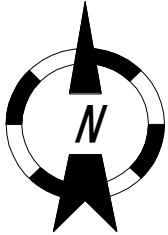


# **Structural Monitoring of the Akashi Kaikyo Bridge**

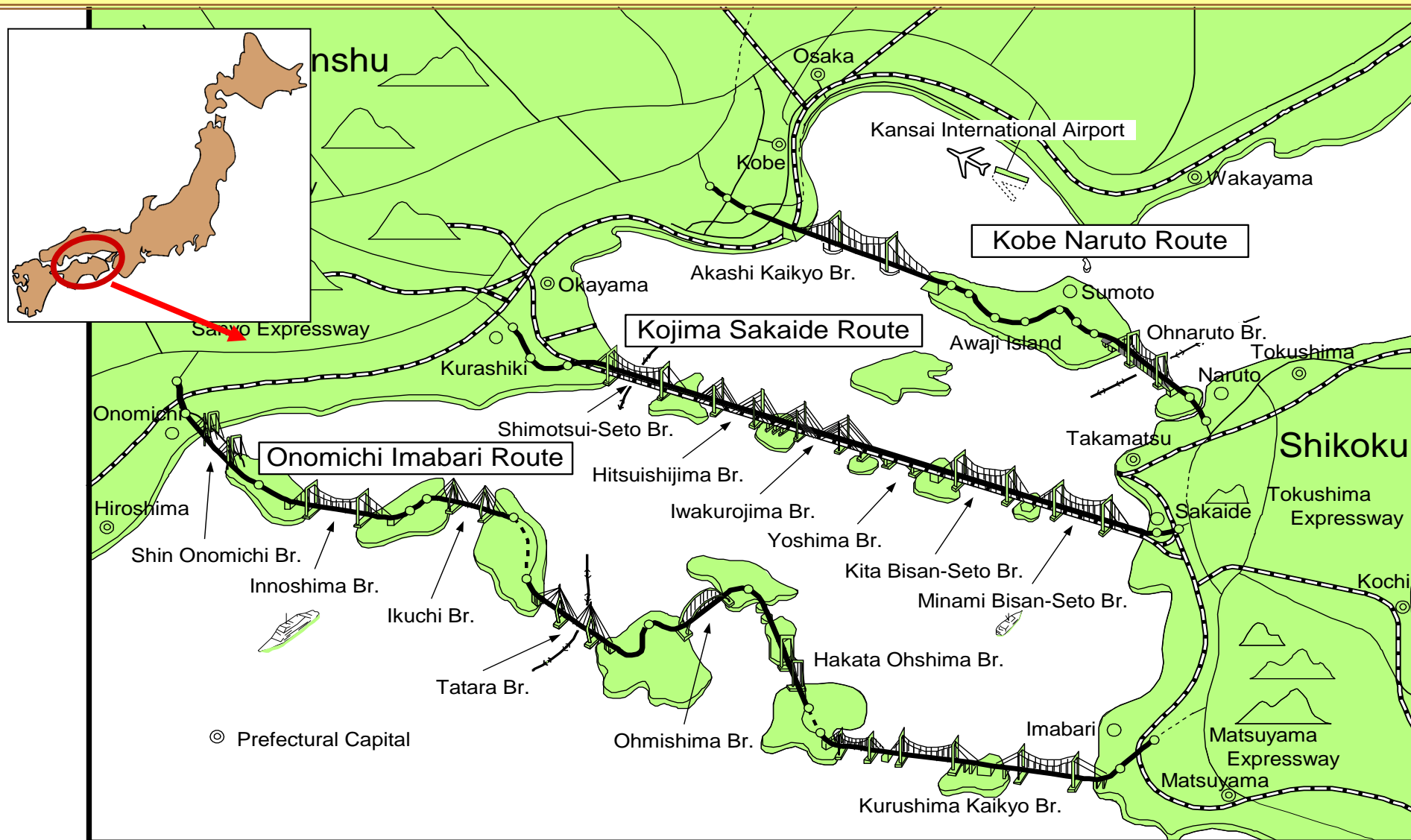
**Kiyohiro Imai**

**Honshu Shikoku Bridge Expressway Co. Ltd.**



# Outline of the Honshu Shikoku Bridges

**Honshu Shikoku Bridges contribute to the national highway network between Honshu and Shikoku Islands**



# Construction history of Honshu Shikoku Bridges

BRIDGE	BRIDGE TYPE	SPAN LENGTH (m) (SIDE+CENTER+SIDE)	CALENDAR YEAR																										
			1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999		
KOBE-NARUTO																													
AKASHI KAIKYO BR.	SUSPENSION	960+1991+960																											
OHNARUTO BR.	SUSPENSION	330+876+330																											
KOJIMA-SAKAIDE																													
SHIMOTSUI SETO BR.	SUSPENSION	230+940+230																											
HITSUISHIJIMA BR.	CABLE-STAYED	185+420+185																											
IWAKUROJIMA BR.	CABLE-STAYED	185+420+185																											
YOSHIMA BR.	TRUSS	175+245+165																											
KITA BISAN-SETO BR.	SUSPENSION	274+990+274																											
MINAMI BISAN-SETO BR.	SUSPENSION	274+1100+274																											
ONOMICHI-IMABARI																													
SHIN-ONOMICHI BR.	CABLE-STAYED	85+215+85																											
INNOSHIMA BR.	SUSPENSION	250+770+250																											
IKUCHI BR.	CABLE-STAYED	150+490+150																											
TATARA BR.	CABLE-STAYED	270+890+320																											
OHMISHIMA BR.	ARCH	297																											
OHSHIMA BR.	SUSPENSION	140+560+140																											
1ST KURUSHIMA KAIKYO BR.	SUSPENSION	140+600+170																											
2ND KURUSHIMA KAIKYO BR.	SUSPENSION	250+1020+245																											
3RD KURUSHIMA KAIKYO BR.	SUSPENSION	260+1030+280																											

Kobe EQ.

# Akashi-Kaikyo Bridge

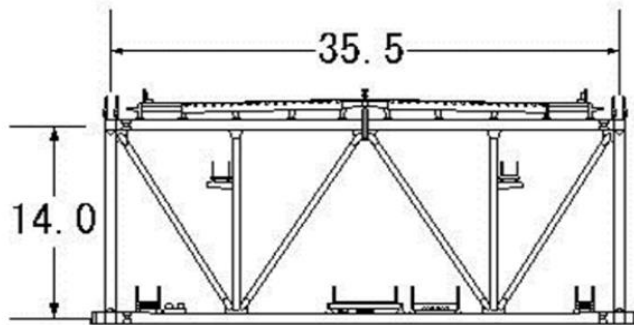
5



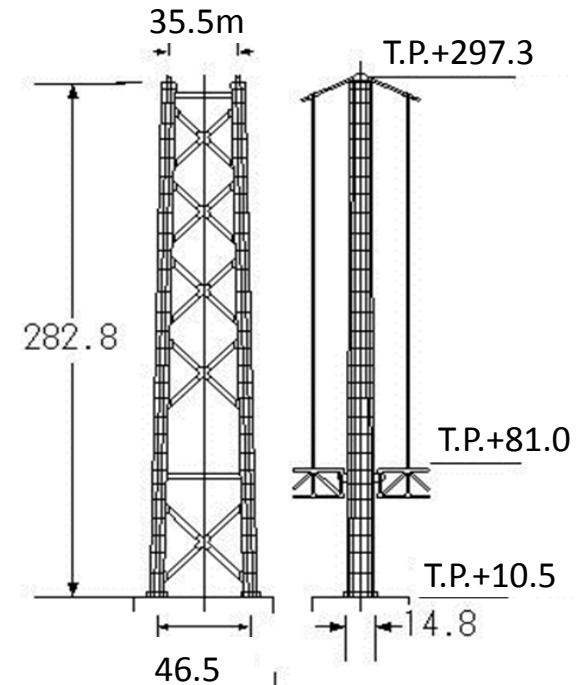
# General View of the Akashi-Kaikyo Bridge

3 span, 2 hinged stiffening girder system  
 Number of lanes: 6  
 Opened to traffic in 1998

