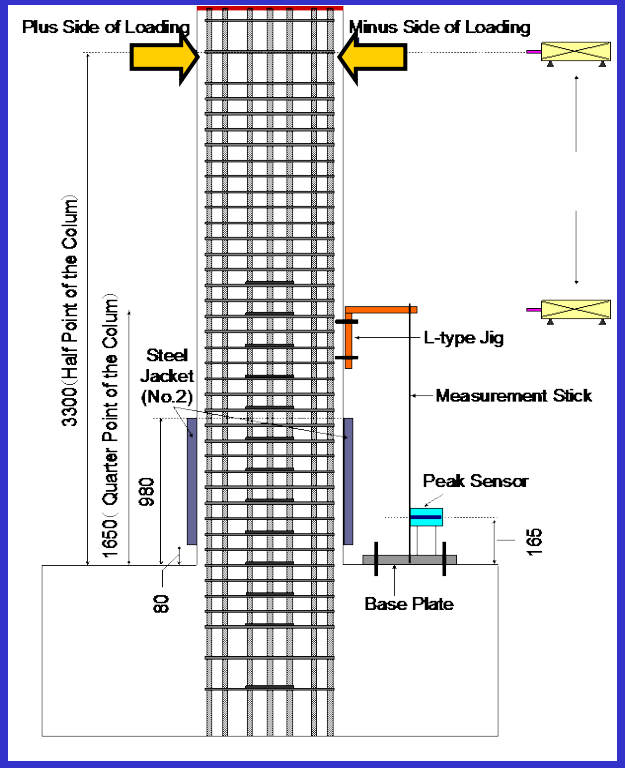
Static excitation tests



Structure of the test specimen

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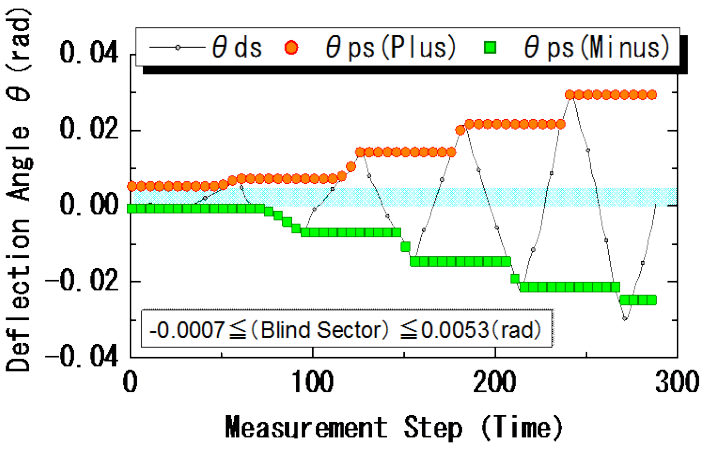
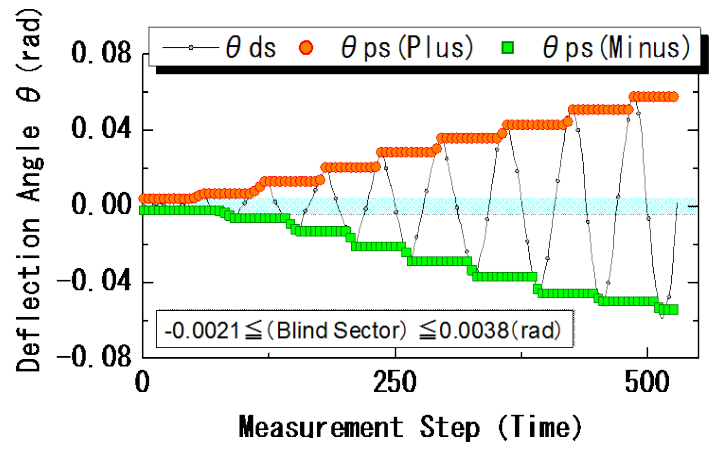
Static excitation tests

Damage state at 6δy
(Left:No.1, Right:No.2)

