



# **Pavement condition monitoring system at Shanghai Pudong International Airport**

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# ***Outline***

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**1. Introduction**

**2. Design of system**

**3. Verification tests of the sensors**

**4. Process of installation**

**5. Initial responses test of pavement**

**6. Conclusion and Acknowledgments**

# Introduction



## ✦ Airport System in China

— 2013

- Public airports: 190
- Passenger throughput: 754 million
- Aircraft operation times: 7.3 million
- PEK airport: 83 million annual passenger capacity
- 24 airports: more than 10 million annual passenger capacity

>230 in 2015



— Air transportation volume: the 2<sup>nd</sup> largest in the world

# *Introduction*



## *✦ Development of Instrumentation Projects*

### **USA:**

- **Denver Airport**
- **Atlanta Airport**
- **Laguardia Airport**
- **JFK Airport**



*Airport Instrumentation Projects in USA*

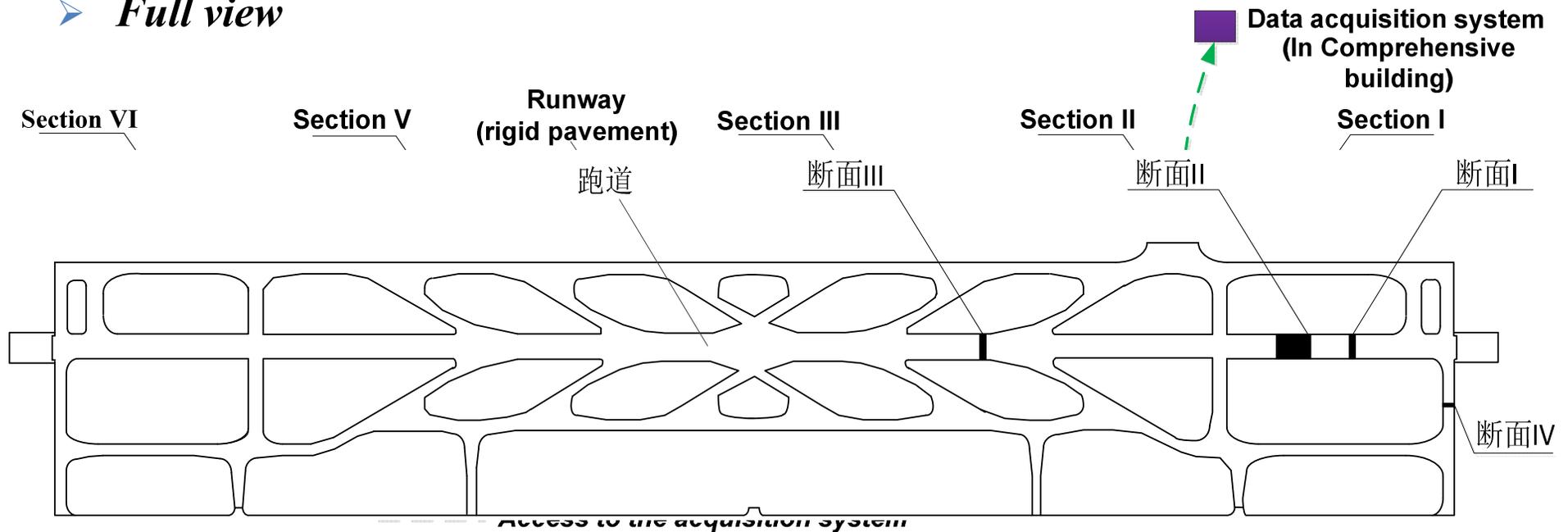
—*Better Understanding of **pavement performance model** under factual climatic and operating condition*

# Introduction



## ★ Basic information of Pudong system

### ➤ Full view



Section	Sensors	Activities of the aircrafts
I	Strain gauges, MDDs, Temperature and moisture sensors	takeoff
II	Strain gauges, MDDs, Earth pressure cells	takeoff, landing
III	Strain gauges	taxing, turning
IV	Strain gauges, MDDs, Temperature and moisture sensors, Earth pressure cells	taxing on asphalt pavement
V~VII	Earth pressure cells	taxing

# Introduction



## ➤ *Sensor used*

- **290 static and dynamic sensors**
- **22 kinds tested and 8 kinds chosen**
- **Widely Use of Fiber Bragg Grating (FBG) sensors**

## *Detailed Information of sensors*

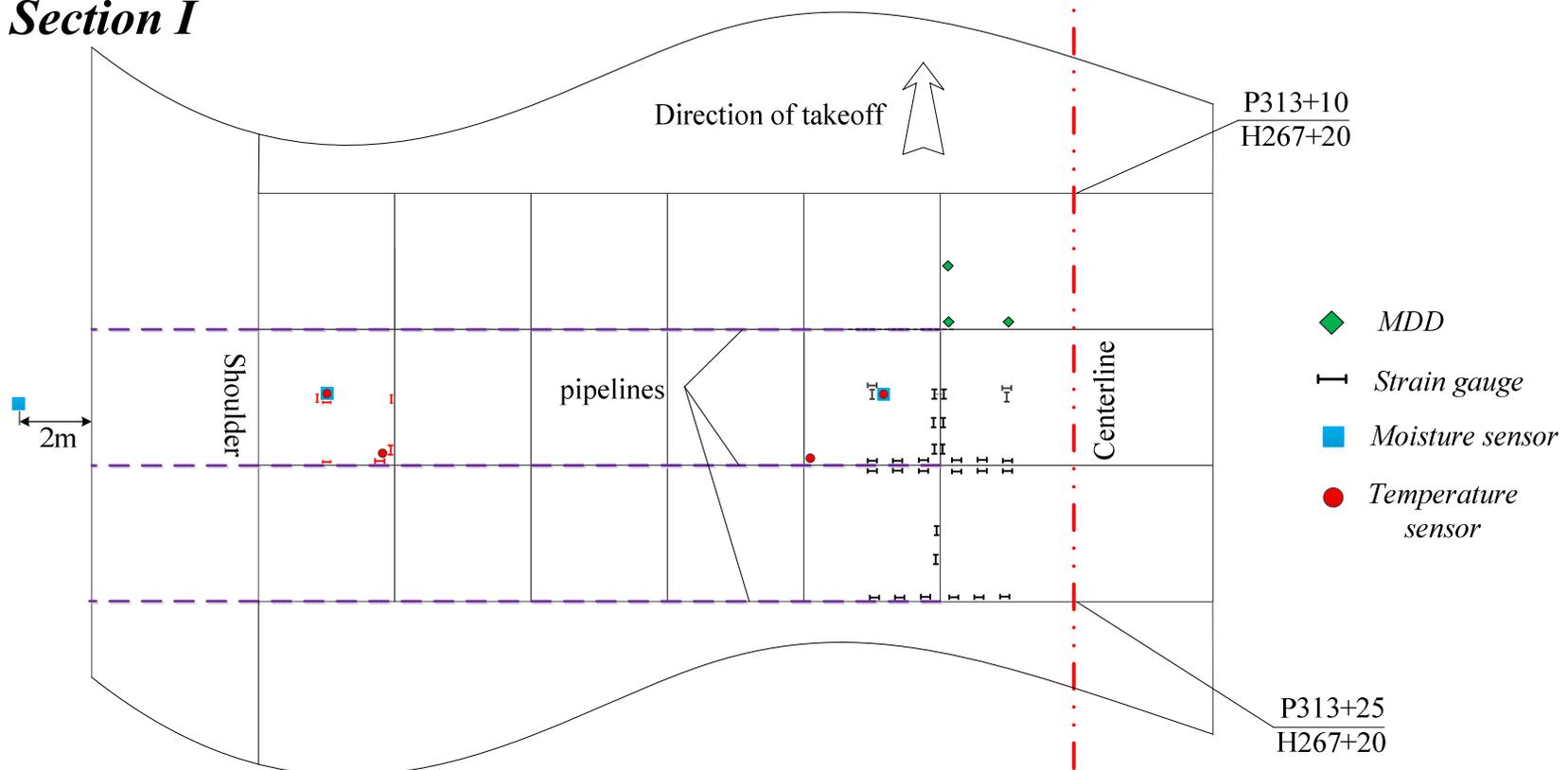
Category	Manufacturer	Model	Amount	Type
Concrete strain gauge	Beijing Geokon	BGK-FBG-4200T	108	Fiber Bragg Grating Sensor
	Beijing Geokon	BGK-4200	10	Vibrating wire sensor
	Tokyo Sokki	KM-100B	8	Resistance strain gage
Asphalt strain gauge	Tokyo Sokki	KM-100HAS	40	Resistance strain gage
Temperature sensor	Beijing Geokon	BGK-FBG-4700	63	Fiber Bragg Grating Sensor
MDD	Beijing Geokon	BGK-A3	6	Fiber Bragg Grating Sensor
Pressure cells	Beijing Geokon	FBG-FBG-4800	40	Fiber Bragg Grating Sensor
Moisture sensor	Beijing Micromulti	SWR-3	15	Standing Wave Ratio