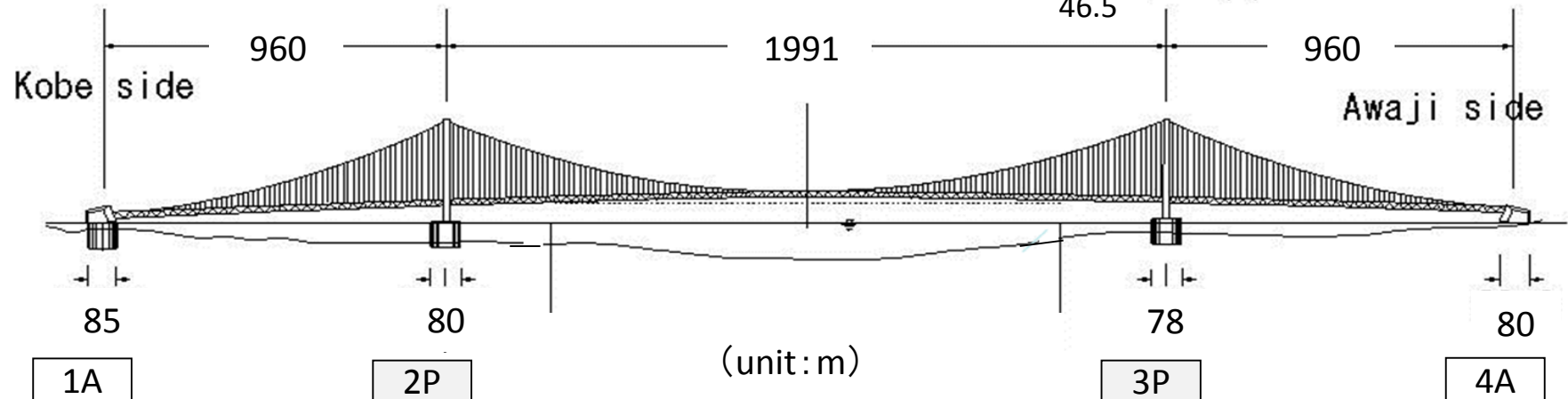
## Stiffening Girder



## Main Tower



## Side View





# Akashi Kaikyo Bridge just after the Earthquake (January 23, 1995)

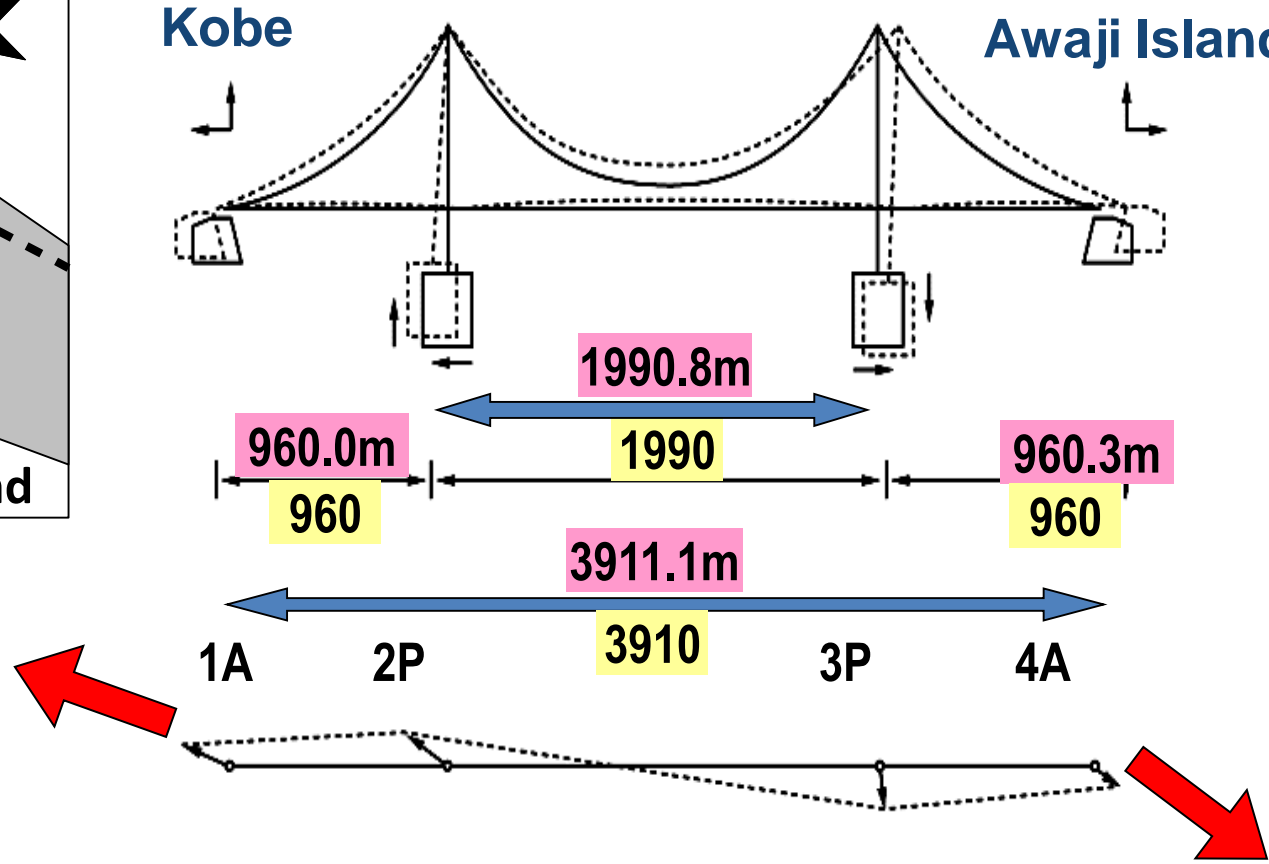
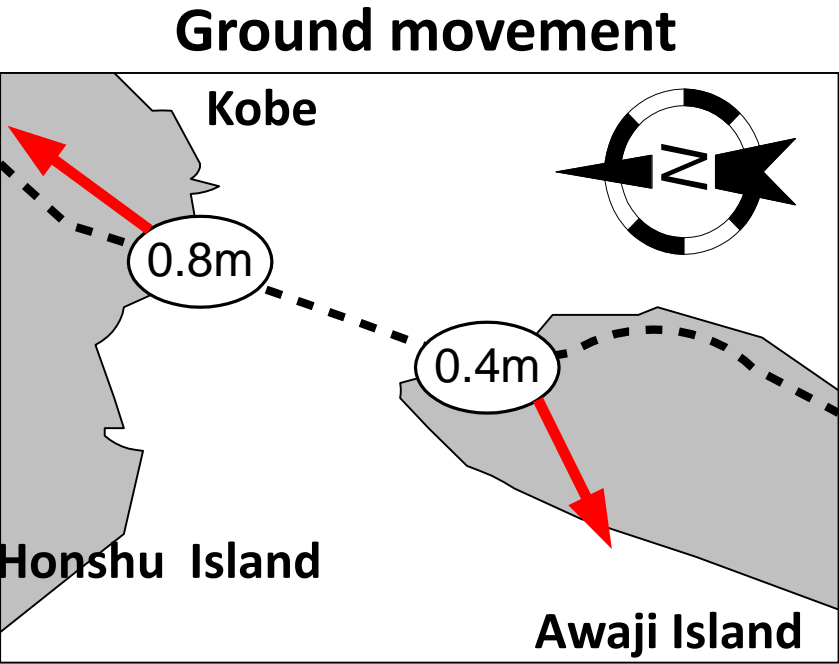
7



Effects of Kobe earthquake on

the Akashi Kaikyo Bridge

8



Relative deformation of bridge



# Dynamic Monitoring and Precise Inspection

in order to know change of the state with time

Categories	Monitoring or Inspection	Object parts	Items measured	Intervals
Structural	Precise Inspection	Whole bridge	Shape of the whole bridge	5 years
			Displacement of foundations	
			Suspender rope tension	
	Dynamic Monitoring	Whole bridge	Wind velocity and direction, displacement, velocity, acceleration	always
Material	Precise Inspection	Paint for steel members	Film thickness, glossiness, adhesion	About 5 years
	Monitoring	Main cables	Temperature and humidity inside of main cables and in spray saddle rooms	always
	Precise Inspection	Concrete structures	Chloride ion concentration, neutralization depth	5 years
Others	Precise Inspection	Tower foundation	Seabed scour condition around Tower foundation	5 years or more

# Outline of Dynamic Monitoring

## Long-span Bridges in the Honshu-Shikoku Bridges

- 10 Suspension bridges, 5 Cable-stayed Bridges, 1 Truss bridge, 1 Arch bridge (span length > 200m)

## Objectives

- Evaluation of bridge behavior during extraordinary event
- Evaluation of bridge soundness after extraordinary event