Test cases

Test specimen No.	Maximum member angle
No.1 (no steel plate)	6 δy
No.2 (with steel plate)	8 δy





Static excitation test results (Left:No.1, Right:No.2)

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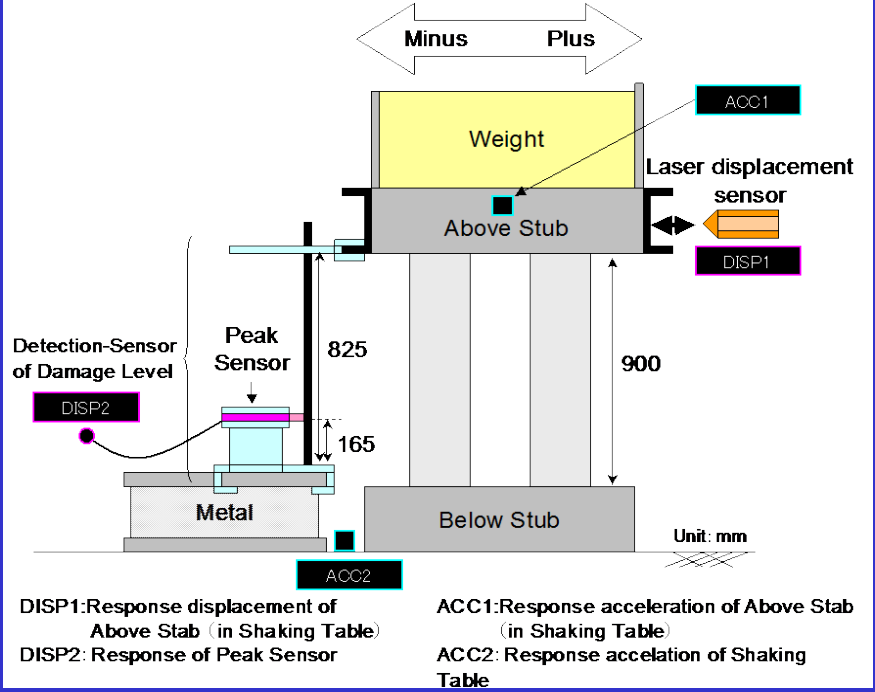
Dynamic vibration tests



Measurement method and device installed state

Test specimen parameters

Item	Value
Weight excluding lower stub	150 kg
Deadweight	1400 kg
Natural period	0.44 s(before damage) 0.47 s(after damage)
Response acceleration at yield	330 gal
Damping constant	2.6%