# Design of system



## ★ Sensor layout

### ➤ Section I

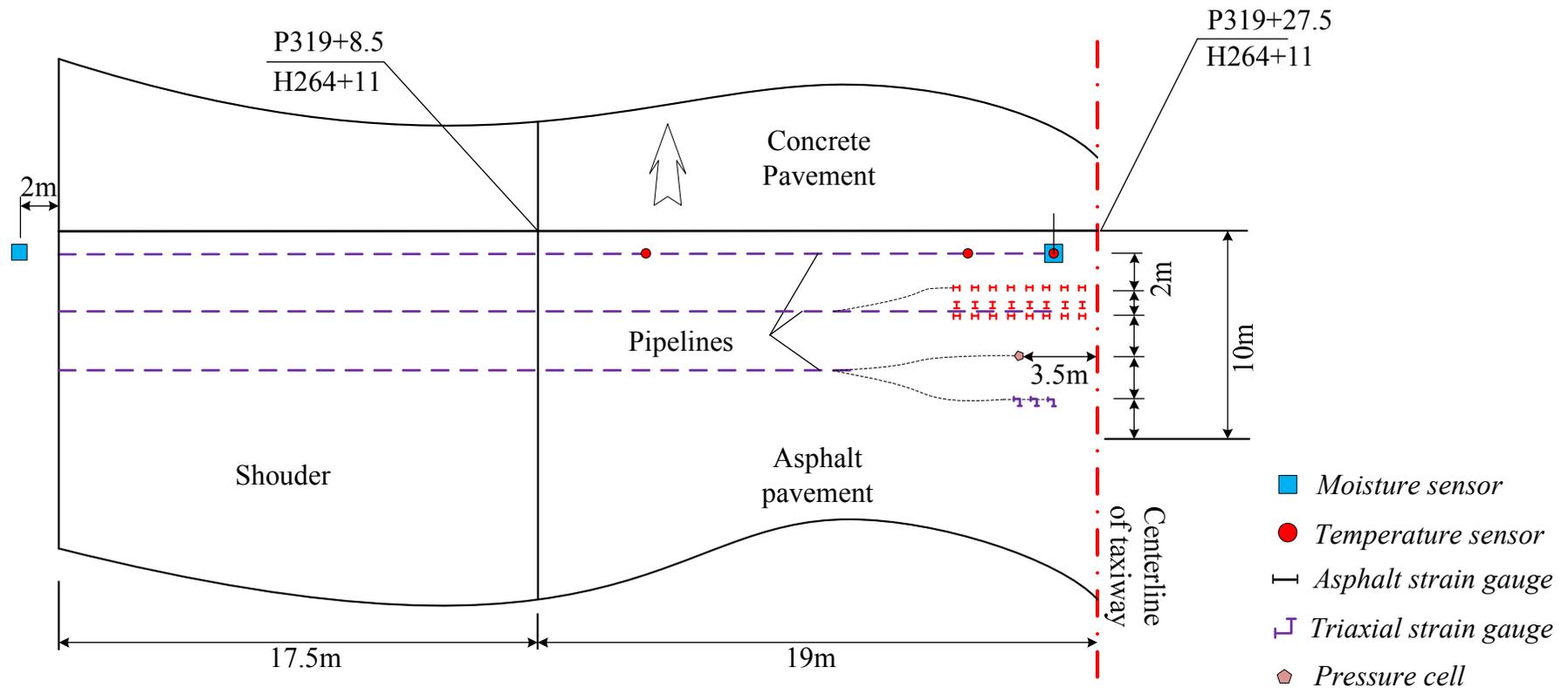


- End of taxiway
- Loaded and “unloaded” areas
- various Comparison

# Design of system

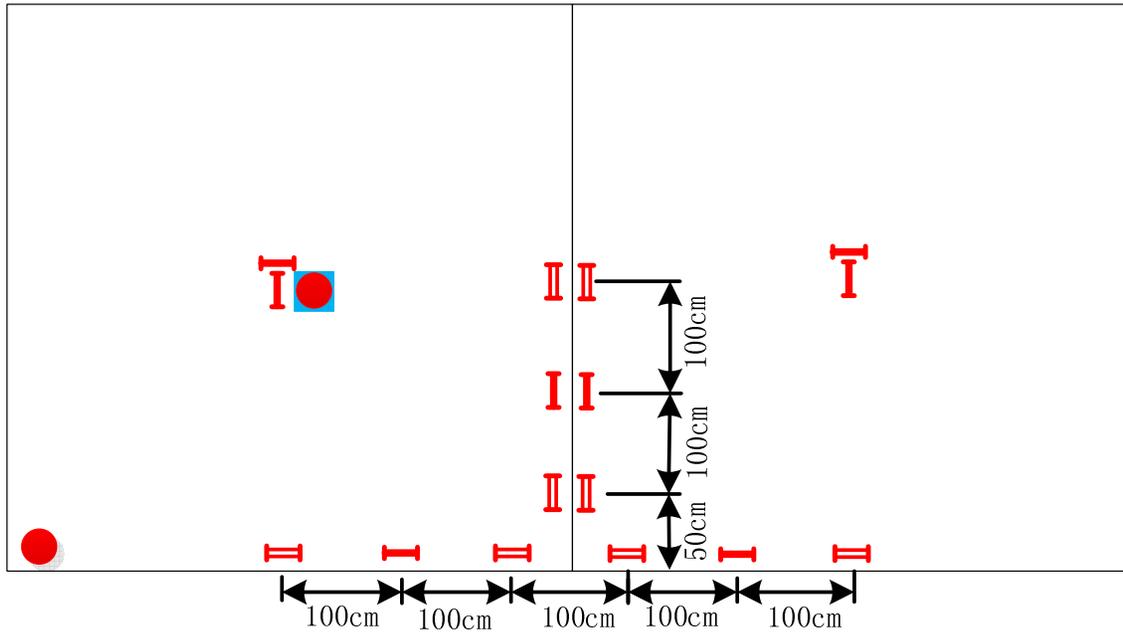


## ➤ Section IV

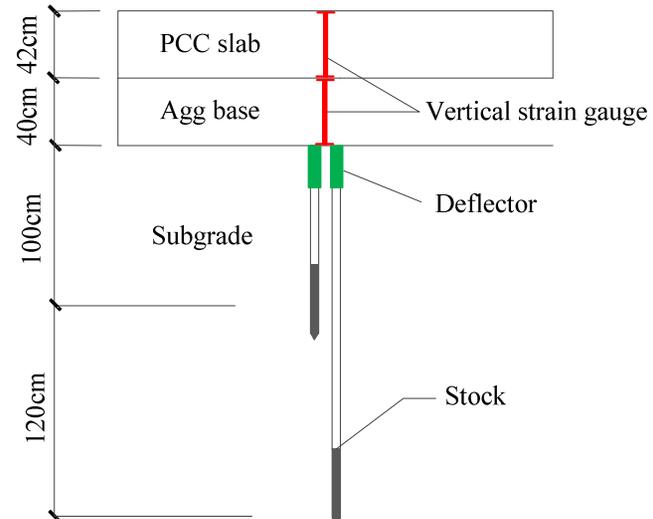
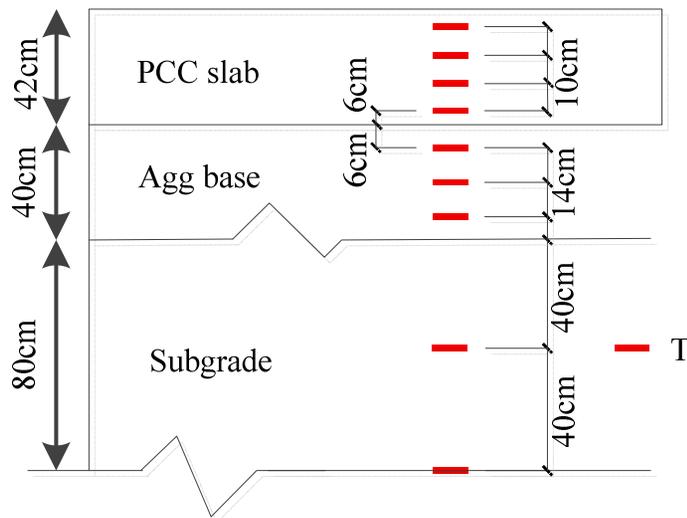


- *Waiting area for taking off*
- *Cover the wheel tracks*
- *Special asphalt sensors*