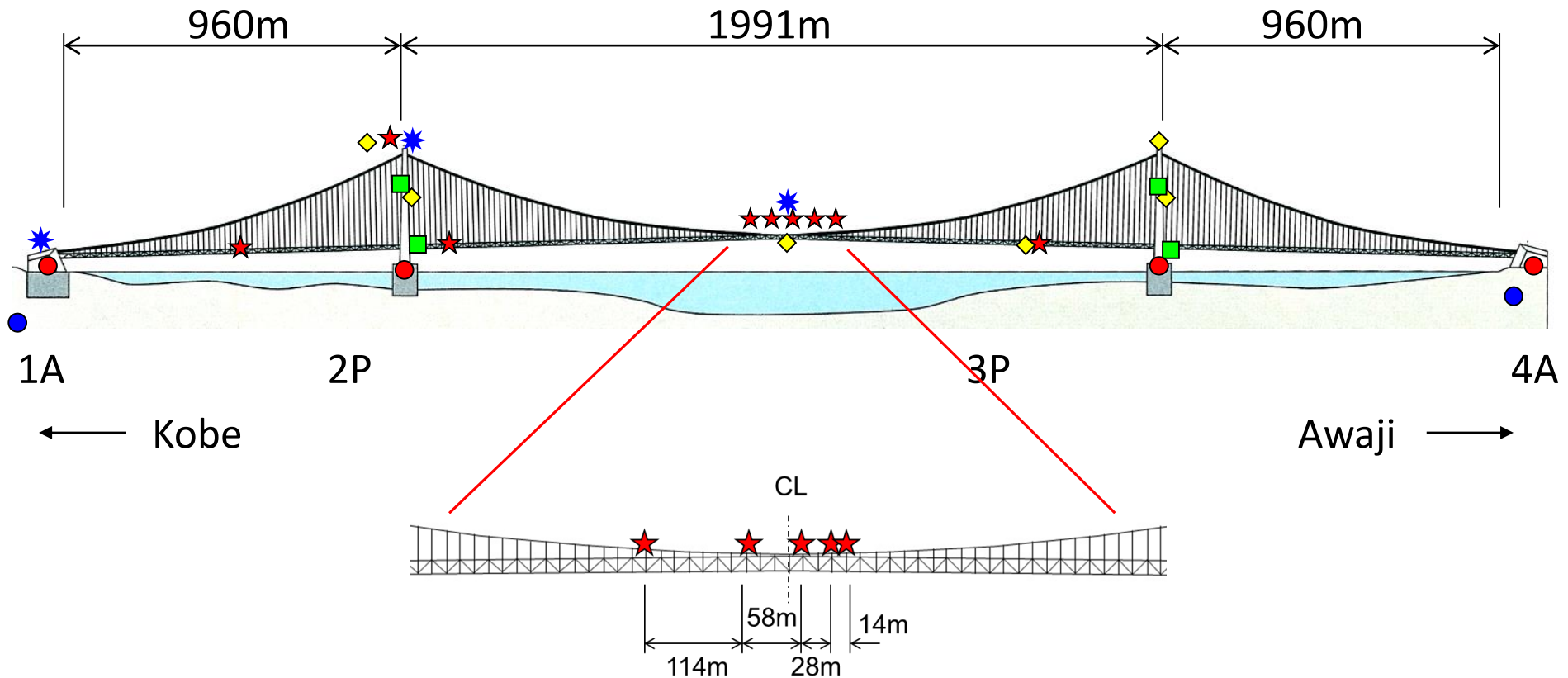
## Sensors arrangement

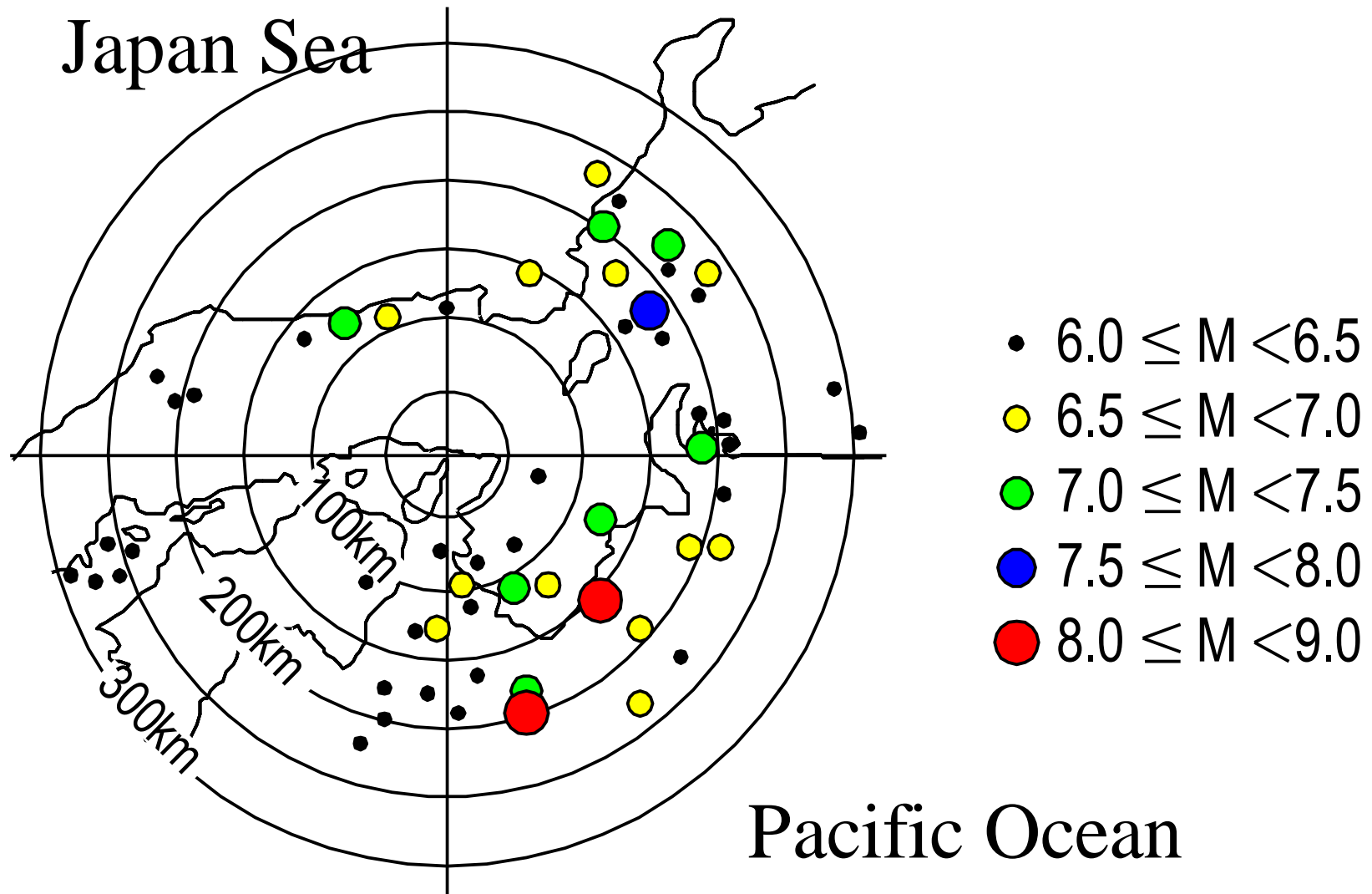
- Wind characteristics are observed on the Akashi-Kaikyo Bridge and the Tatara Bridge.
- Seismic motions are observed at 2 locations on each route.
- Bridge behavior is observed on the representative bridges.
  - ① Akashi-Kaikyo Bridge, ② Ohnaruto Bridge,
  - ③ Minami Bisan-Seto Bridge,
  - ④ Tatara Bridge, ⑤ Kurushima Kaikyo Bridges

# Arrangement of Monitoring Sensors on the Akashi Kaikyo Br.

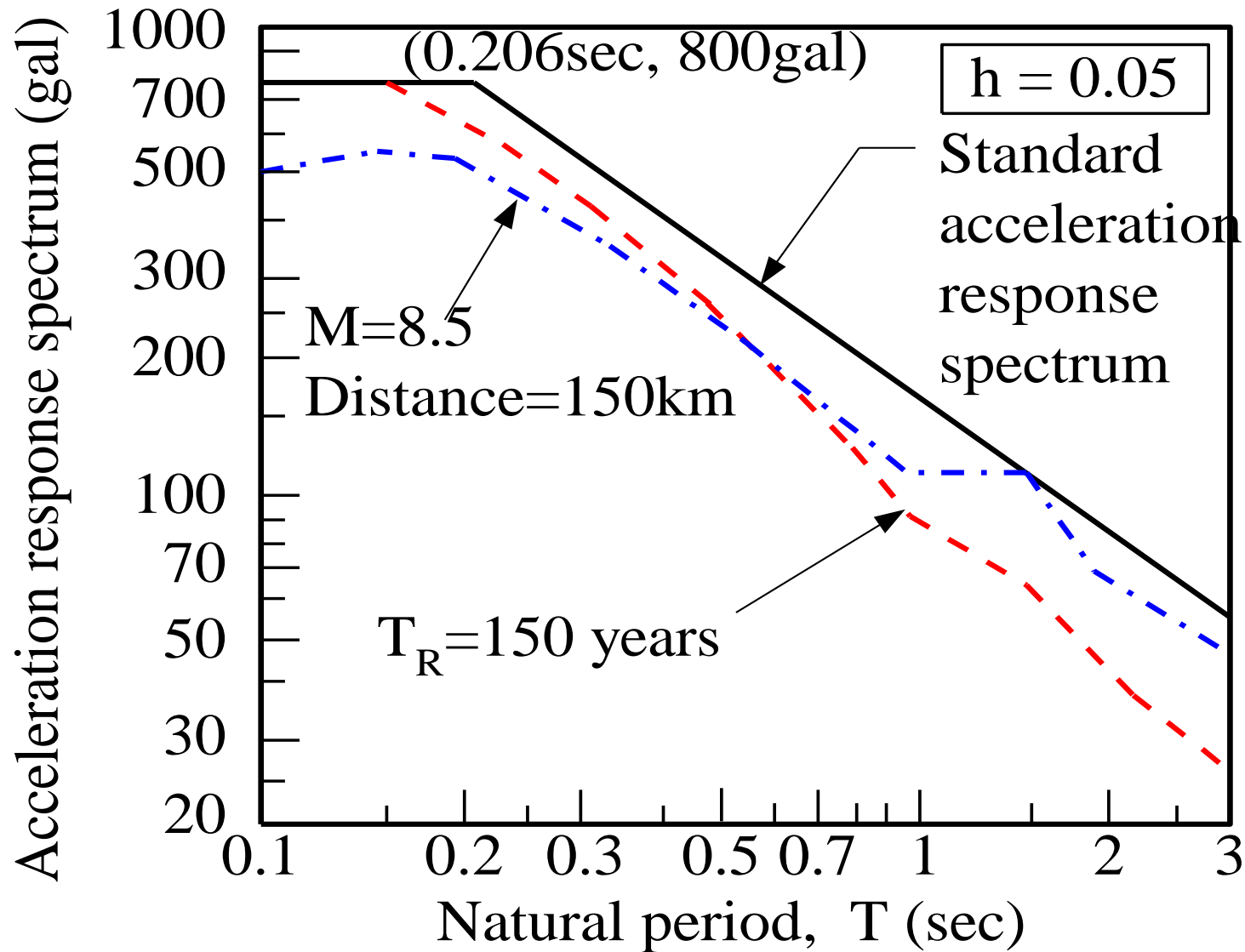
11

- ★ : Wind Speed Gauge    ♦ : Velocity Gauge    ■ : Displacement Gauge  
● : Earthquake recorder    ● : Accelerometer    ★ : GPS



