Health Monitoring of Large Civil Structures

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The Hong Kong Polytechnic University

The Second Future Infrastructure Forum (FIF2), 17-18 January 2012, Cambridge, UK

Department

42 Academics of 6 Disciplines:

Structural Engineering, Geotechnical Engineering, Construction Engineering, Transportation Engineering, Hydraulic Engineering, and Environmental Engineering Science.

Structural Engineering

12 Academics in Structural Engineering











Major Research Areas

Group	Major Research Areas
Structural Dynamics	*Structural health monitoring, Structural control, Smart structures,* Wind engineering, Earthquake engineering.
Steel Structures	Steel-concrete composite structures, cold-formed structures, Stability, Second-order and nonlinear analysis.
FRP composites	High-performance structures, Durability, Life-cycle management, Retrofit of structures, Structural fire engineering.

Outline of Presentation

1. Background
2. Structural Health Monitoring Systems (SHMS)
3. SHMS in Landmark Structures
4. University Niche Area Program
5. Future Infrastructure

1. Background

1.Background

Many innovative large civil structures have been built or are under construction throughout the world.

1. Background

Tall Buildings

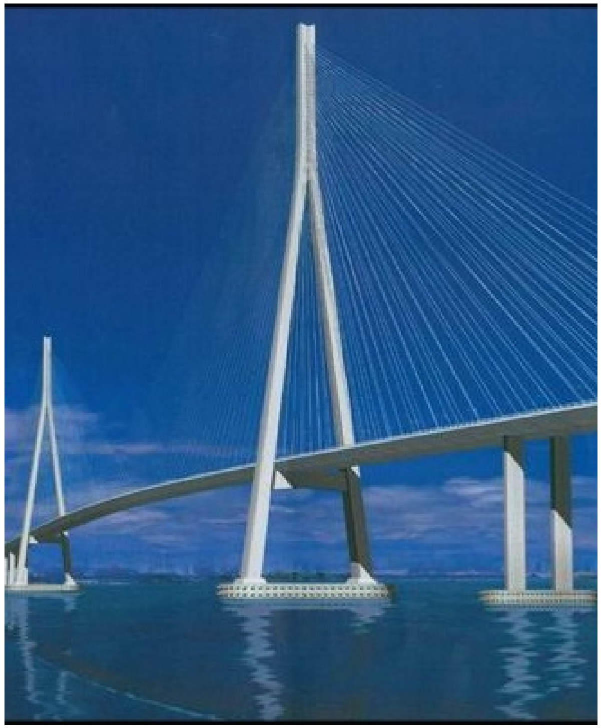
Burj Khalifa, Dubai , 828m

Taipei 101, Taipei, 509 m

ICC, Hong Kong, 484m

Petronas Twin Tower, Kuala Lumpur, 452 m

Long-span Bridges



Sutong Bridge, China, 1088 m

Akashi Kaikyo Bridge, Japan, 1991 m

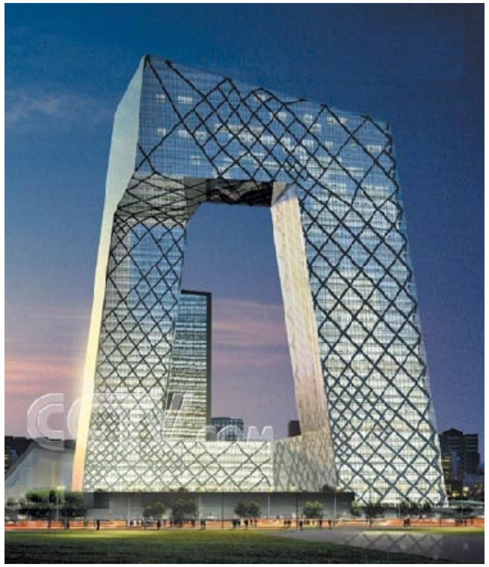
Stonecutters Bridge, Hong Kong, 1018 m

1. Background

Large Spatial Structures

National Stadium

National Grand Theater



CCTV New Headquarters

National Aquatics Centre

1. Background

Civil structures, on the other hand, have become increasingly vulnerable to natural and man-made hazards.

Sichuan Earthquake, May 12, 2008

1. Background

Civil structures built in strong wind regions are vulnerable to wind-induced damage

1. Background

I-35W Bridge, USA, August 1, 2007

Guangdong Bridge, June 15, 2007

1. Background

Global climatic change presents many challenges to our engineering community, such as stronger hurricanes and faster material deterioration.

1. Background

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Serviceability, safety and sustainability of large civil structures are therefore main concerns of our society.

Recently-developed long-term structural health monitoring technology is one of cutting-edge technologies for monitoring serviceability, safety, and sustainability.