# Design of system



-  Strain gauge at both top and bottom of the slab
-  Strain gauge at only bottom of the slab
-  Temperature sensor "tree"
-  Moisture sensor "tree"



# Design of system



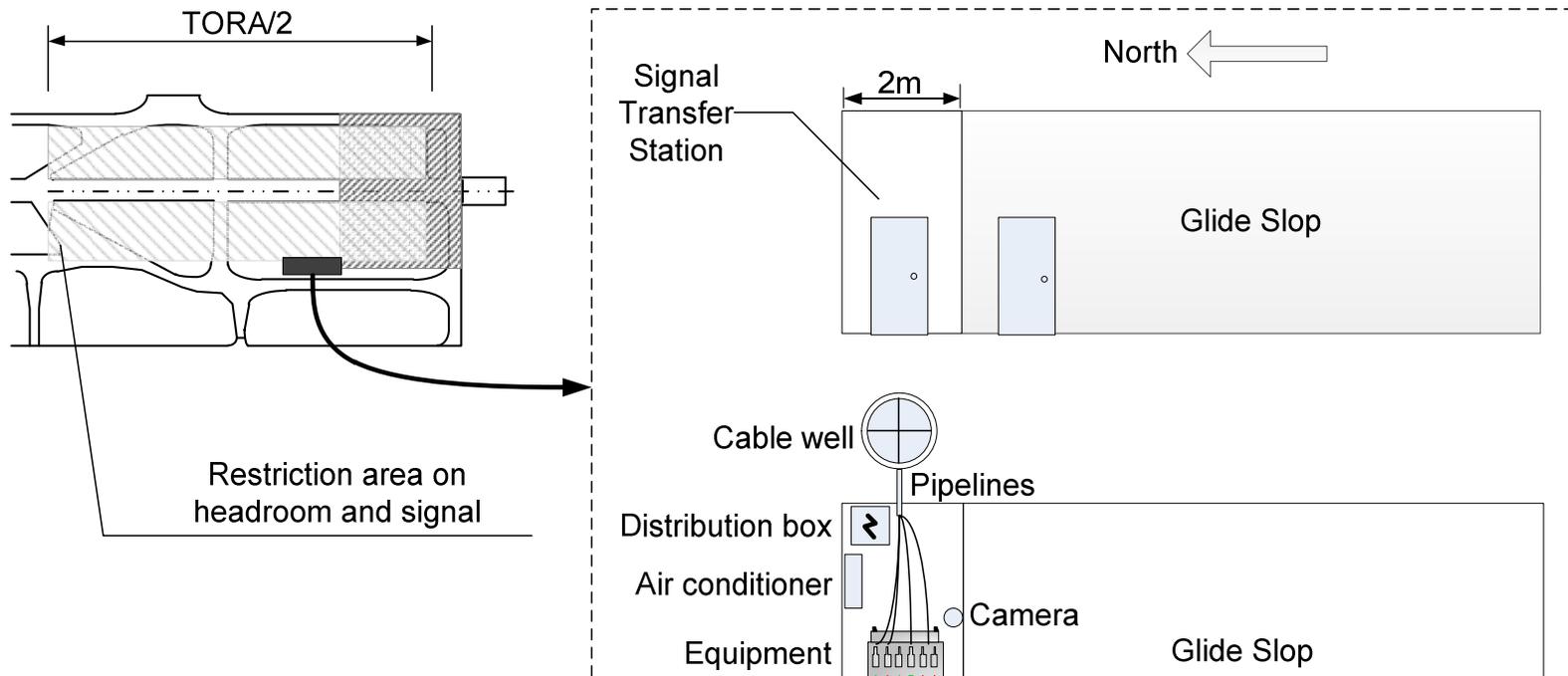
## Sensors depths

Layers	Distance below pavement layer top(cm)			
	Strain gauges	Temperature sensors	Moisture sensors	Pressure cells
PCC slab(42cm)	4,38	6,16,26,36,	\	\
base(40cm)	\	48,62,76	\	60
Subgrade	\	122,162	102,142,182	100~1400