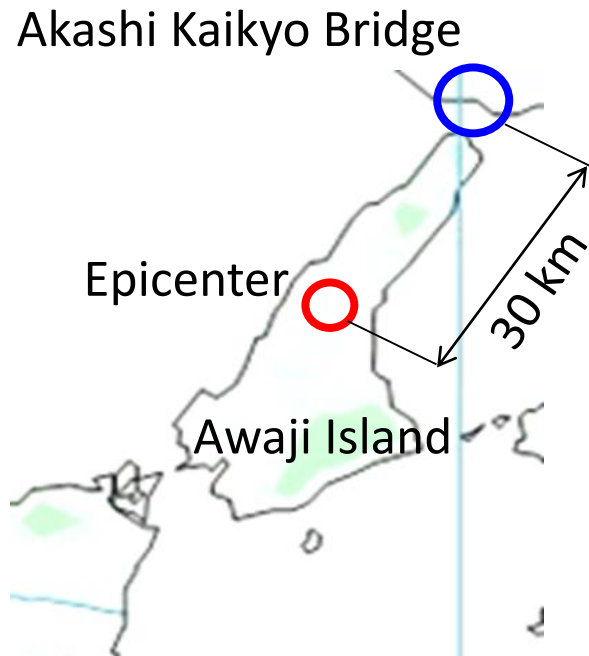


# Acceleration response spectrum for the design





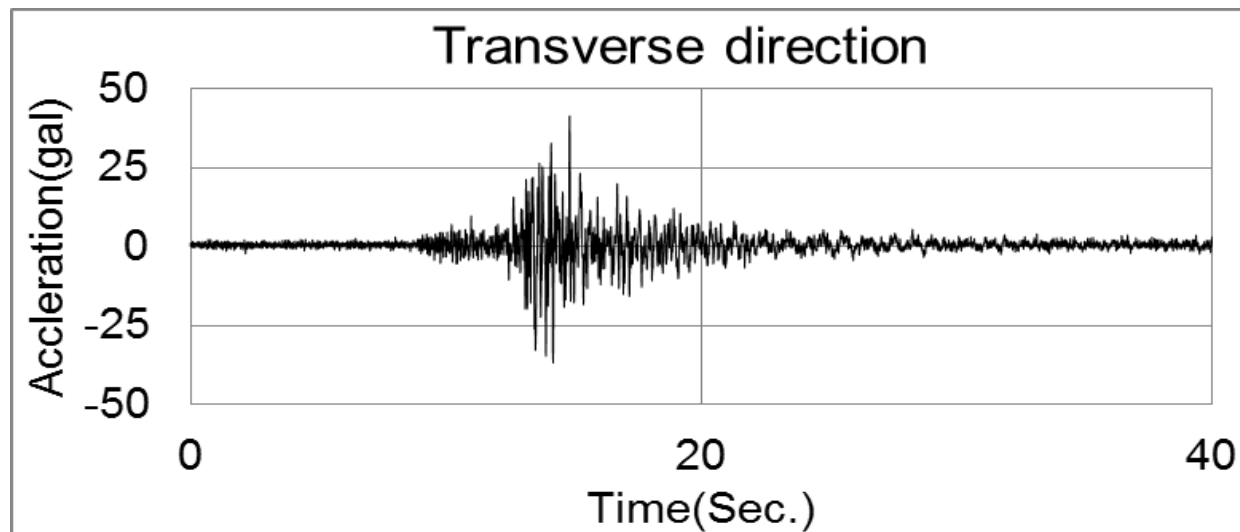
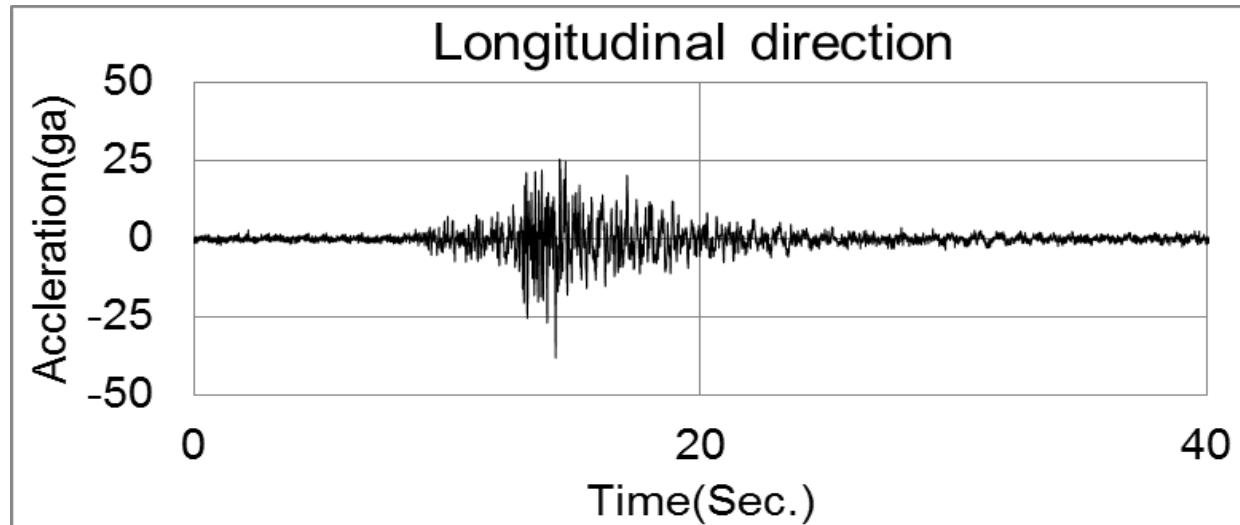
## M6.3 Earthquake on April 13, 2013



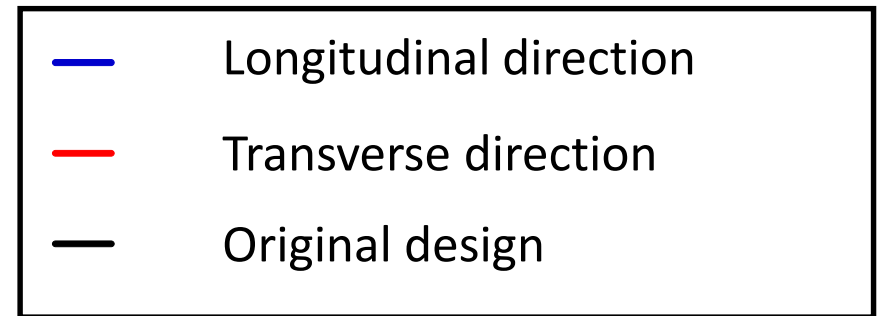
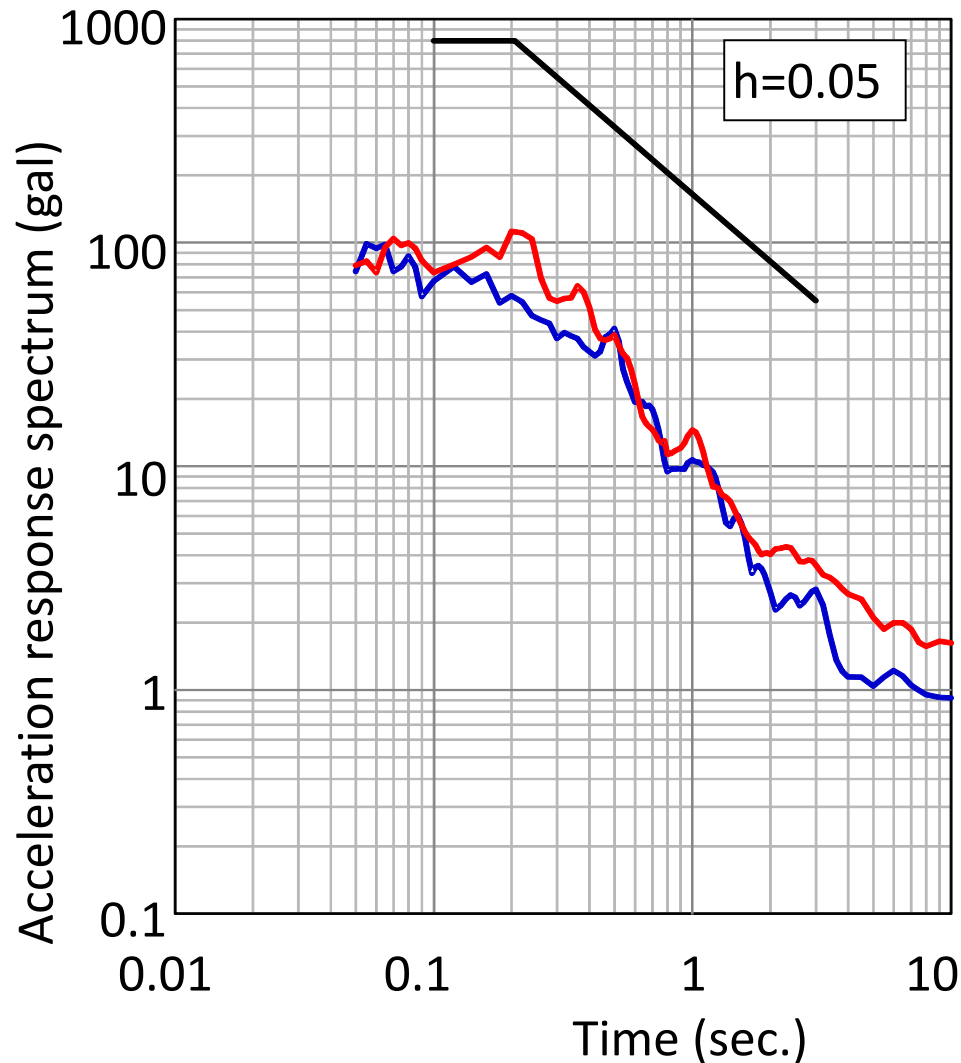
Location of Seismometer