2. Structural Health Monitoring Systems (SHMS)

2. Structural Health Monitoring Systems

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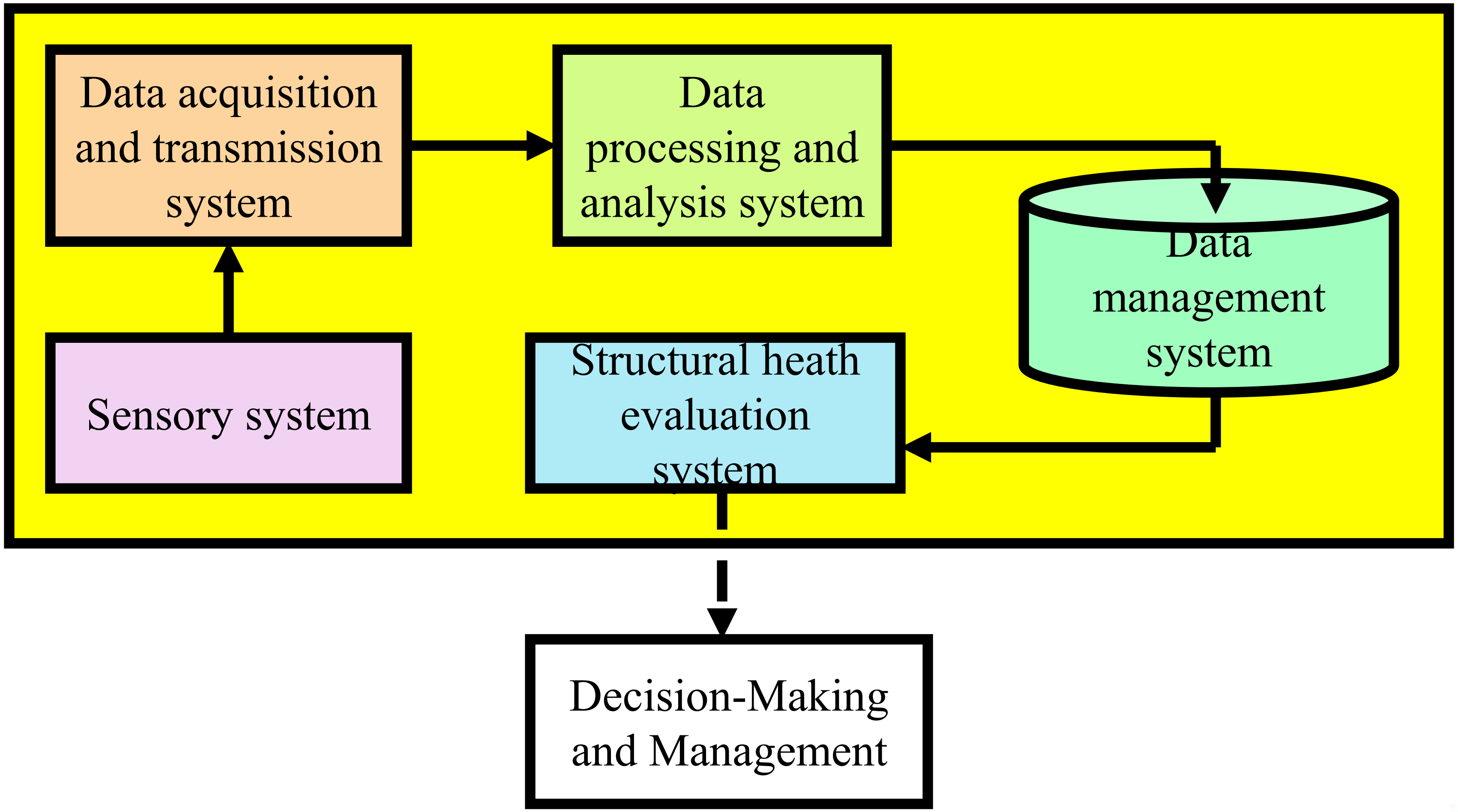
A long-term structural health monitoring system shall include at least five integrated modules/systems:

- Sensory system.
- Data acquisition and transmission system.
- Data processing and analysis system.
- Date management system.
- Structural heath evaluation system.

2. Structural Health Monitoring Systems



2. Structural Health Monitoring Systems

Main functions of structural health monitoring

- Monitor and assess load conditions
- Examine current design philosophy
- Verify new analytical methods and computer simulations
- Assess structural performance and detect damage
- Facilitate inspection and maintenance works
- Help authority to make quick and right decision in emergency cases

- Ultimate goal is to ensure serviceability, safety, and sustainability

3. SHMS in Landmark Structures

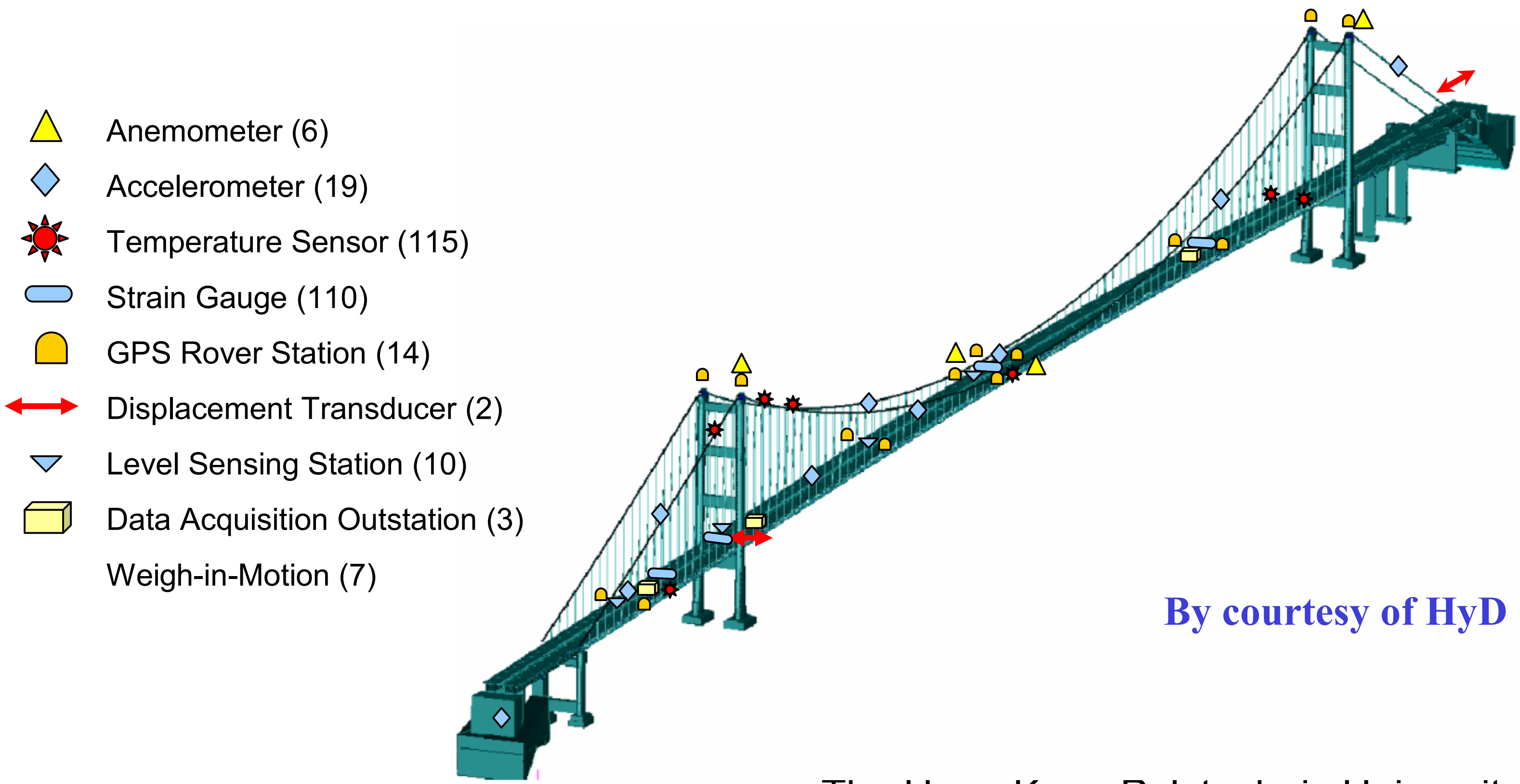
3.1 SHMS of Tsing Ma Bridge
3.2 SHMS of Stonecutters Bridge
3.3 SHMS of Canton Tower
3.4 SHMS of Shanghai Tower

3.1 SHMS of Tsing Ma Bridge

Tsing Ma Bridge in Hong Kong is the longest suspension bridge carrying both highway and railway with a main span of 1377m.