# Design of system

## ✦ Signal processing

### ➤ Signal relay

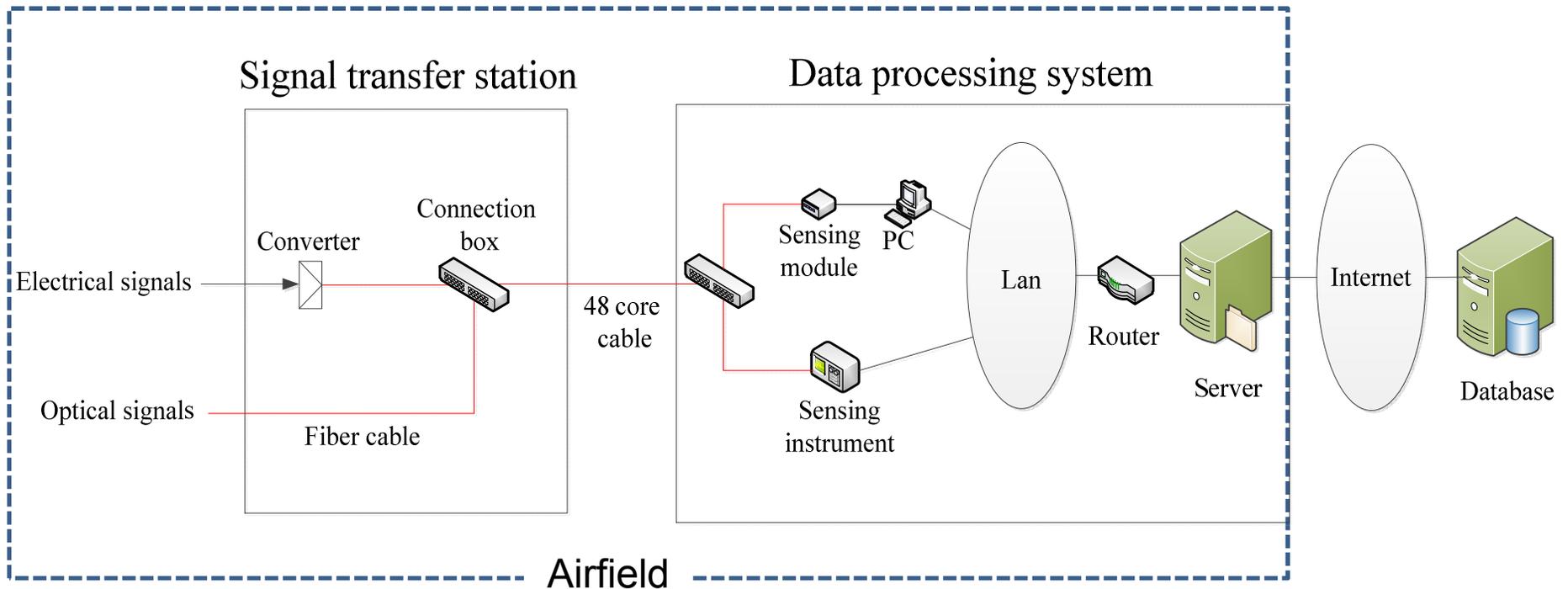


**Glide Slop** is suggested as the signal transfer station area to avoid the electrical sensors influenced and to meet airport safety requirements

# Design of system



## ➤ Data acquisition system (DAQ)



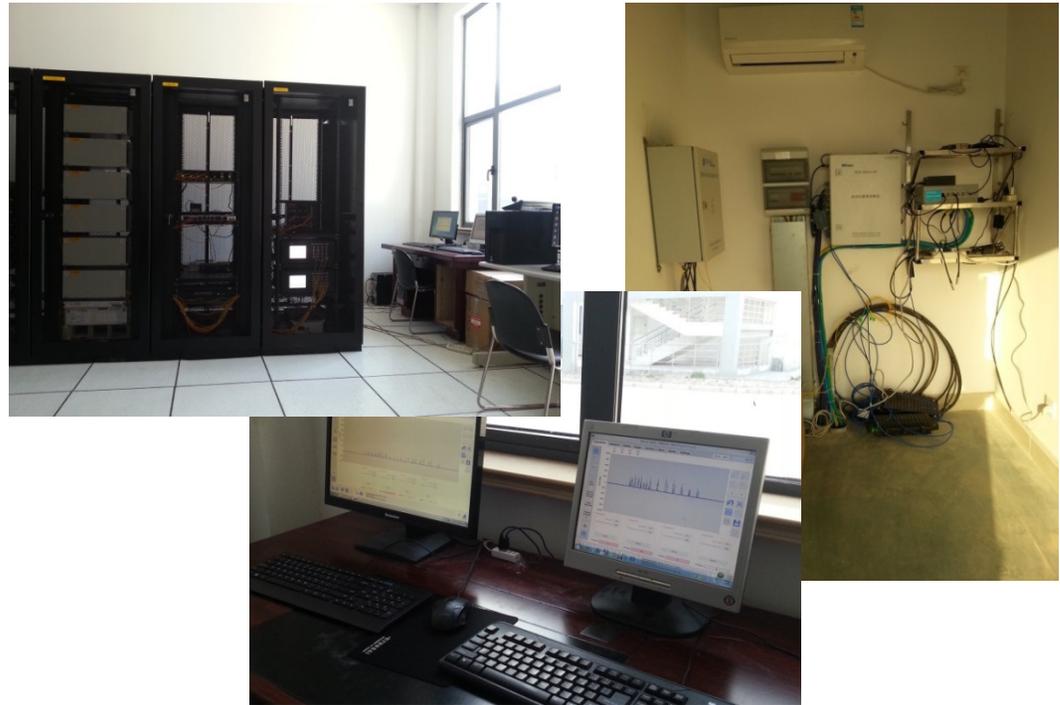
- *Wired networking solution*
- *Possibly use of existing airport facilities*
- *VPN to the Database in Shanghai Airport Authority*

# Design of system



## ➤ *Achievements exhibition*

- *Automatic working*
- *Remote management*
- *Convenient entrance for equipment maintenance*
- *Independent system*
- *Data: 350MB data/day*



*Data acquisition system in Pudong Airport*

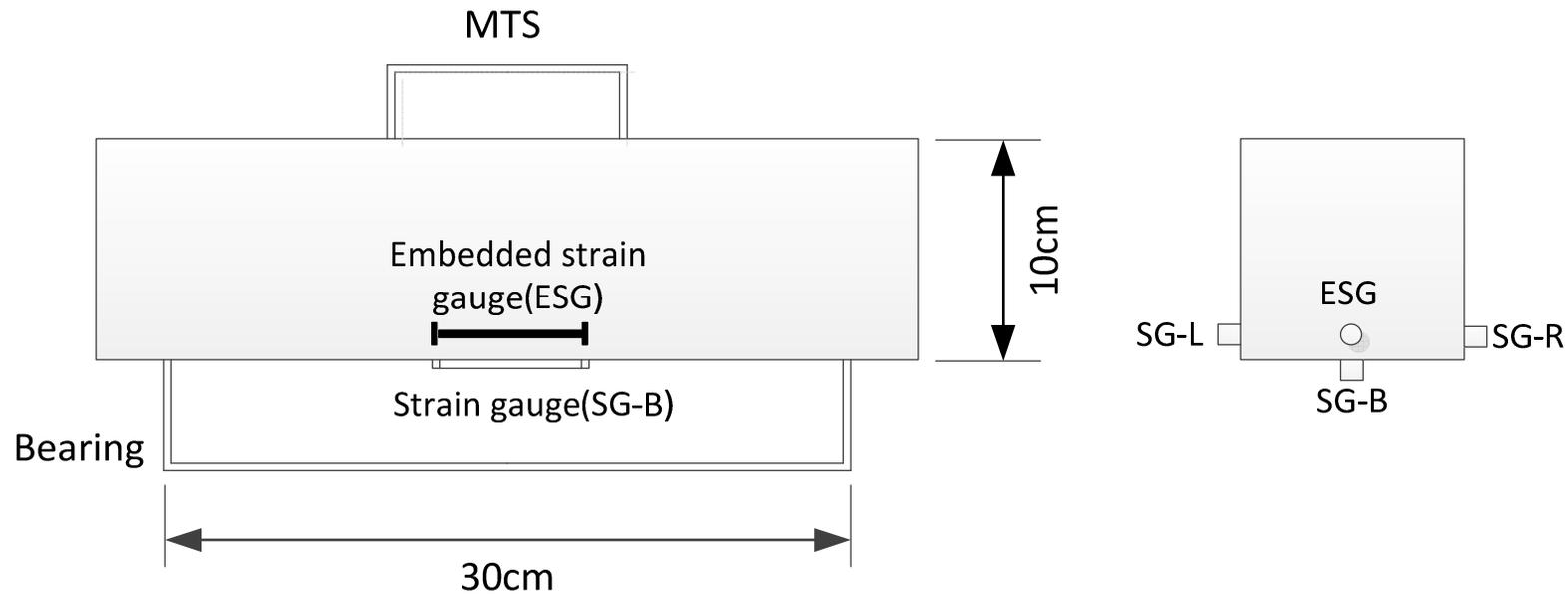
—*Successfully **integrated** our system with airport facilities*