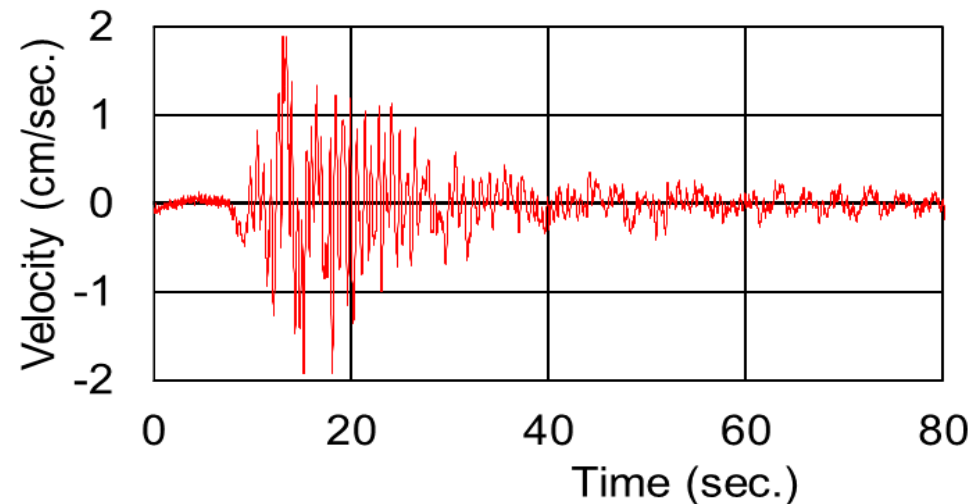
Kobe side



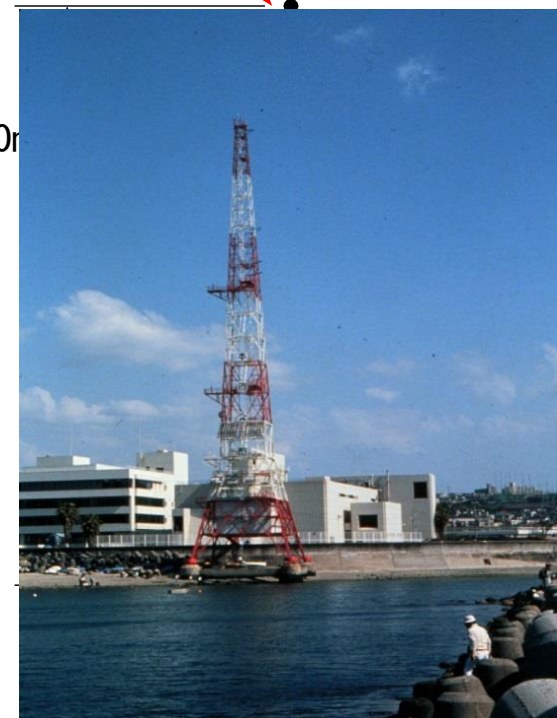
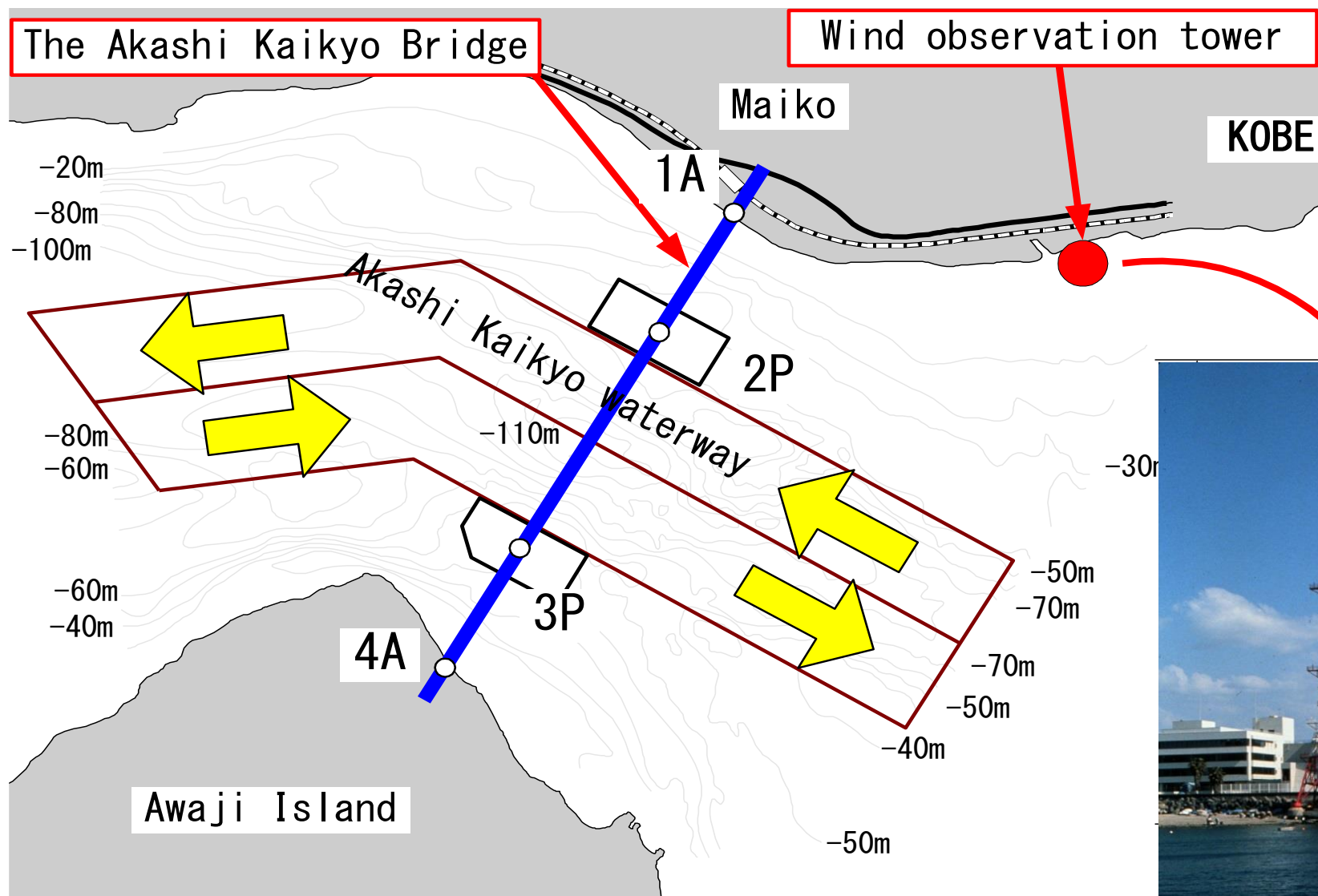
# Acceleration Response Spectrum

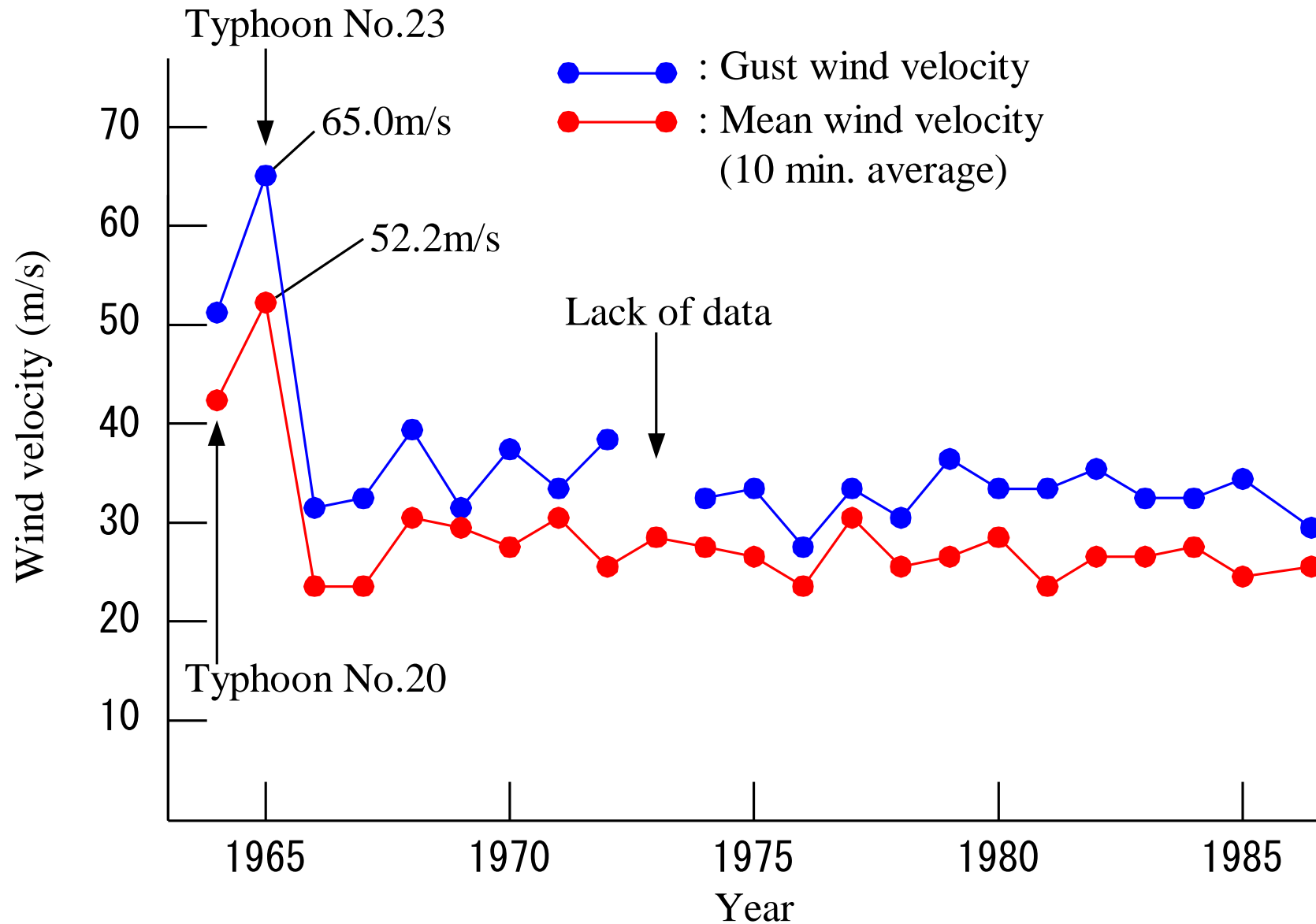


Transverse velocity at the center of the middle span



# Wind Observation Site







# Full-model Wind Tunnel Test ( $S=1/100$ )

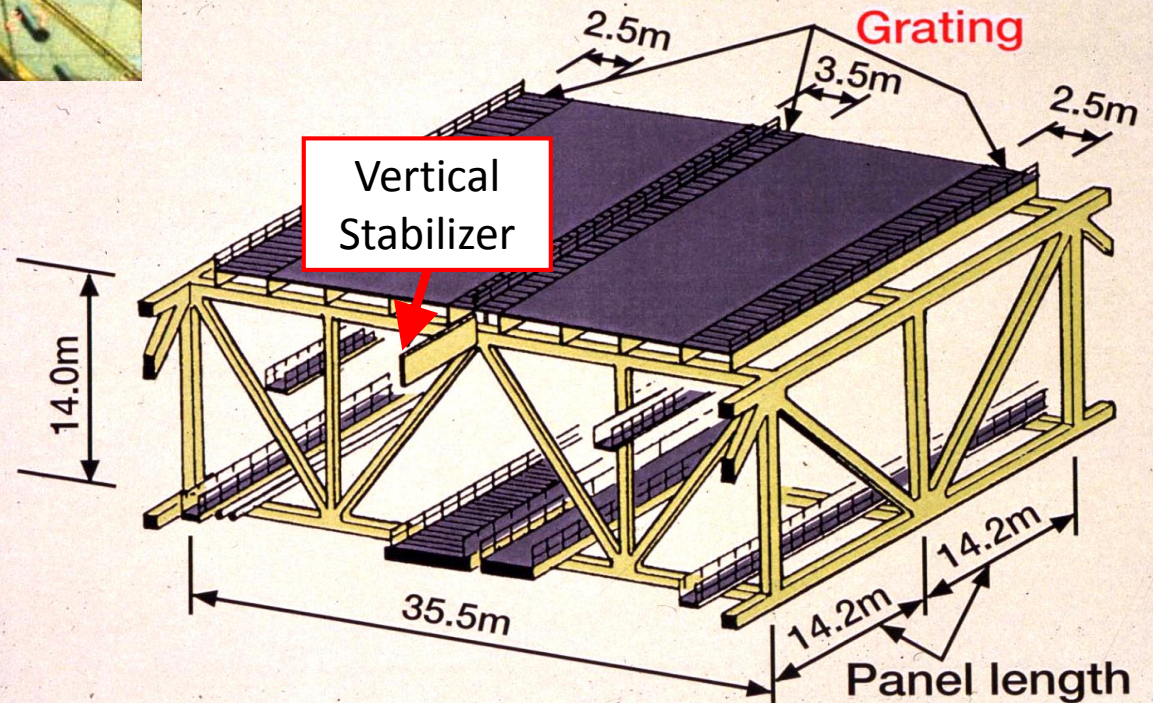
18



$V=60$  m/s (at girder)