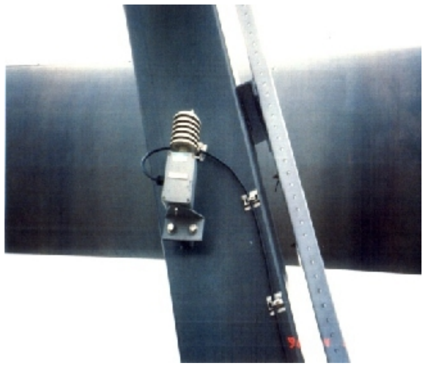
3.1 SHMS of Tsing Ma Bridge

The bridge has been equipped with a Wind and Structural Health Monitoring System (WASHMS) since **1997**.



By courtesy of HyD

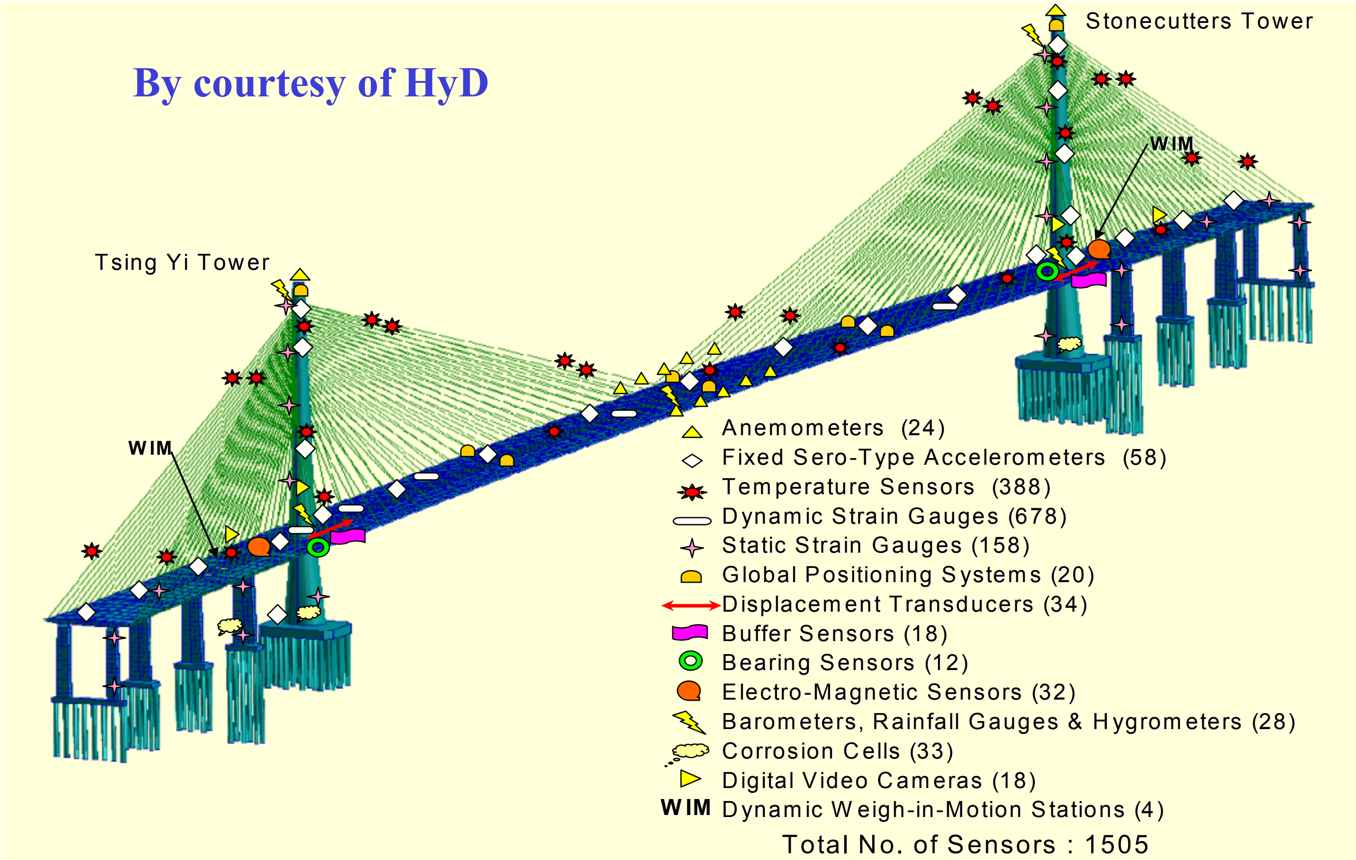
3.1 SHMS of Tsing Ma Bridge



3.2 SHMS of Stonecutters Bridge

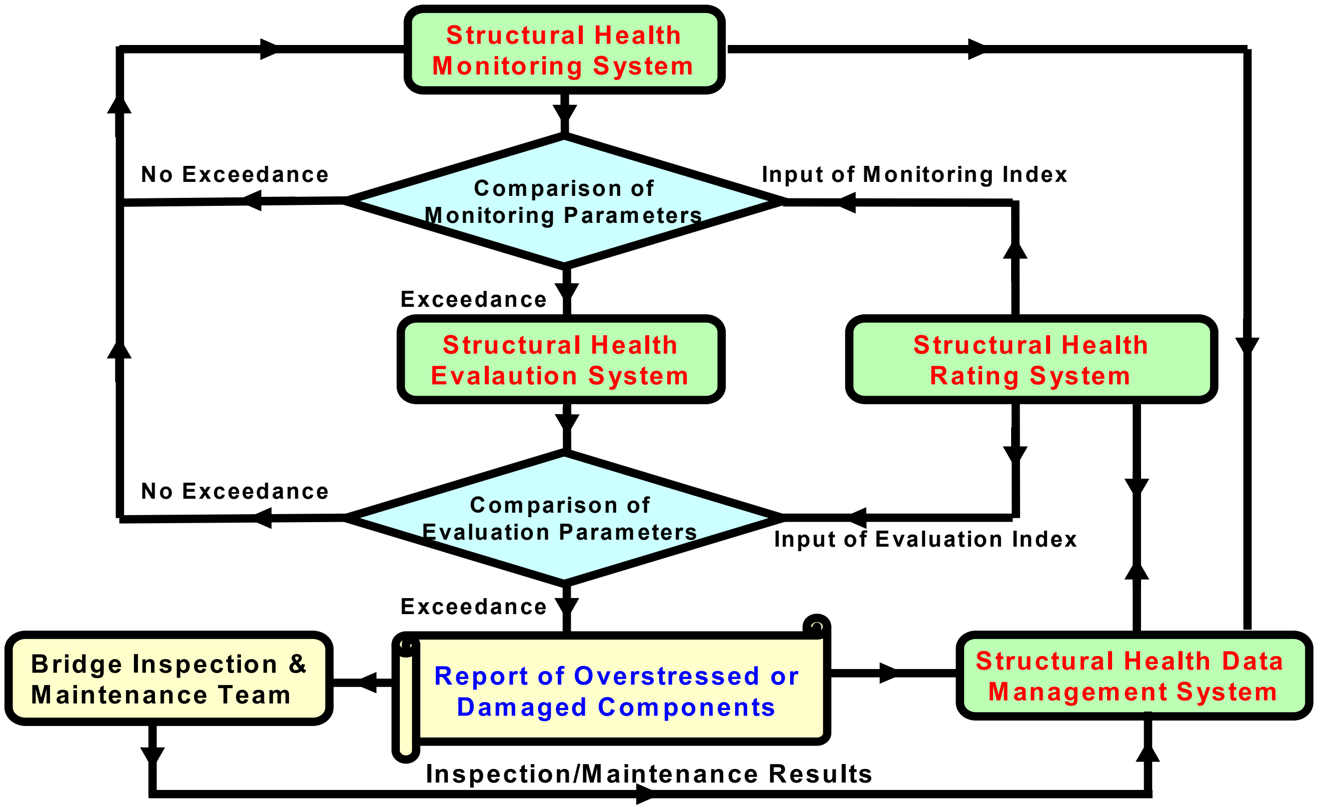
Stonecutters Bridge in Hong Kong: The second longest stay-cabled bridge with a 1018-m main span (2009)