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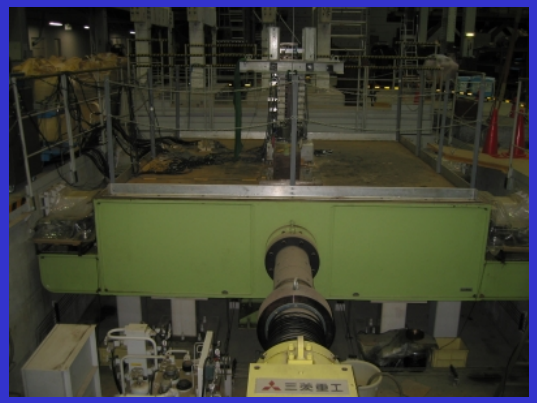
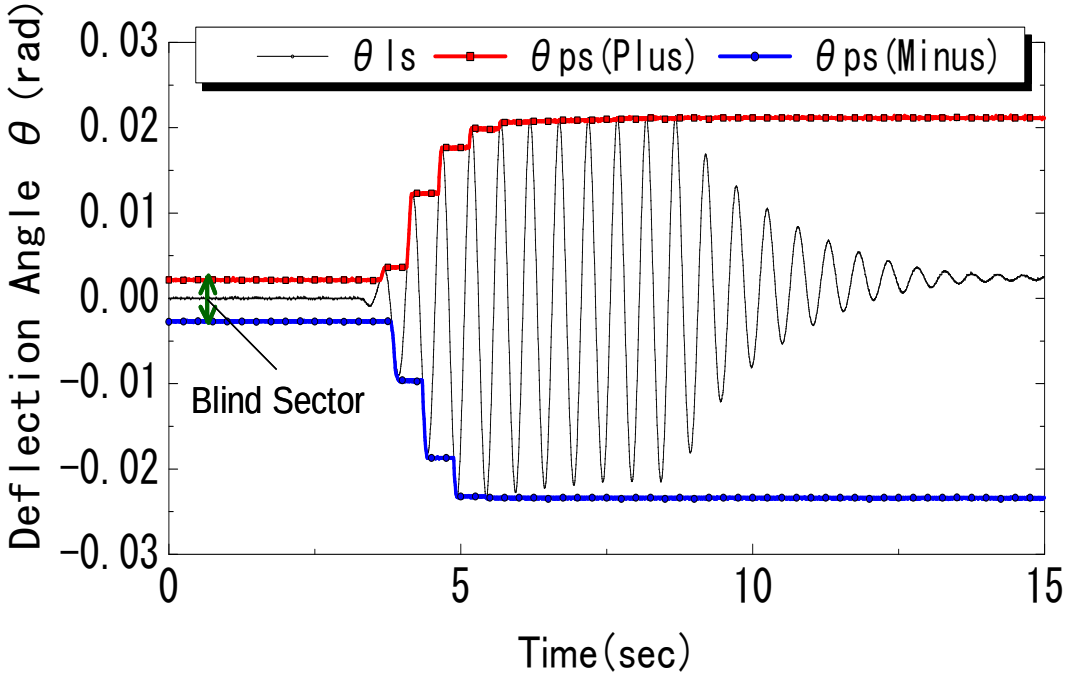
Dynamic vibration tests



Shaking table and device installed state

Dynamic vibration tests



Dynamic vibration test results

The result shows that input wave strongly correlated the measurement value(peak value).

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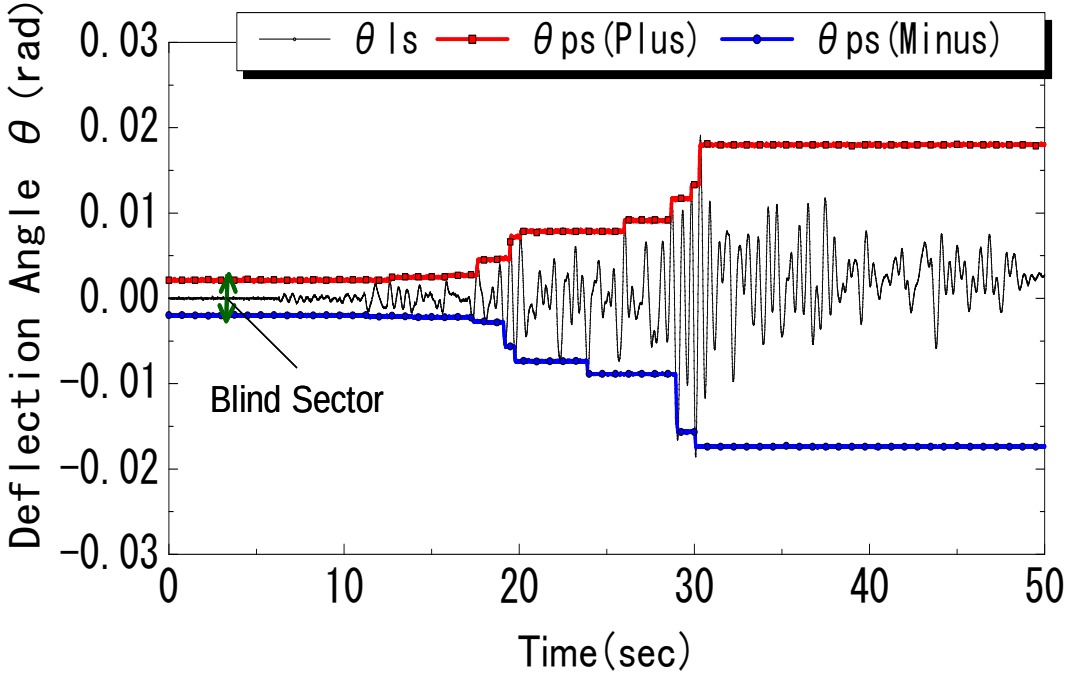
Dynamic vibration tests