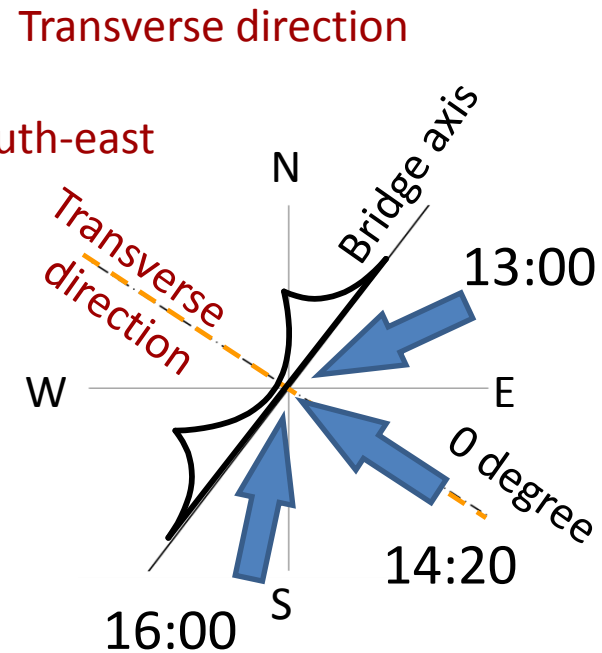
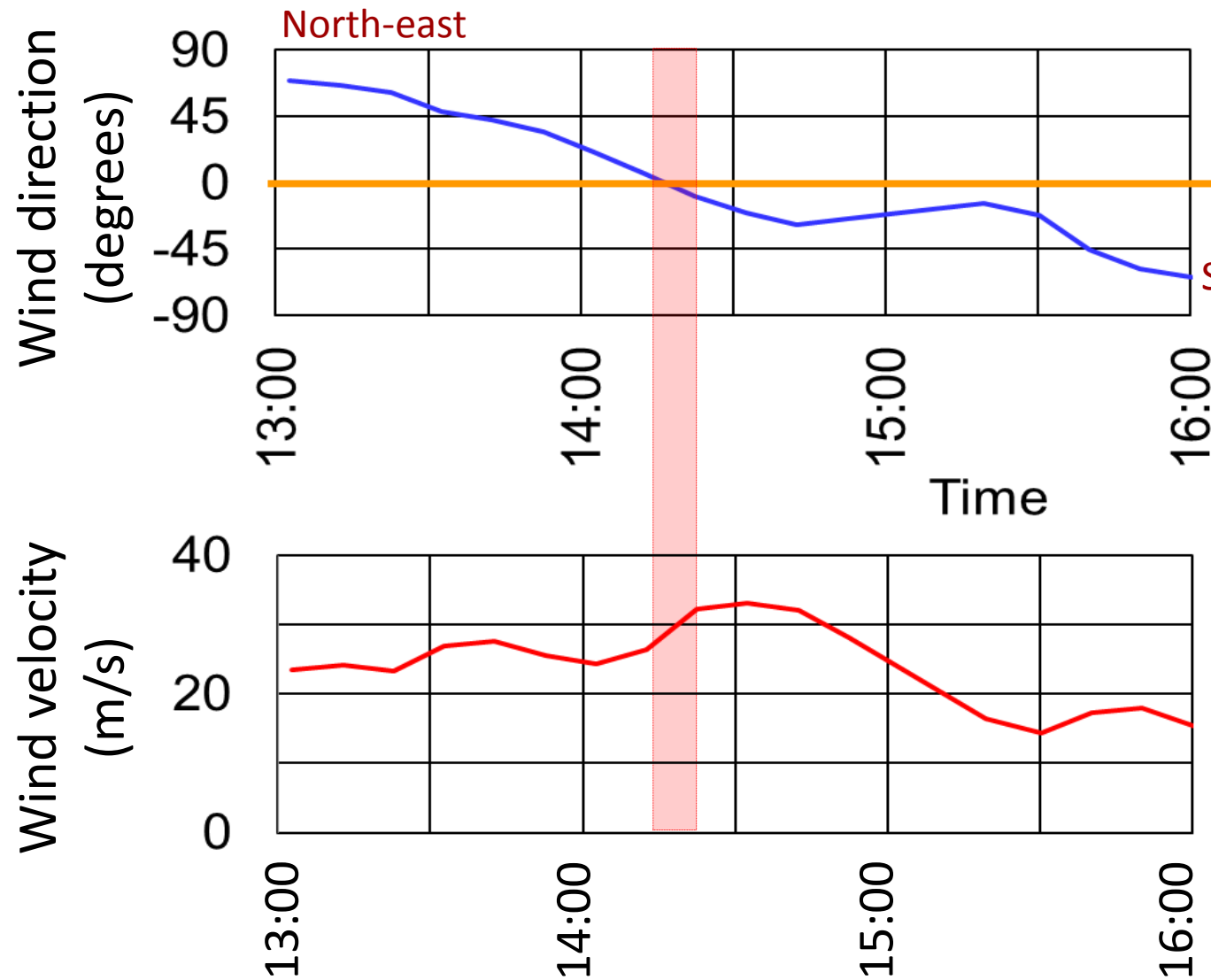
Stiffening girder of the bridge

Grating

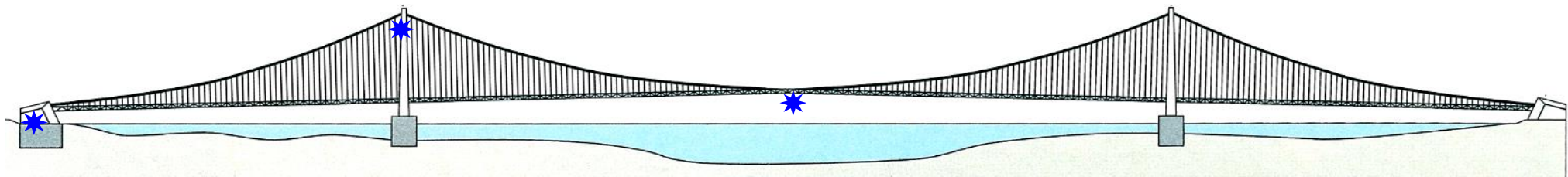




# Observed Wind Data of September 22, 1998 (Typhoon 9807) <sup>19</sup>



# Arrangement of GPS sensors



1A

2P

3P

4A

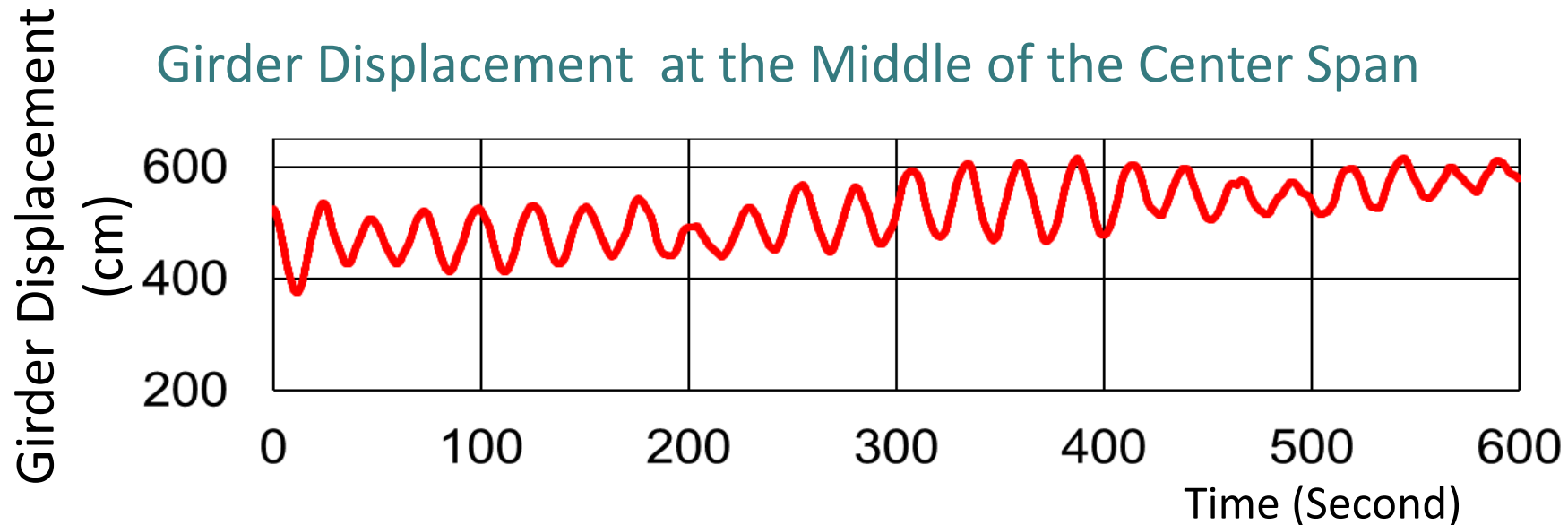
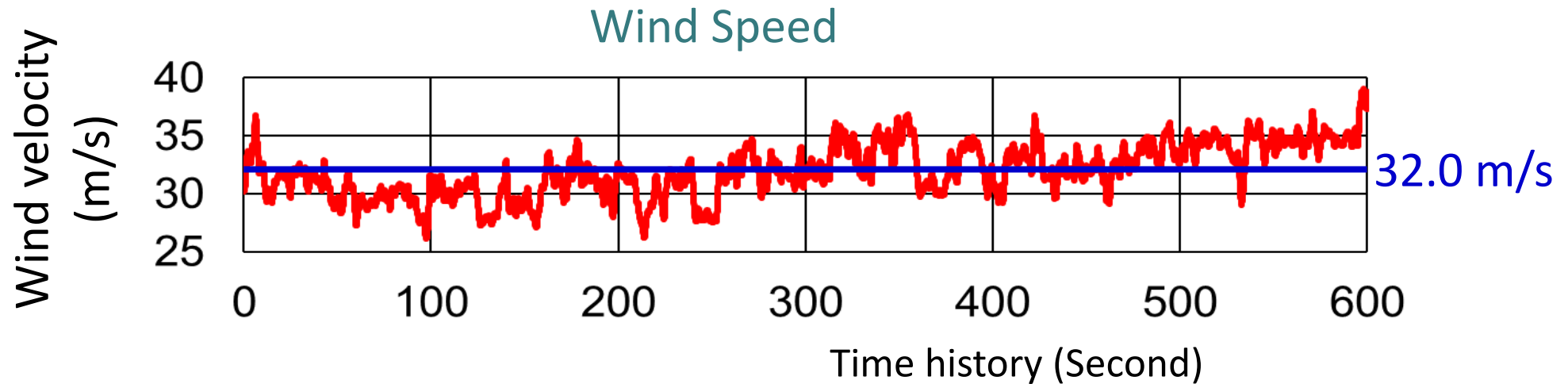
Wind

A diagram showing a cross-section of a bridge structure. Blue arrows on the left represent wind blowing towards the bridge. A green arrow points horizontally to the right, indicating the direction of wind force. A red arrow at the bottom points horizontally to the right, indicating the direction of horizontal displacement.