3.2 SHMS of Stonecutters Bridge



Sensor layout of Stonecutters Bridge

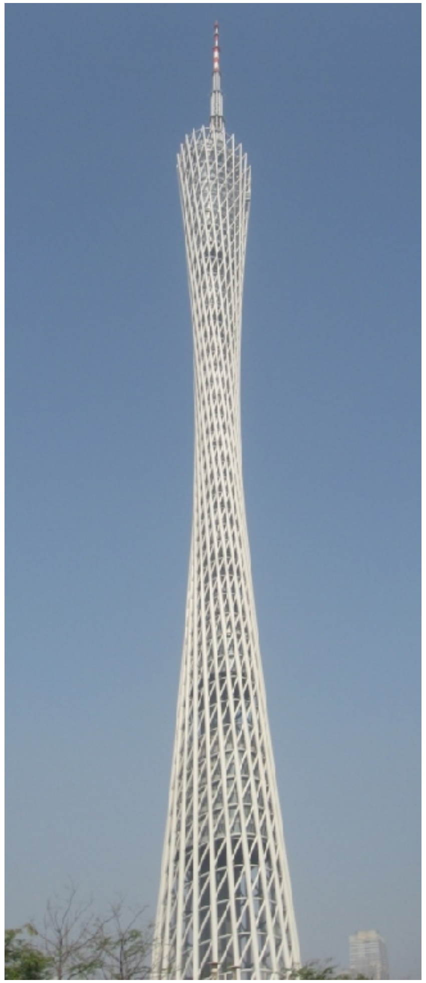
3.2 SHMS of Stonecutters Bridge



By courtesy of HyD

Flow Chart of SHM for Stonecutters Bridge

3.3 SHMS of Canton Tower

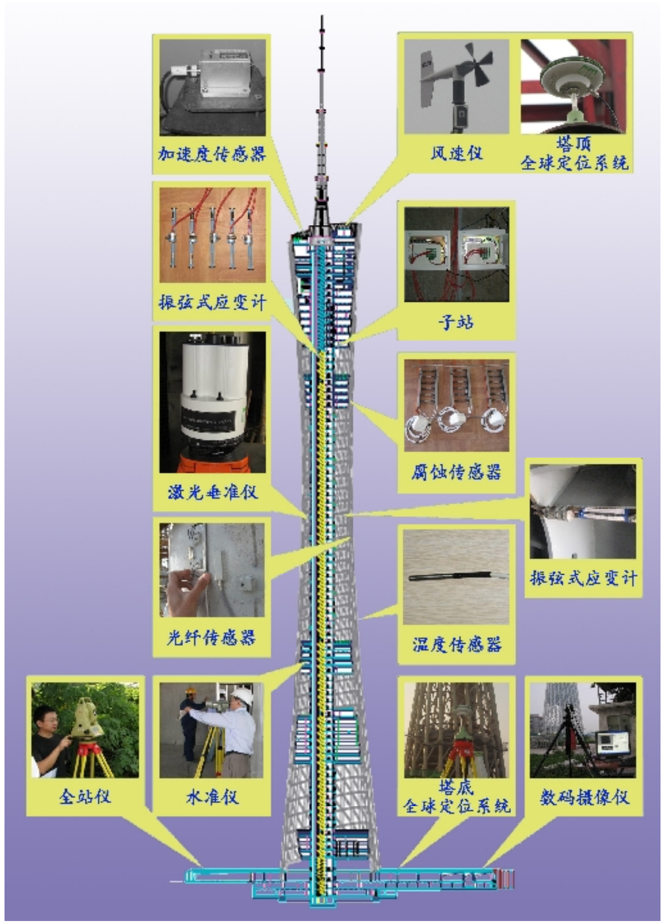


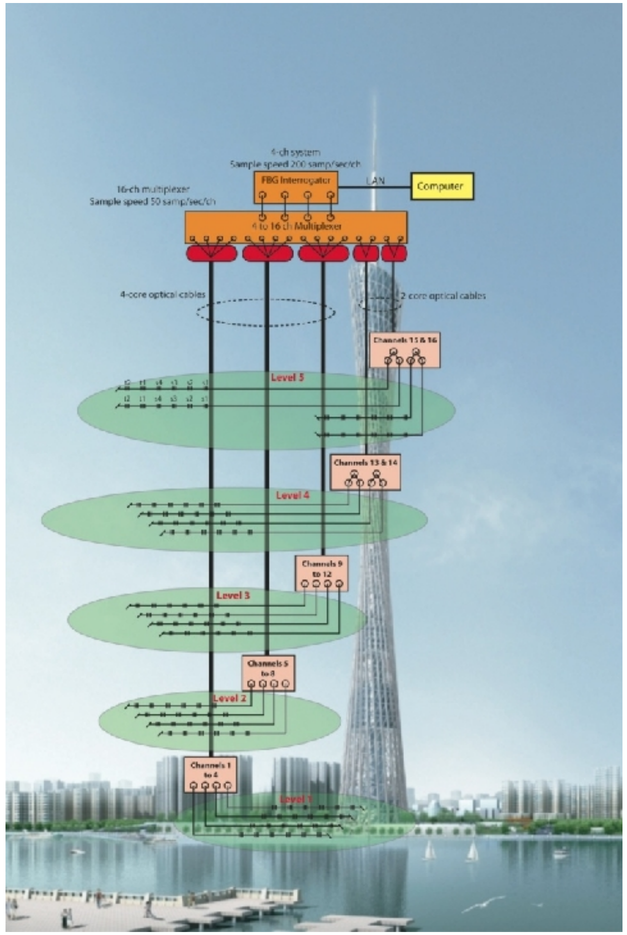
Canton Tower in Guangzhou:
a 450 m high main tower and
a 150 m high antenna.

573 sensors (10types) in
construction stage.