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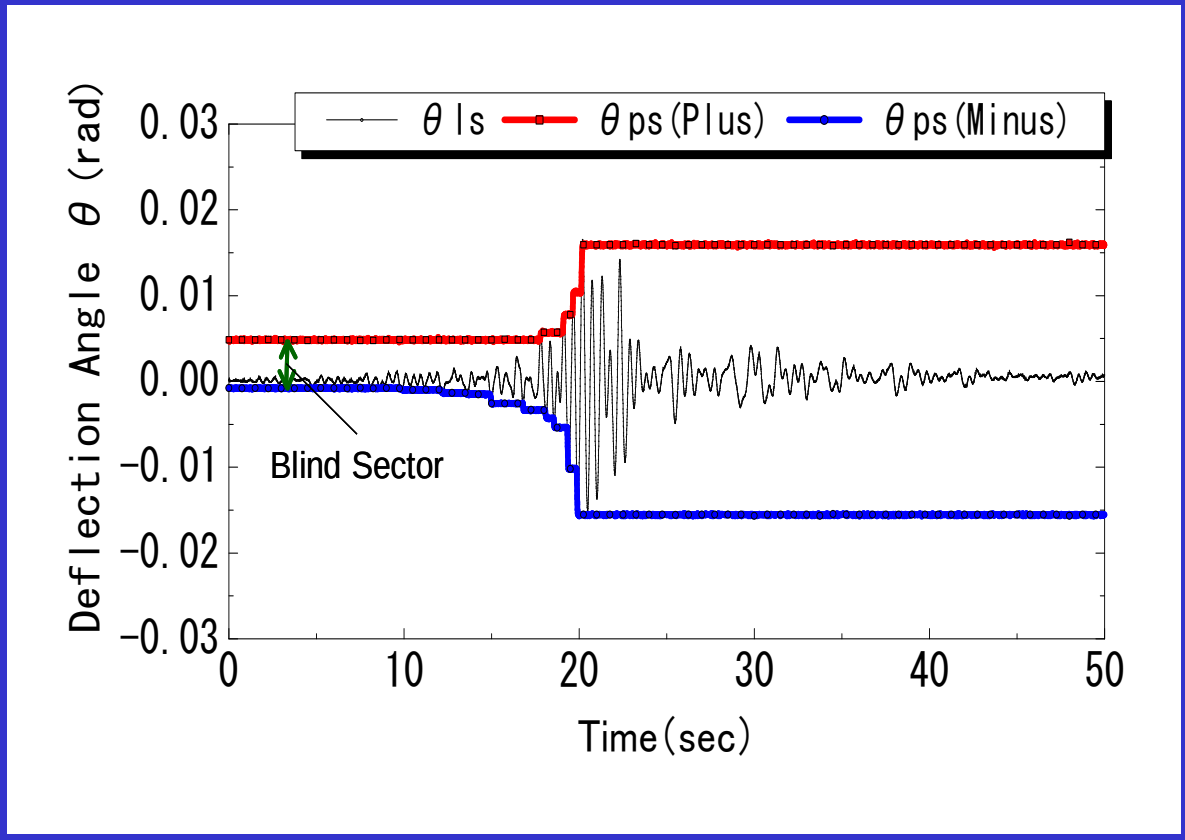