# Verification tests of the sensors



## ✦ Experimental method

### ➤ Based on Four-point flexural tensile



$$\varepsilon_0 = f(\varepsilon_b, \varepsilon_1, a)$$

$\varepsilon_0$  — The actual value

$\varepsilon_1$  — Strain gauge on the surface

$\varepsilon_b$  — Embedded Sensor

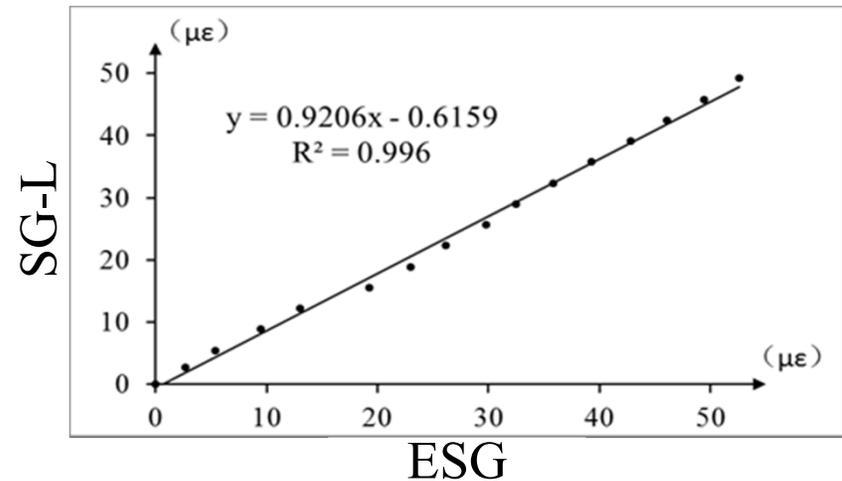
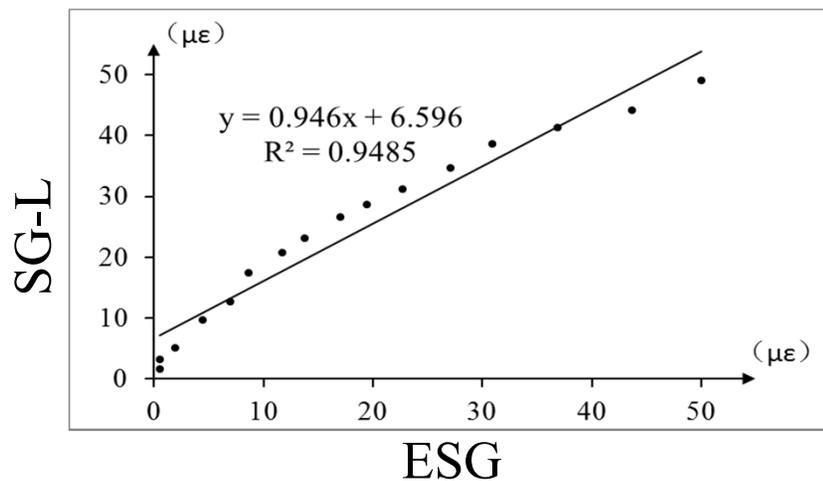
$a$  — Modulus, Temperature...

# Verification tests of the sensors



## ★ Concrete Strain Gauge

Manufacturer	Type	Model	Size	Modulus
Tokyo Sokki	Resistance strain gage	KM-100B	100xΦ17mm ( flange )	1GPa
Vishay	Resistance strain gage	EGP-5-350	100x17x10mm	--
Beijing Geokon	Fiber Bragg Grating Sensor	BGK-FBG-4200T	150xΦ30mm ( flange )	34GPa
Beijing Geokon	Fiber Bragg Grating Sensor	BGK-3700	150xΦ30mm ( flange )	32GPa



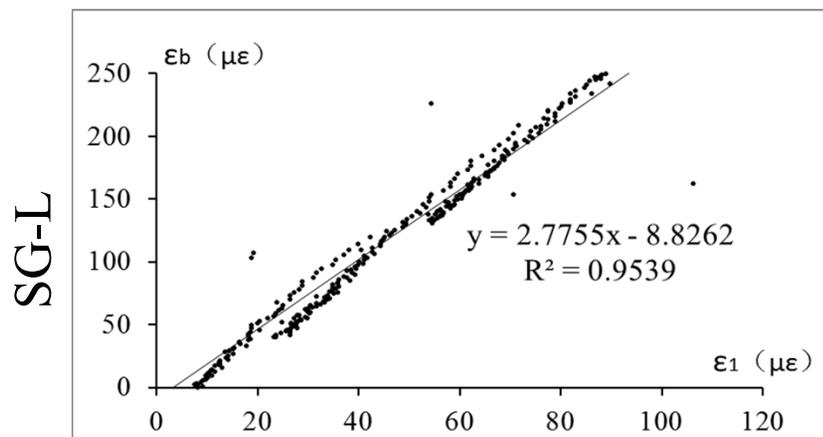
*Concrete strain gauge readings may be explained more reasonably*

# Verification tests of the sensors

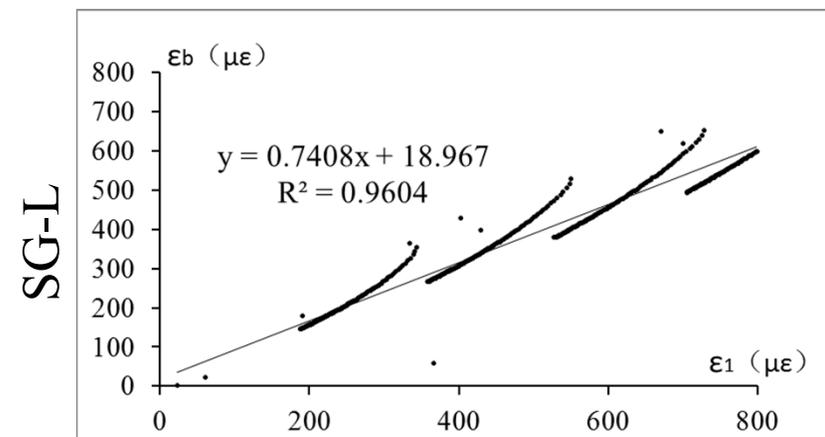


## ★ Asphalt Strain Gauge

Manufacturer	Type	Model	Size	Modulus
Tokyo Sokki	Resistance strain gage	KM-100HAS	100xΦ17mm ( H bar )	1GPa
Tokyo Sokki	Resistance strain gage	PMFLS	100x17x10mm	1GPa
Beijing Geokon	Fiber Bragg Grating Sensor	BGK-FBG-4200T	150xΦ30mm ( flange )	34GPa
Beijing Geokon	Fiber Bragg Grating Sensor	BGK-FBG-4150	70x10x8.5mm ( H bar )	37GPa