280 sensors (12 types) in
service stage

3.3 SHMS of Canton Tower

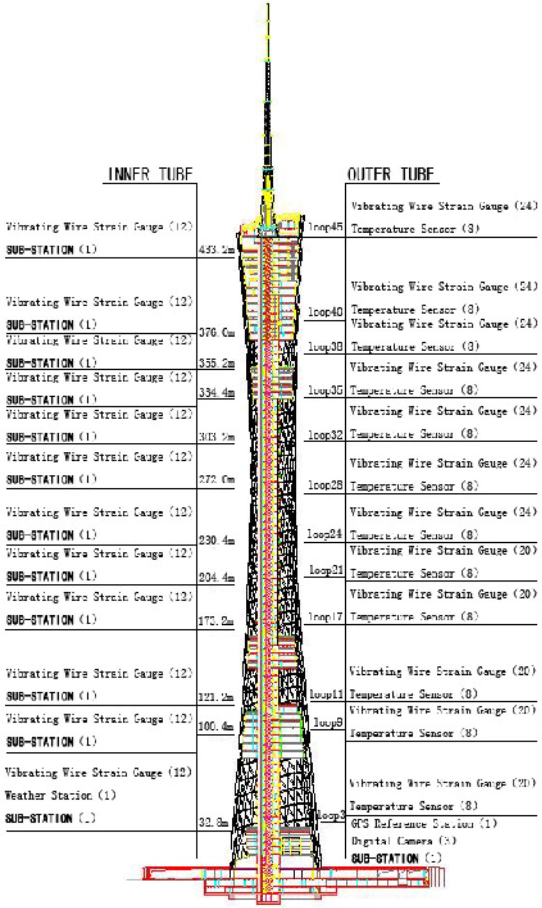




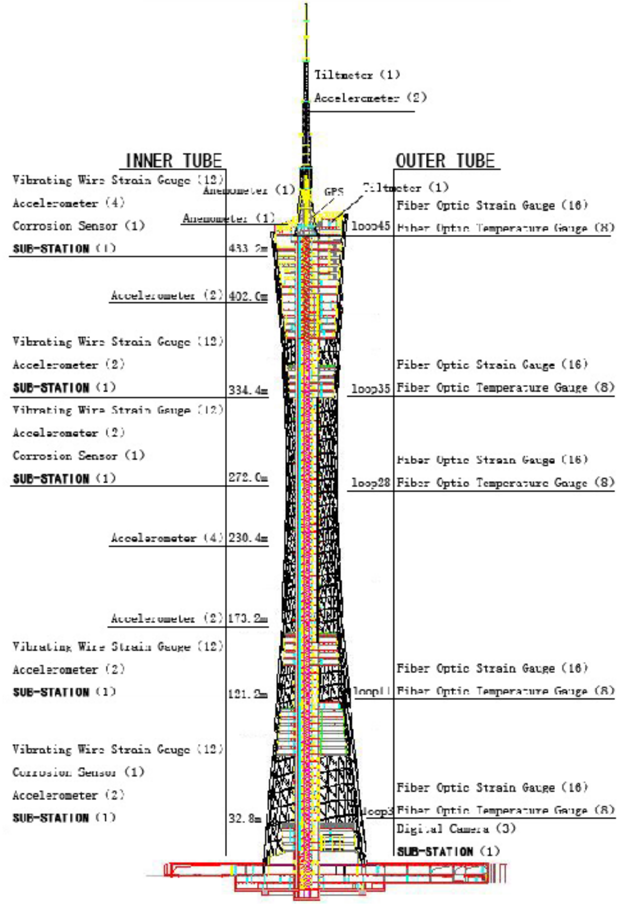
Type of sensors in the SHM system

FBG sensor network

3.3 SHMS of Canton Tower



Sensors and sub-stations for in-construction monitoring

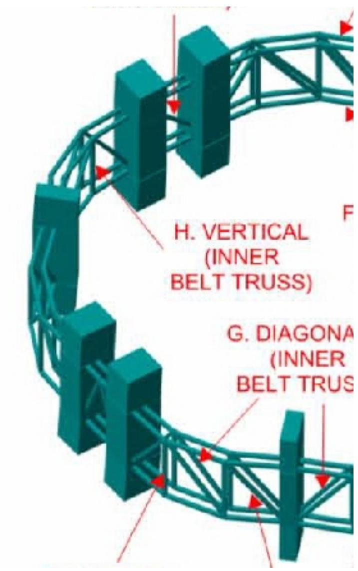


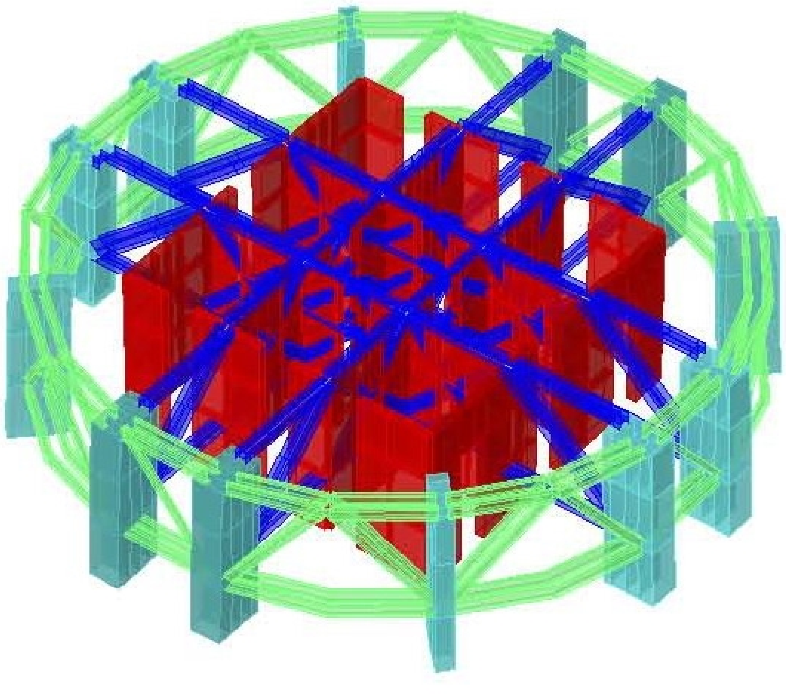
Sensors and sub-stations for in-service monitoring

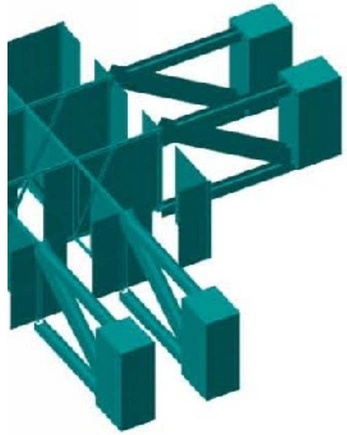
3.4 SHMS of Shanghai Tower

Shanghai Tower (632 m), Jin Mao Tower (421 m), and Shanghai World Financial Center (494 m)

3.4 SHMS of Shanghai Tower







Two-story-high
belt truss

Outer Tube

Inner Tube

3.4 SHMS of Shanghai Tower

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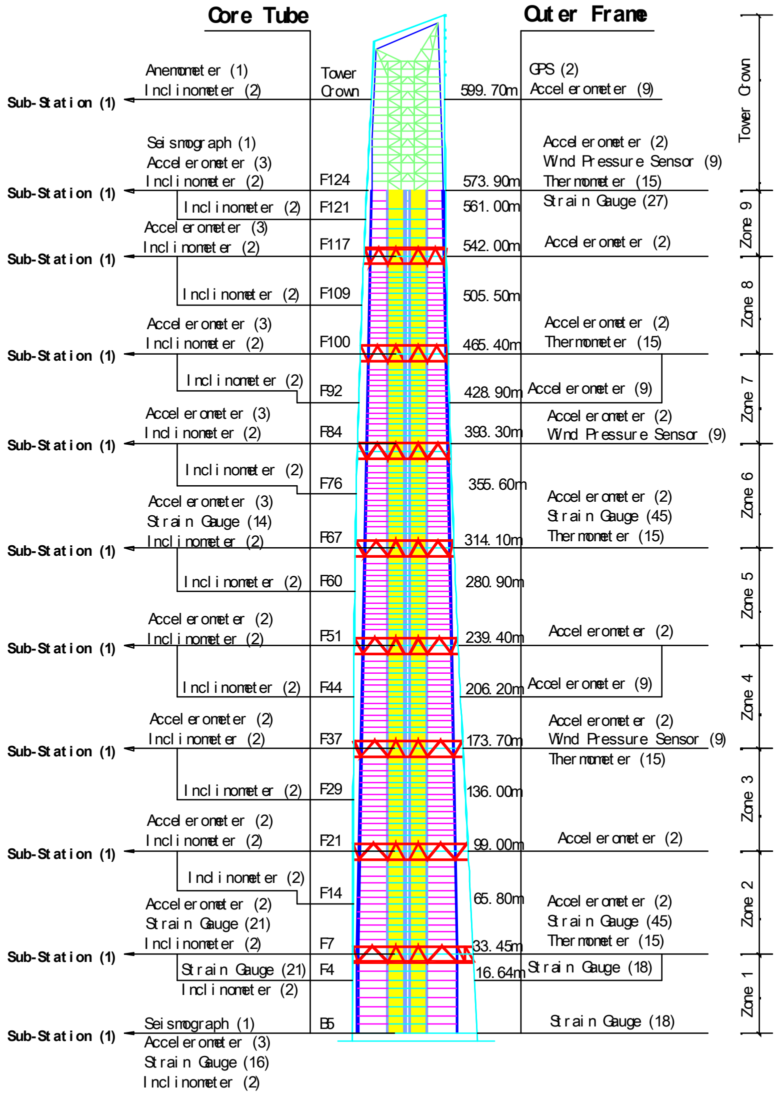


Sensor Layout

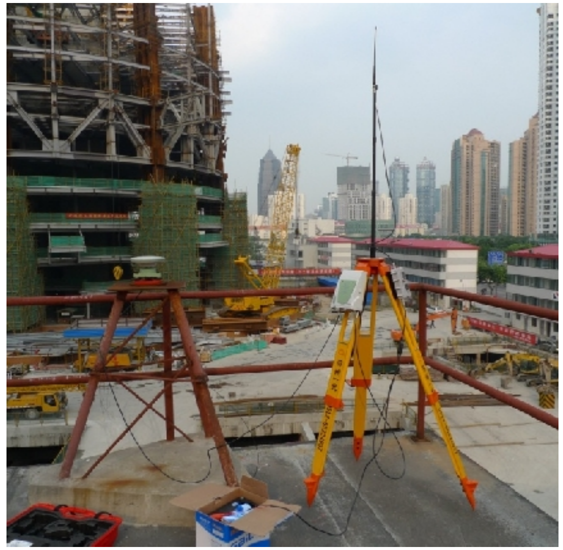
400 sensors of 11 types

11 substations

3.4 SHMS of Shanghai Tower

Strain sensors (vibrating wires) installed inside the RC shear wall of the inner tube – to measure the strain of the concrete

Strain sensors (vibrating wires) installed on the embedded steel column of one mega column – to measure the strain of the steel



GPS reference station

4.University Niche Area Program

- Some progress has been made, but there are many key issues to be solved.
- Hong Kong is a suitable place to pioneer this technology because Hong Kong has many tall buildings an long span bridges.
- Hong Kong also has a strong infrastructure development program for next ten years
- The Hong Kong Polytechnic University has a strong team of experts in sensing technology, spatial information technology, computing, civil and structural engineering.