Horizontal Displacement



# Observed Horizontal Displacement on the Akashi Kaikyo Bridge<sup>21</sup>



# Comparison of Observed and Analytical Data

## Horizontal Girder Displacement at the Middle of the Center Span

	Observed displacement (m)	Analytical results (m)	
		Case 1	Case 2
<b>Average displacement</b> ①	5.17	5.43	5.43
<b>Dynamic displacement</b> ②	0.78	2.62	0.68
<b>Total displacement</b> (①+②)	5.95	8.05	6.11

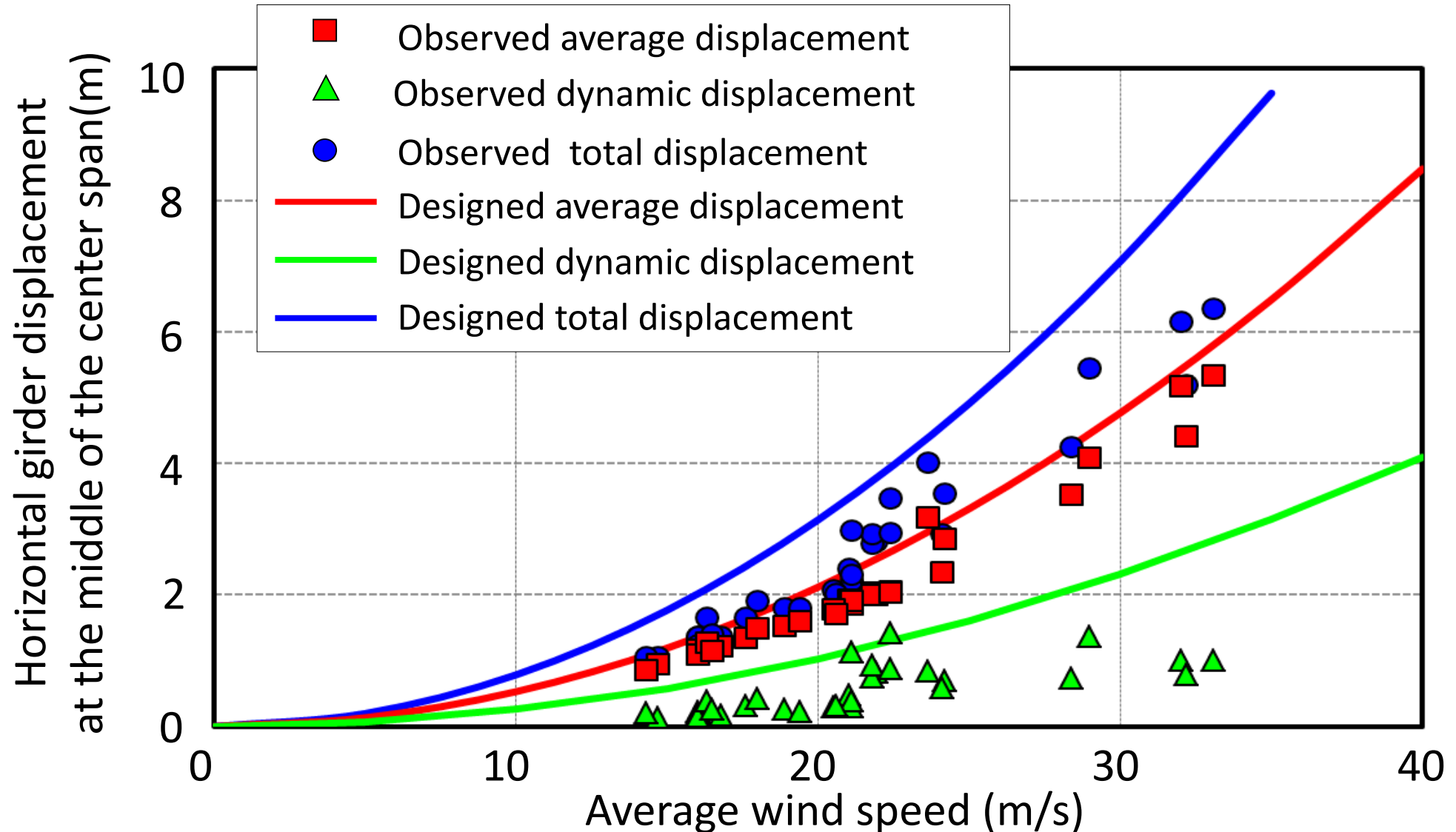
Note : Average wind speed was 32.0 m/s

Case 1 was using **designed** power spectrum and spatial correlation

Case 2 was using **observed** power spectrum and spatial correlation

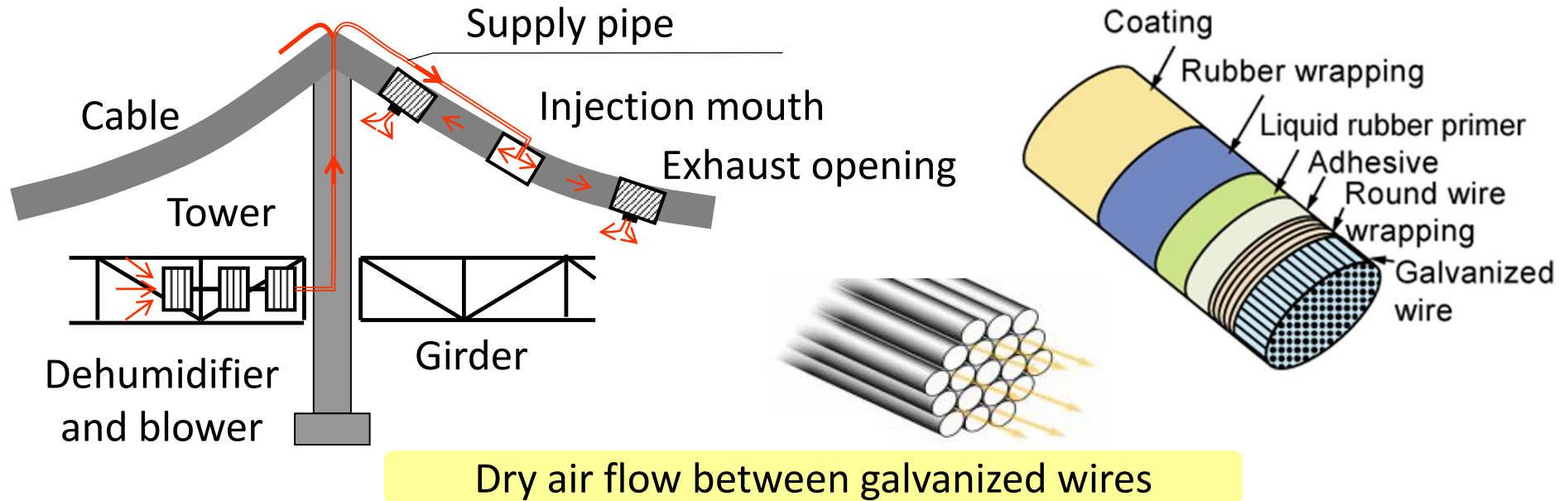
# Relation between Girder Displacement and Wind Velocity