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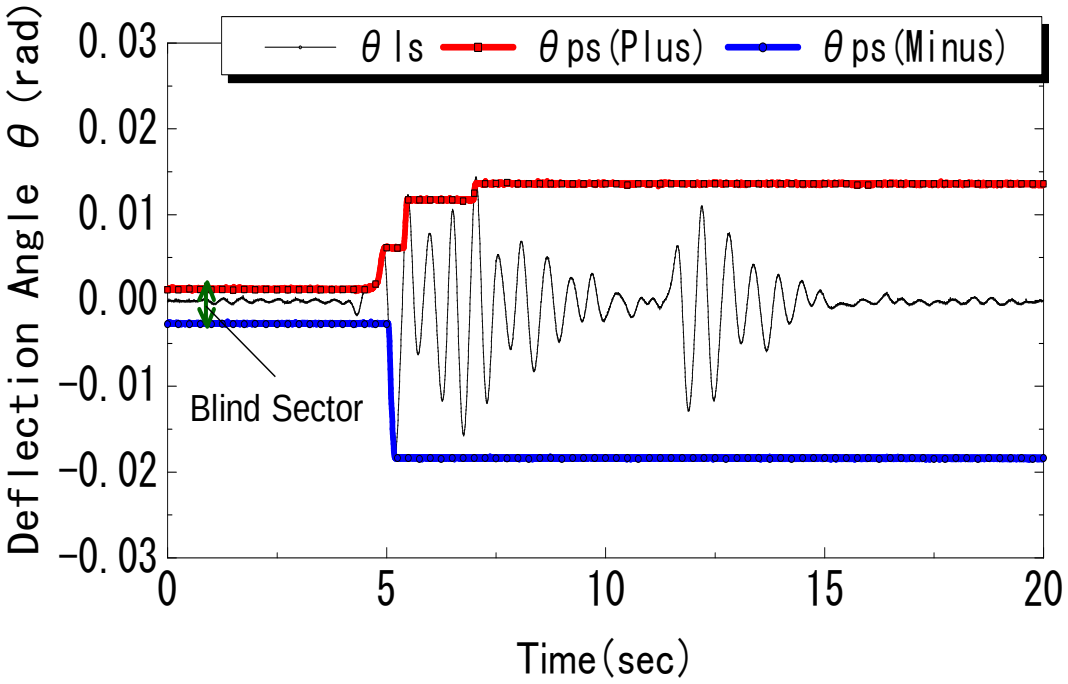

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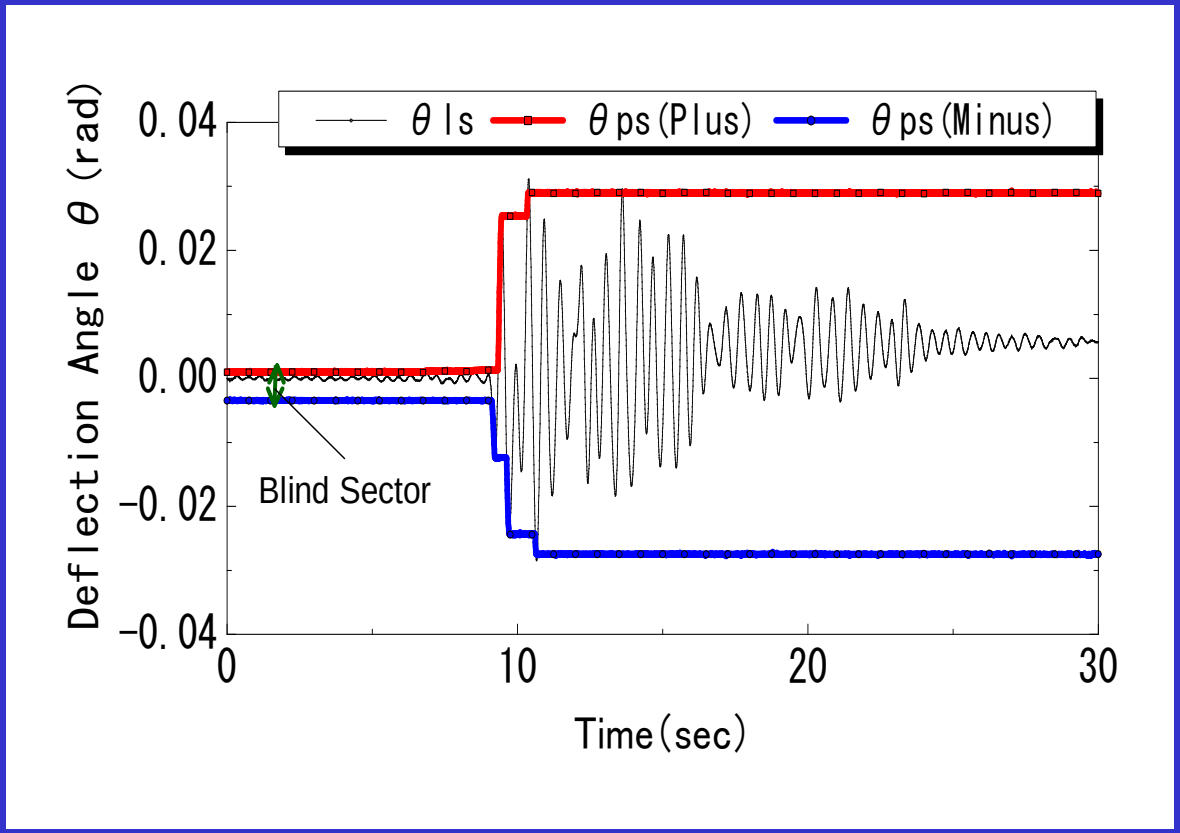