4. University Niche Area Program

Health Monitoring of Large Civil Structures

4.1 Principal and Co-Investigators
4.2 Four Tasks
4.3 Ten Projects
4.4 Research Milestones

4.1 Principal and Co-Investigators

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Name	Department	Area of Expertise
Y L Xu	CSE (PI) Chair Prof.	*Structural Dynamics, Structural Health Monitoring,Wind Engineering*
Y Q Chen	LSGI (CoI) Chair Prof.	*GPS Technique, Monitoring of Building Structures*
X L Ding	LSGI (CoI) Chair Prof.	*GPS Technique, Monitoring of Building Structures*, *Interferometric Synthetic*
H Y Tam	EE (CoI) Chair Prof.	*Fibre-Optics Sensors*, *Photonics Sensor Networks*, *Optical Fibre Communication*
J N Cao	COMP (CoI) Chair Prof.	*Wireless Sensors,Computer Networks*, *Parallel and Distributed Computing*
S S Law	CSE (CoI) Prof.	*Structural Dynamics*, *Structural Damage Detection*, *System Identification*
Y Q Ni	CSE (CoI) Prof.	*Structural Dynamics*, *Sensing Technology*, *Structural Health Monitoring*
Y Xia	CSE (CoI) Assist. Prof.	*Structural Damage Detection*, *Structural Health Monitoring*
S Zhu	CSE (CoI) Assist. Prof.	*Structural Assessment*, *Structural Control*

4.2 Four Tasks

Task	Topic
1	Special Sensing Technology for SHM
2	Performance-based design of SHM systems
3	Real-time structural damage detection methods and structural rating systems
4	Real-time loading simulation and structural performance assessment

4.3 Ten Projects

Task	Project	Project Title
1	1	Fiber Bragg Sensor Networks for SHM
1	2	GPS Technology for SHM
1	3	Wireless Sensor Networks for SHM
2	4	Performance-based Design of SHM Systems
2	5	Advanced Data Acquisition, Transmission and Management Systems
3	6	New Modeling Technologies and Model Updating Methods
3	7	Novel Damage Detection Algorithms with Consideration of Uncertainties and Operation Conditions
3	8	SHM-based Bridge Rating Systems
4	9	SHM-based Life-cycle Deterioration Models
4	10	Performance Simulation and Assessment of Structures under Extreme Loadings

4.4 Research Milestones

No.	Research Milestones
1	Establishment of Bridge Rating System for Tsing Ma Bridge
2	Development of Structural Health Prognosis Tools and Condition Rating System for Stonecutters Bridge
3	Development of Structural Health Monitoring System for Canton Tower
4	Development of Structural Health Monitoring System for Shanghai Tower

4.4 Research Milestones

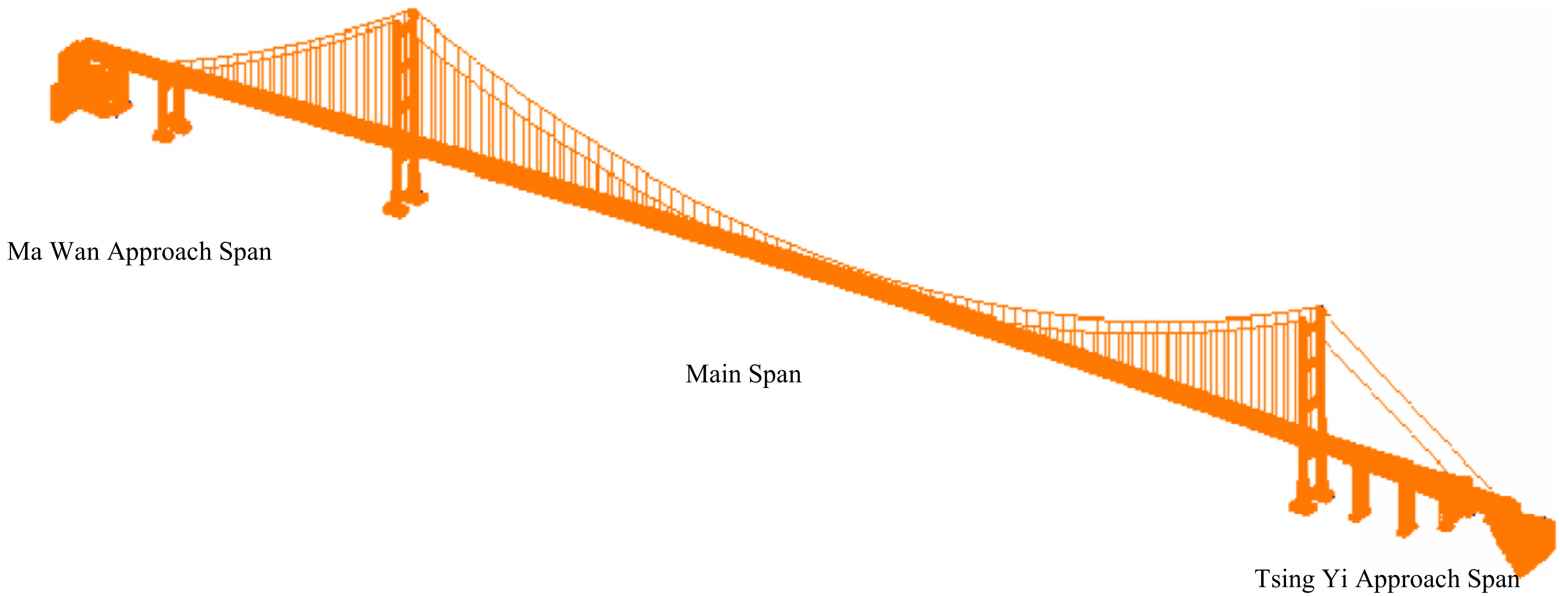
The Hong Kong Highways Department asked the research team to establish a SHM-based bridge rating system for Tsing Ma Bridge in 2006. The project was completed in 2010. A total of 12 reports have been submitted to HyD. The research team analyzed enormous measurement data, developed a few analytical methods, and established the new rating system.