23





# Dry-air Injection System developed by HSBA



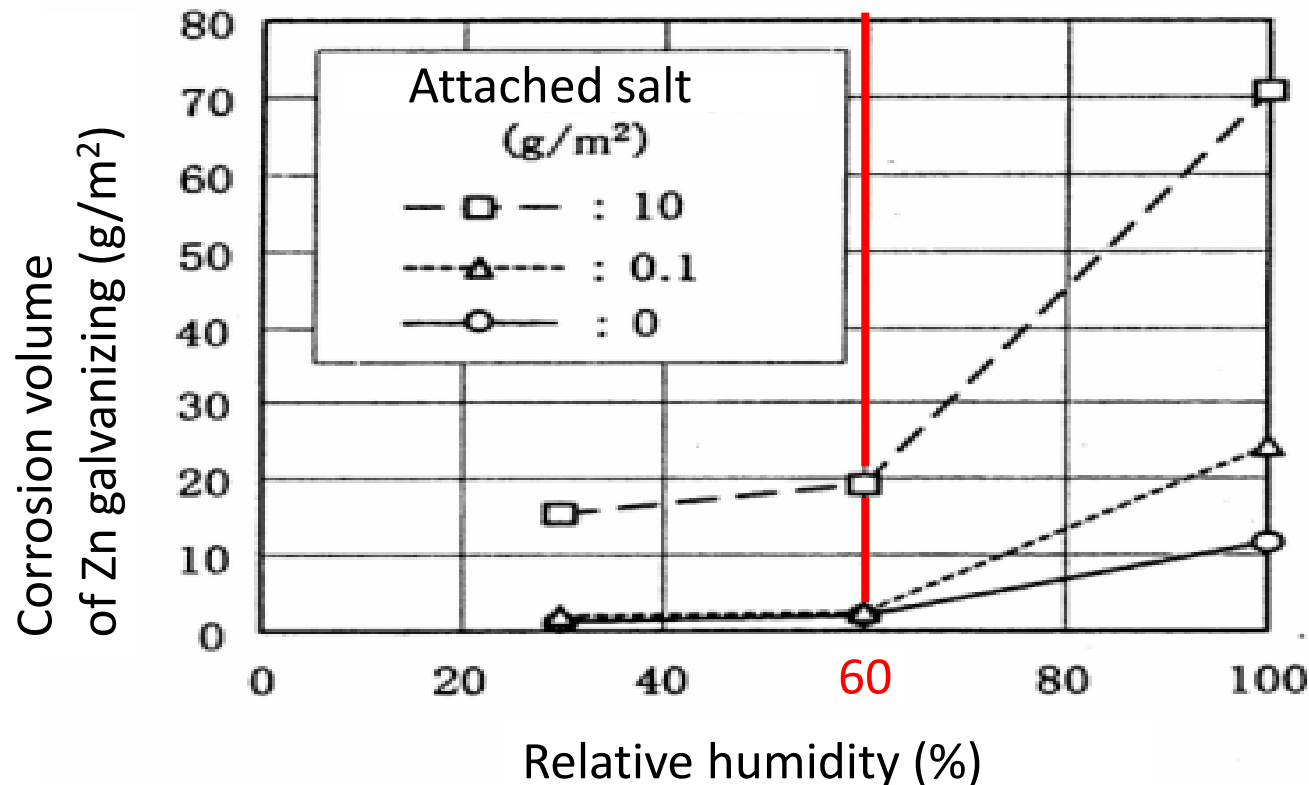
Dehumidifier and blower



Air injection cover

# Monitoring of Dry-air Injection System

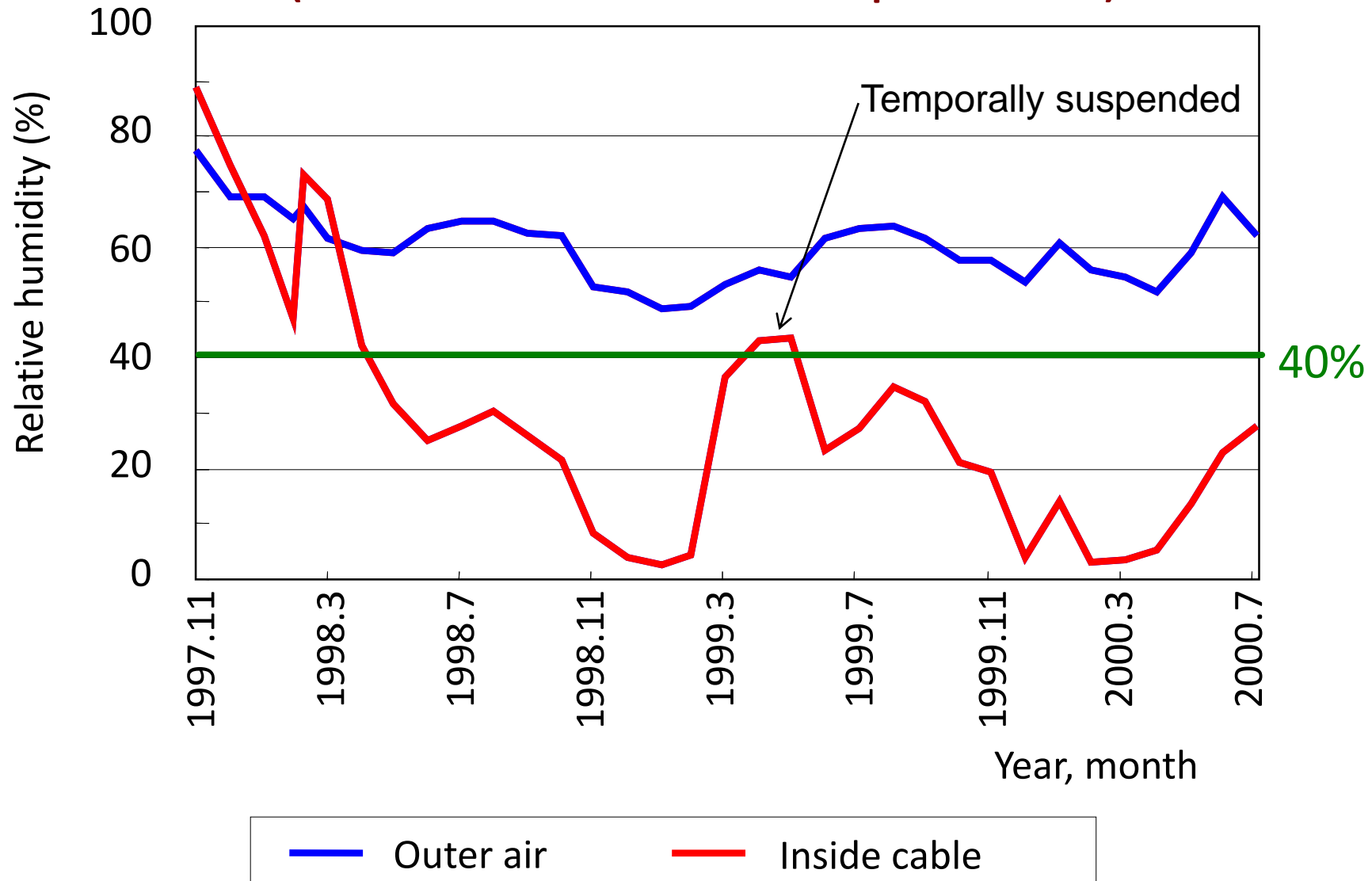
- Keep relative humidity in the cables less than 60%, and the cable can be protected from corrosion.
- Dry-air injection system was introduced to keep relative humidity less than 40% in the cables.



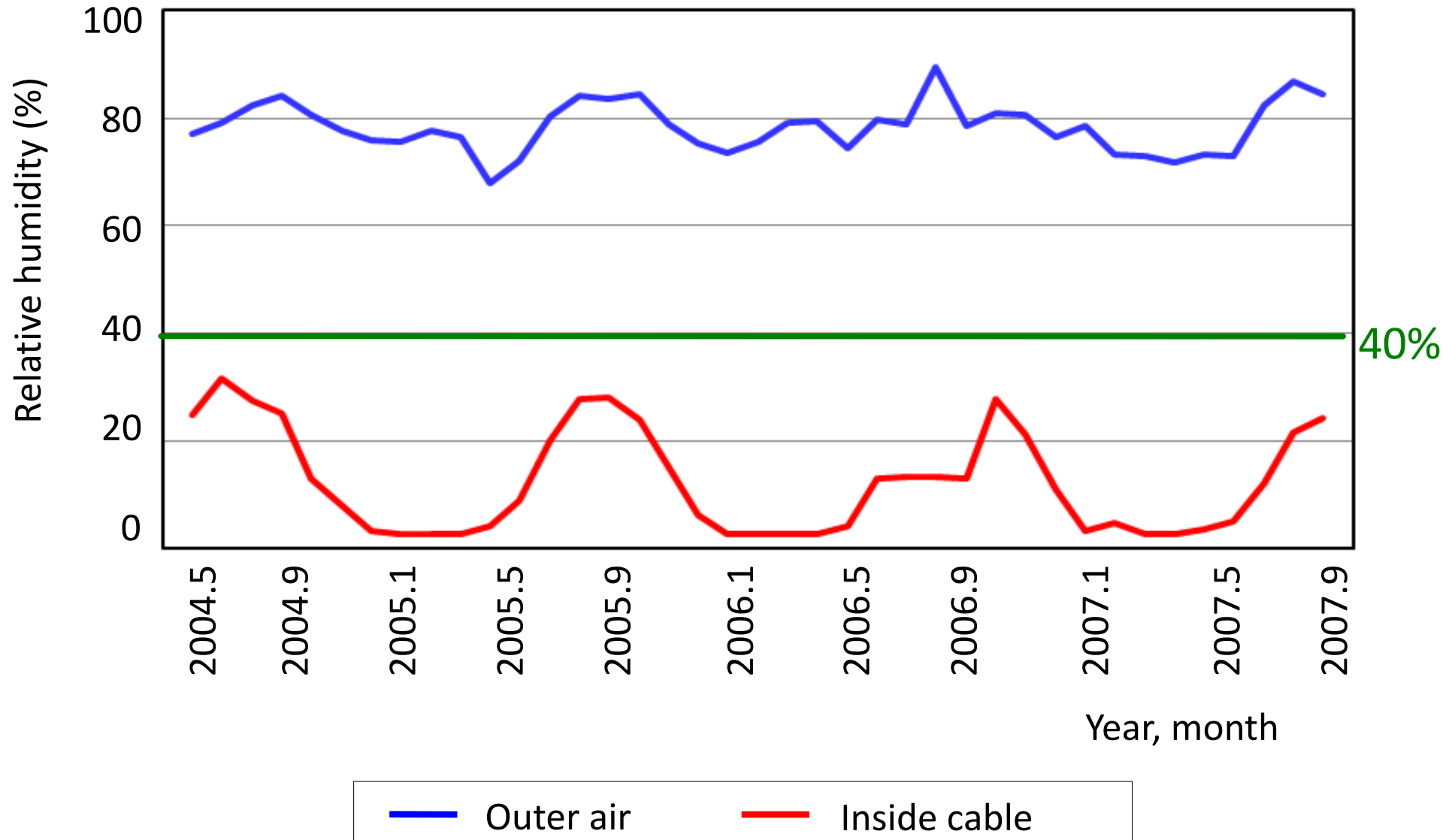
Corrosion of a main cable

# Monitoring Data of Humidity in Cables

(Just after a start of operation)



(During normal operation)

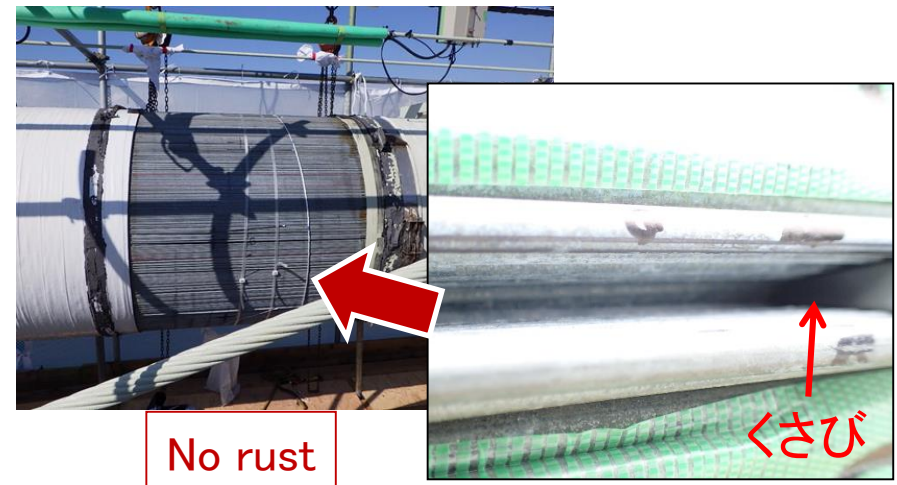
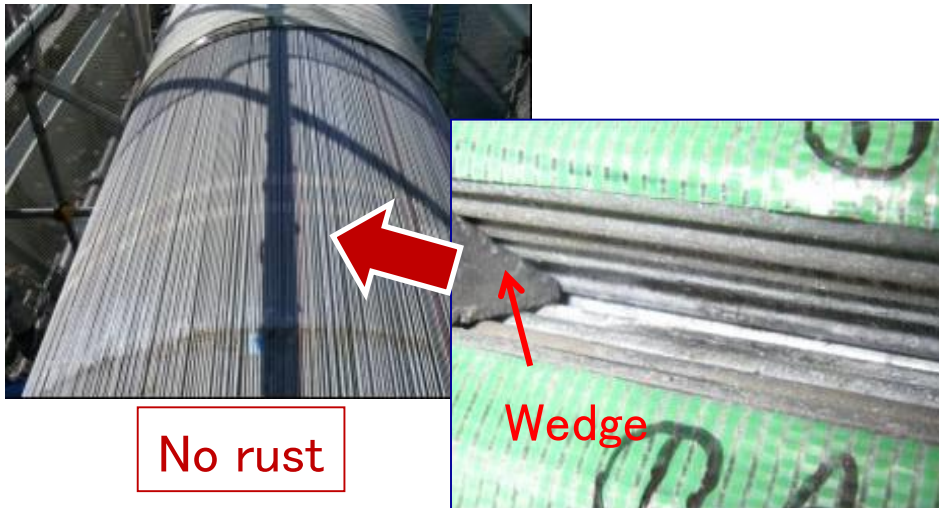


## 9 and 20 years after Completion

February, 2008 (9 year)



November, 2018 (20 years)





# Conclusion

- Dynamic monitoring has been conducted on major Honshu Shikoku Bridges
- It was confirmed that original design of the bridges is appropriate and proved to be conservative.
- Main Cables have been protected against corrosion by the Dry-air Injection System.
- It was confirmed that main cables are in proper condition.
- In order to improve the Dry-air injection system, more efficient operation has been currently investigated and introduced. (Reduction of operation units, reduction of air pressure, installation of pre-cooling units, etc.)

**Thank you very much  
for your attentions !**

**Akashi Kaikyo Bridge**