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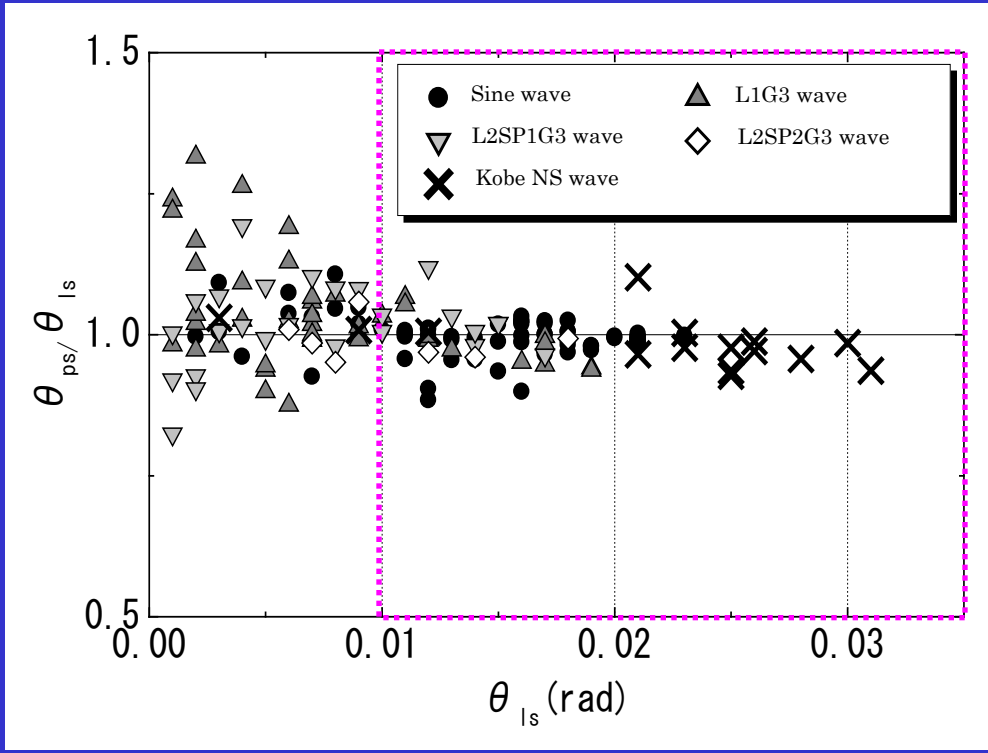