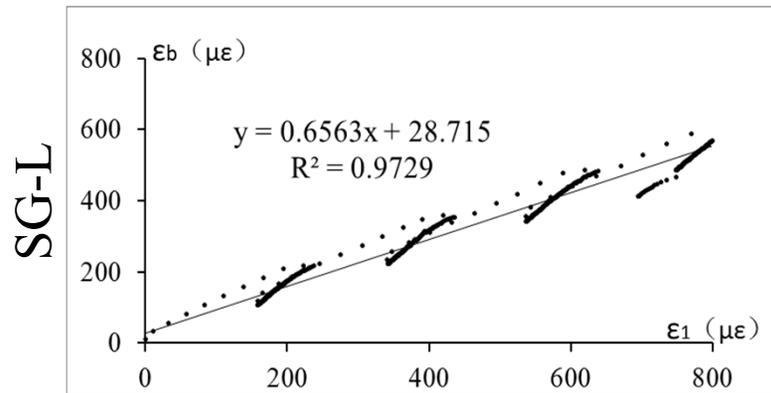
BGK-FBG-4200T



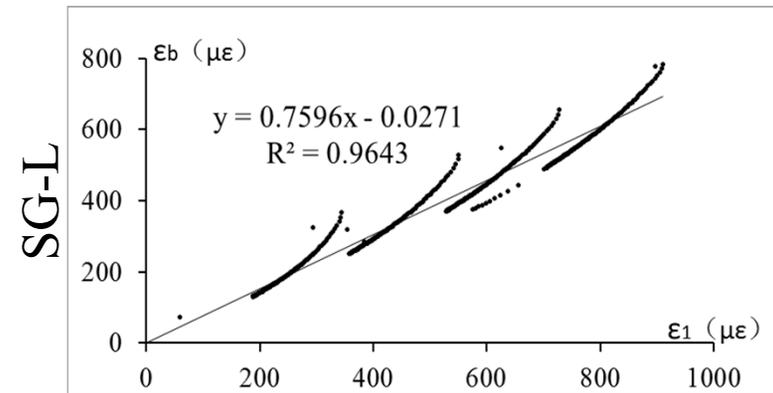
KM-100HAS

—Asphalt strain gauge readings should be modified

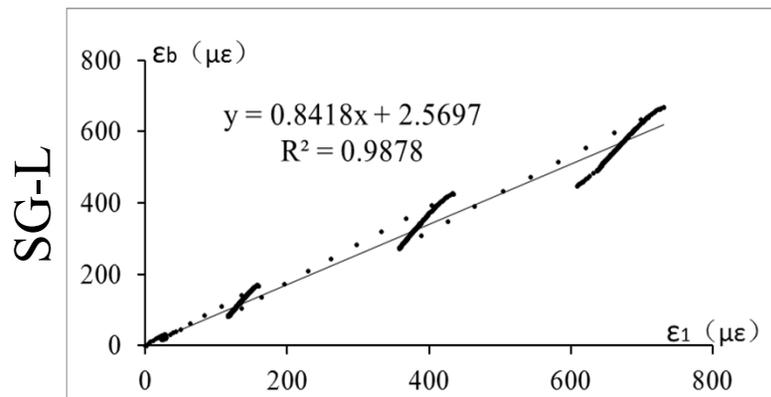
# Verification tests of the sensors



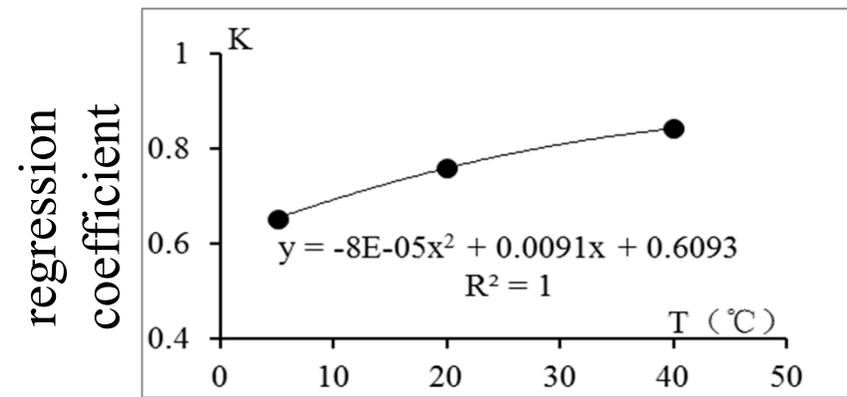
KM-100HAS at 5°C



KM-100HAS at 20°C



KM-100HAS at 40°C



Temperature

— *Temperature* affect readings of Asphalt strain gauge

# Verification tests of the sensors



## ➤ *Modification formula*

— Asphalt strain gauge reading can be modified by

$$\varepsilon_0 = \varepsilon_1 \times K(T)$$

K — Linear regression coefficient

T — Temperature

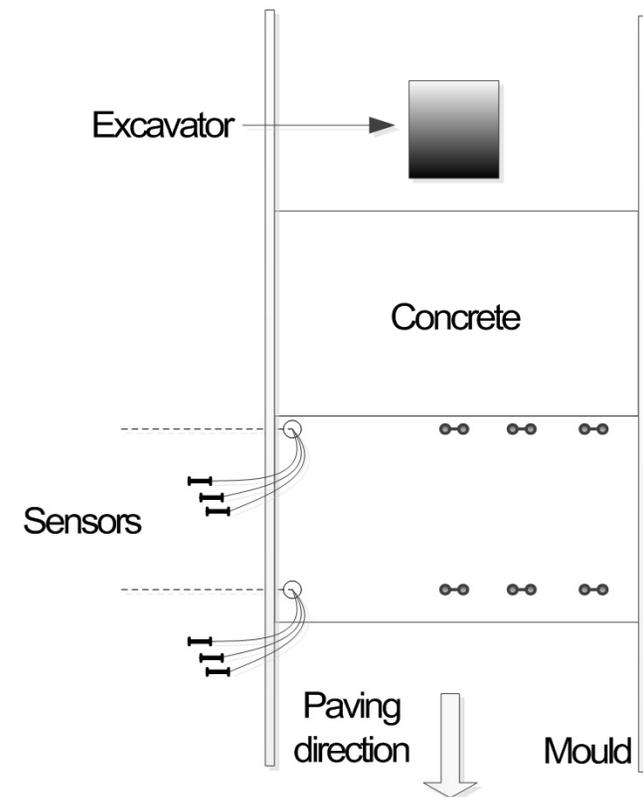
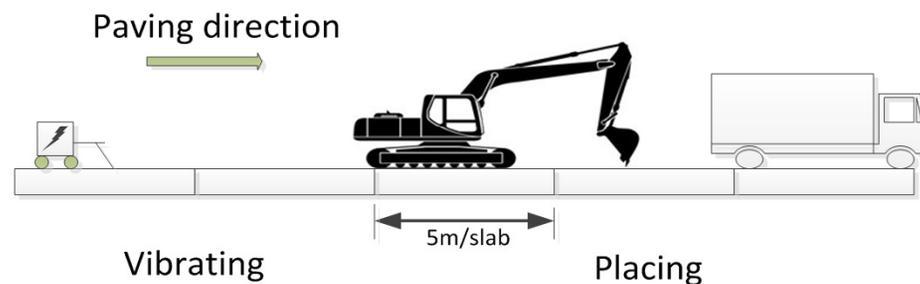
Model	Modification formula	Fatigue test
KM-100HAS	$\varepsilon_0 = \varepsilon_1 \times (0.0086T^2 - 0.2257T + 3.13)$	Qualified
PMFLS	Failure	--
BGK-FBG-4200T	$\varepsilon_0 = \varepsilon_1 \times (0.0001T^2 - 0.0091T + 0.609)$	Failure
BGK-FBG-4150	$\varepsilon_0 = \varepsilon_1 \times (0.0036T^2 - 0.1199T + 3.739)$	Qualified

# Process of installation



## ✦ collaborative construction

- *Prewired cable*
- *Sensors stored nearby*
- *Quick fixtures*
- *Cooperate with paving team*

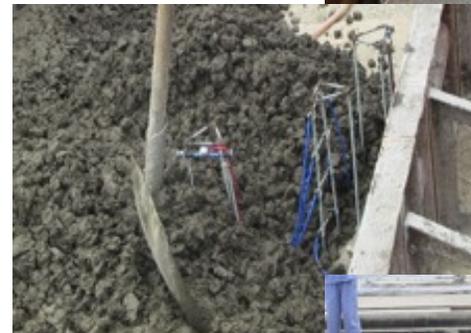


# Process of installation



## ➤ *Tips for installation*

- *Good supporting device*
  - Fix, Locate sensors*
- *Repeatedly positioning*
- *Minimize redundant cable*
  - Fix cables on base*
- *Casing protection for cables*
- *Marking sensors all the time*
- *Keeping eye on the reading*