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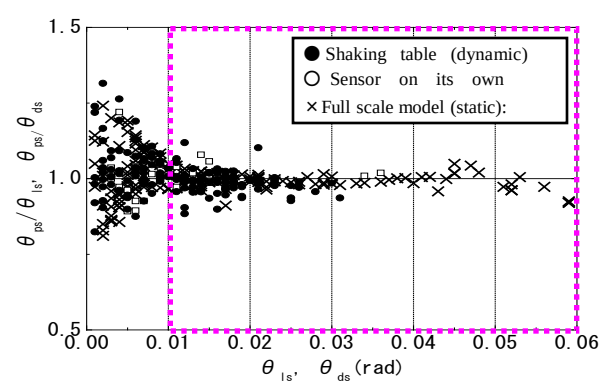
Dynamic vibration tests



*Comparison wave form

Shaking table (dynamic) : θ ls and θ ps

Sensor on its own: θ ds and θ ps

Full scale model (static): θ ds and θ ps

Comparison of dynamic measurement accuracy and static measurement accuracy

Error rates

Input wave form	All data		≧0.01 (rad)	
	Average value	Coefficient of variation (%)	Average value	Coefficient of variation (%)
Sine wave	1.00	3.6	0.99	2.9
L1 wave	1.03	9.4	0.99	4.5
L2SP1G3 wave	1.02	7.4	1.02	4.3
L2SP2G3 wave	0.99	3.7	0.98	4.1
Kobe NS wave	0.98	4.4	0.98	4.5
All test cases	1.00	6.4	0.99	3.6
Sensor on its own (static)	0.99	7.4	0.98	4.7
Full size column (static)	1.00	6.1	0.99	2.8

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Application to an actual Bridge

Installation on an actual Shinkansen (Bullet Train) viaduct

Full view of installation part

Sensor system installation situation

Protective cover installation situation

Protective cover installation situation

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Application to an actual Bridge

Installation on an actual Shinkansen (Bullet Train) viaduct

RF-ID transmitter

Data measurement by RF-ID

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Application to an actual Bridge

Installation on the column of a roofed passage

Full view of installation part

Sensor system installation situation

Protective cover installation situation

Protective cover installation situation

Conclusions

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・The maximum response member angle measurement device has been developed as the development of a system for evaluation of the damage level in columns after an earthquake, and laboratory accuracy confirmation tests, static excitation tests, and dynamic vibration tests have been carried out.

From the result

・For the dynamic vibrations as well as the static excitations it was possible to track each input test wave and measure the maximum response member angle.

As a result, it was concluded that the maximum response member angle measurement device has sufficient accuracy for the evaluation of the damage level when applied to actual bridges.

Conclusions

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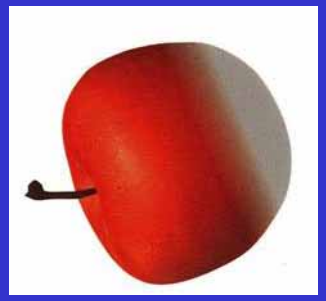
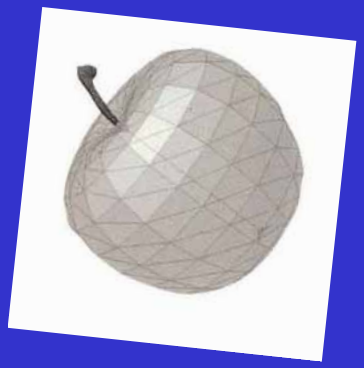
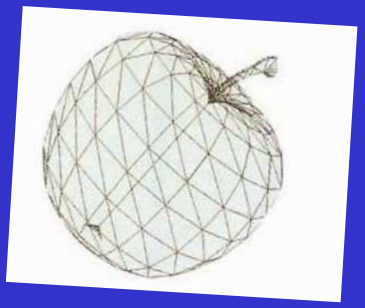
・Currently the device is installed on an RC railway rigid-frame viaduct that is in actual service, a durability test is being carried out, and data is being continuously obtained.

In the future

・It is expected that the device will be widely deployed as a damage level detection system capable of contributing to the efficiency of the work of inspection after an earthquake.

Fin.

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for your kind attention.

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