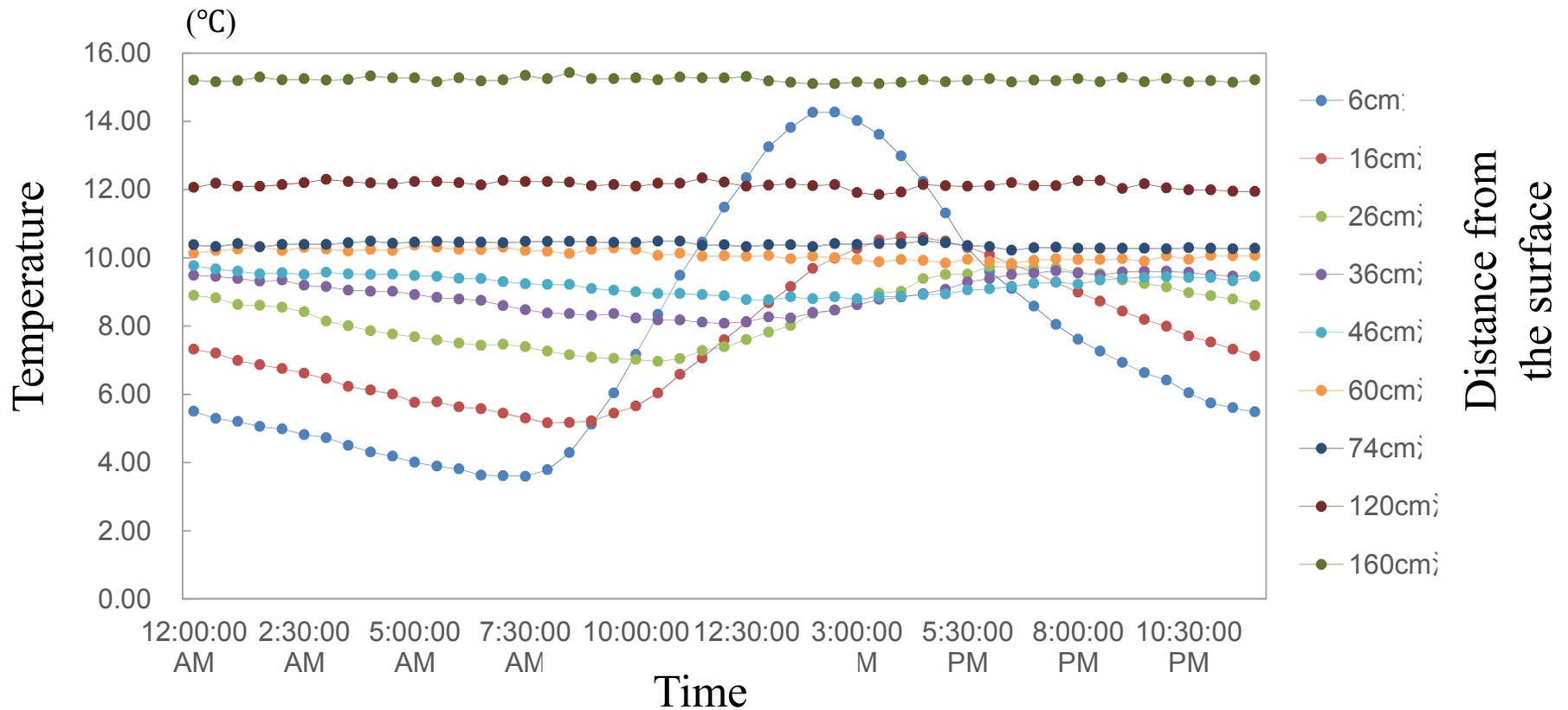
# Initial responses test of pavement



## ★ Pavement Performance Model

### ➤ Temperature

● January 15, 2014

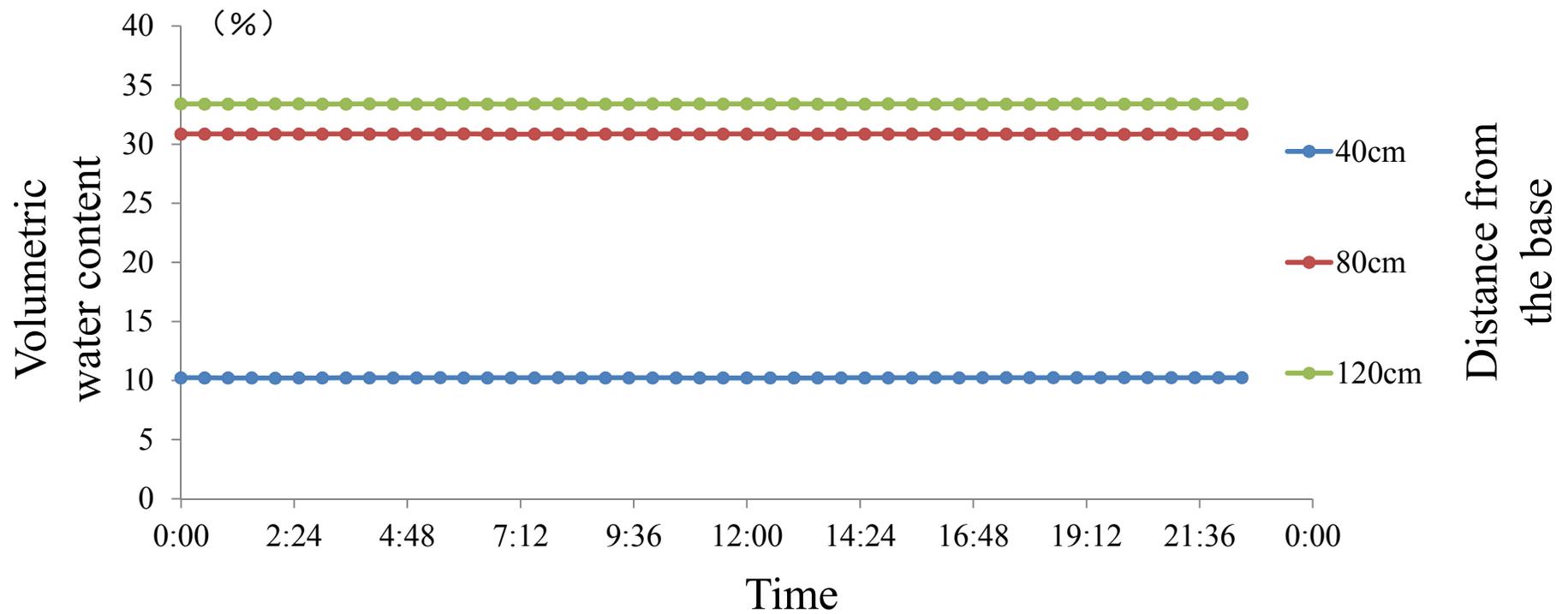


# Initial responses test of pavement



## ➤ *Moisture*

• *January 20, 2014*



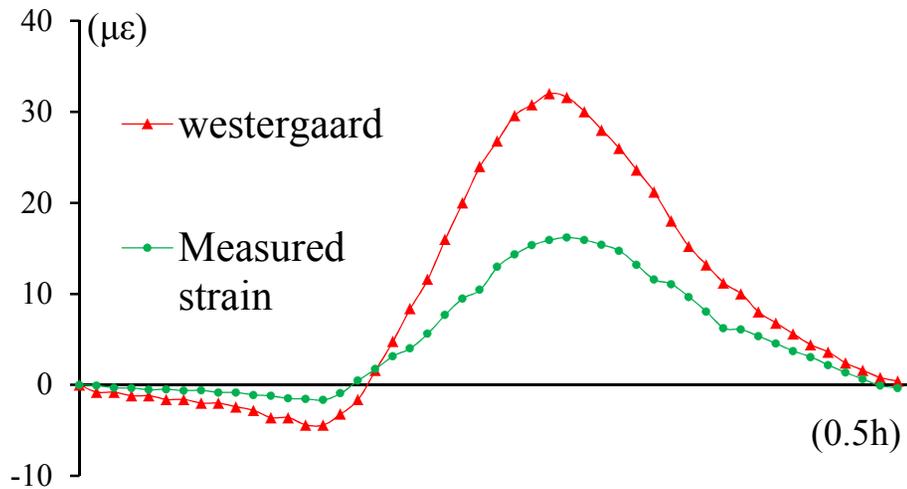
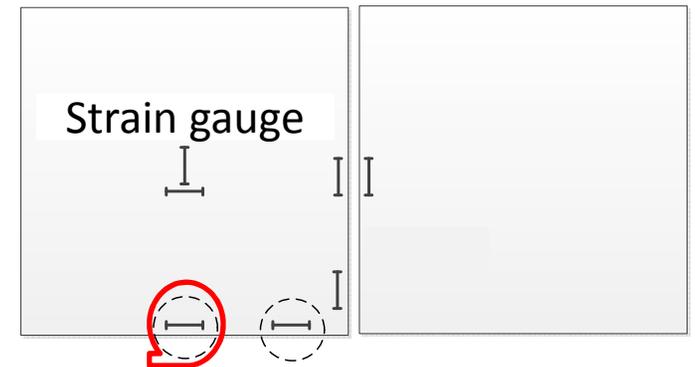
# Initial responses test of pavement



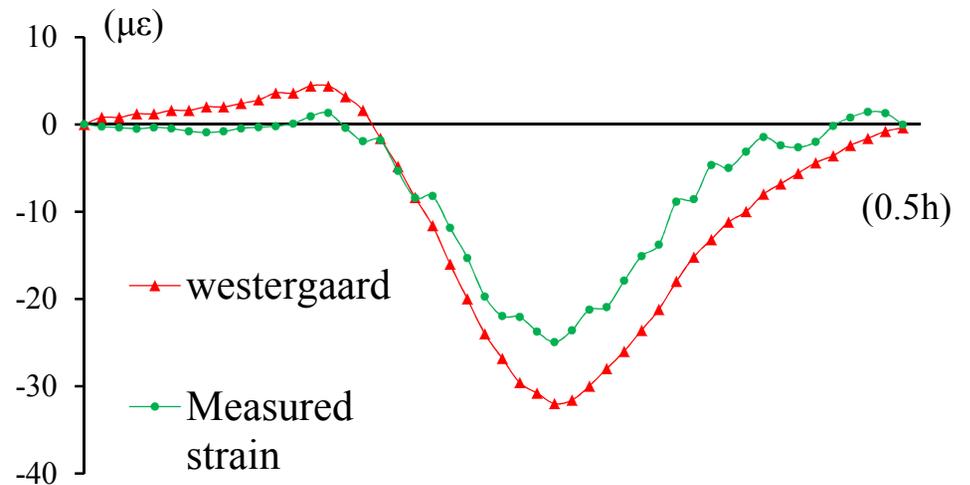
## ➤ *Static concrete strain*

• *January 20, 2014*

Temperature strain comparing result



Strain gauge at the bottom



Strain gauge at the top

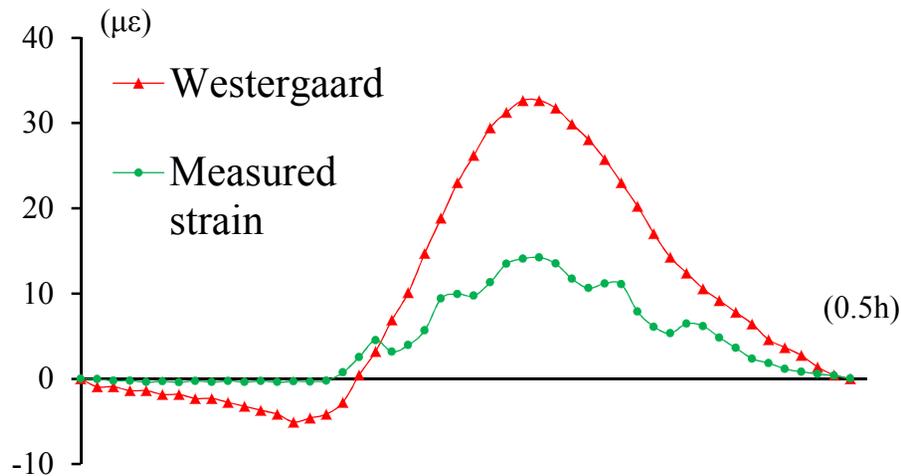
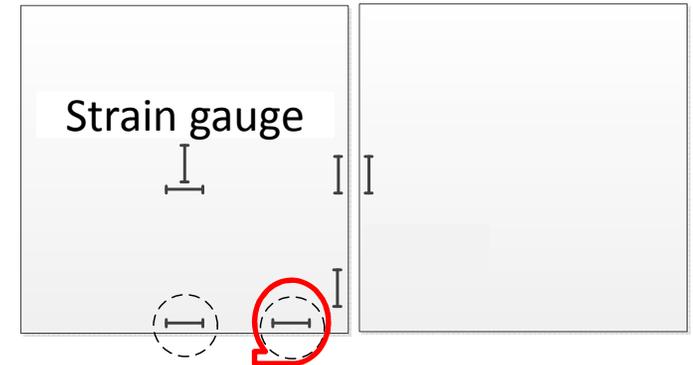
# Initial responses test of pavement



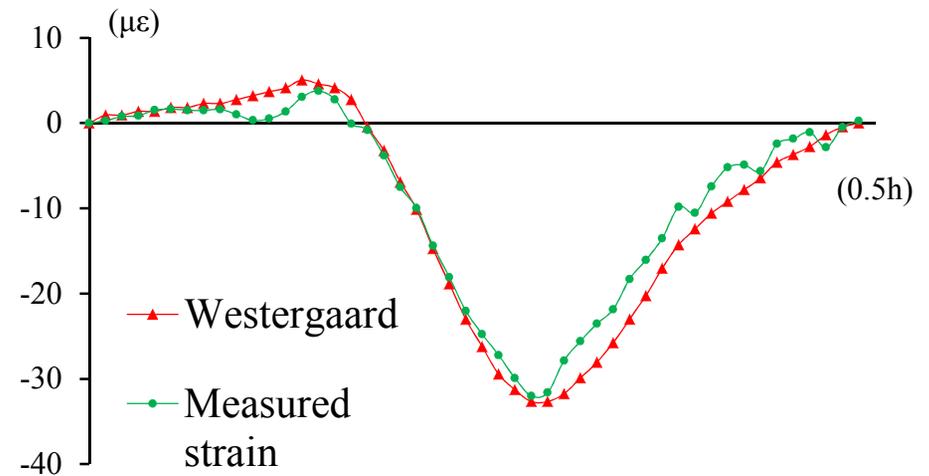
## ➤ *Static concrete strain*

• *January 20, 2014*

Temperature strain comparing result



Strain gauge at the bottom



Strain gauge at the top

—*Data is reasonable but still need more verification tests*

# Conclusion and Acknowledgments



## ★ Conclusion

1

*A system of monitoring pavement inner condition is developed including strain gauges, MDDs, temperature and moisture sensors, earth pressure cells. The system **maybe** the effective platform to build more reasonable pavement performance model.*

2

*A process is developed to synchronize the construction of PCC and installation of sensors.*

3

*Glide Slop is suggested as the signal transfer station area in the design of signal transfer station.*

4

*A lot of works should be do to build pavement performance model through pavement structural condition monitor system.*

# ***Conclusion and Acknowledgments***

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## ***★ Acknowledgements***

- **The financial support of HTRDC (2012AA112505), NSFC (50908176)**
- **Ministry of Transport of the People's Republic of China (2011318801670)**



# *Pavement condition monitoring system at Shanghai Pudong International Airport*

# QUESTION?

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