4.4 Research Milestones

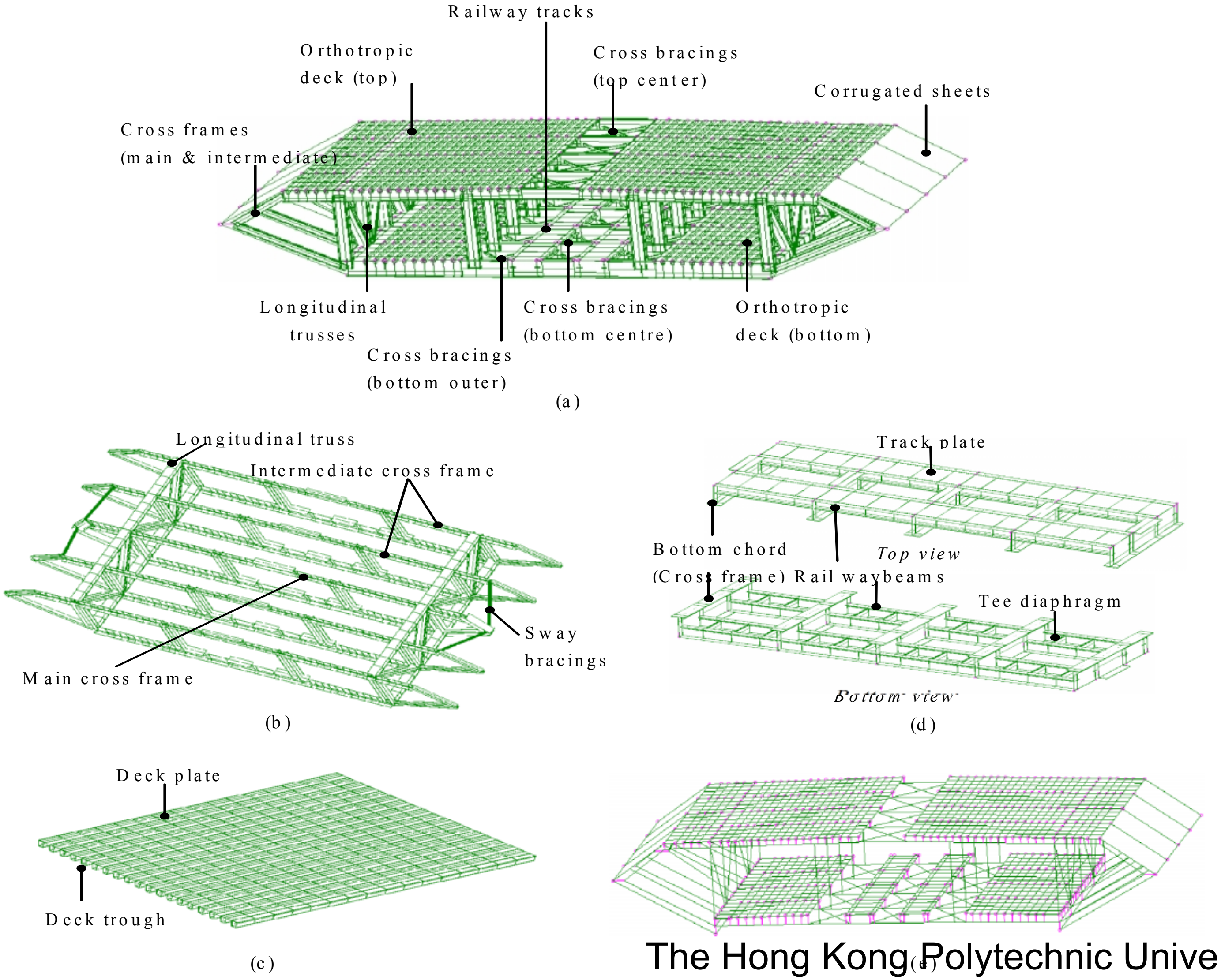
- SHM-oriented finite element model of the bridge.
- Predominating wind loading.
- Predominating temperature loading.
- Predominating highway loading.
- Predominating railway loading.
- Criticality and vulnerability analyses.
- New bridge rating method.
- SHM-based bridge rating system.

4.4 Research Milestones

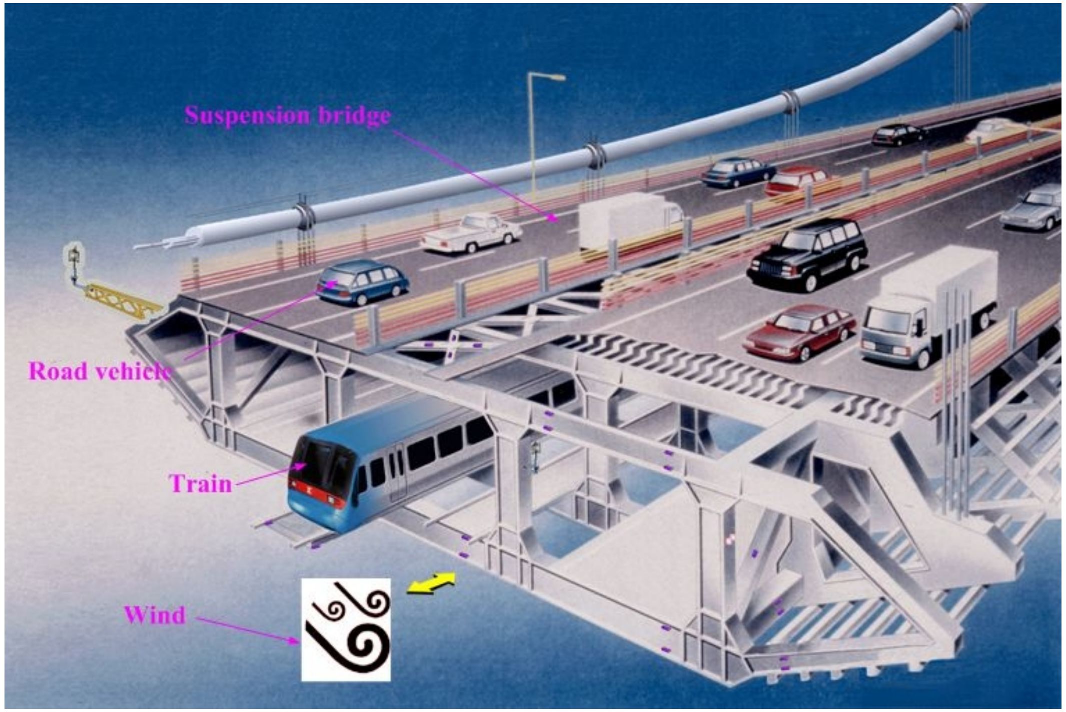
A structural health monitoring-oriented (multi-scale) 3D finite element model of the bridge such that stresses in major structural components can be directly computed.



4.4 Research Milestones



4.4 Research Milestones



Long-span Suspension Bridge under Railway, Highway, and Wind Loading

4.4 Research Milestones

A SHM-based framework for fatigue and reliability analyses of long-span suspension bridges under multiple loading

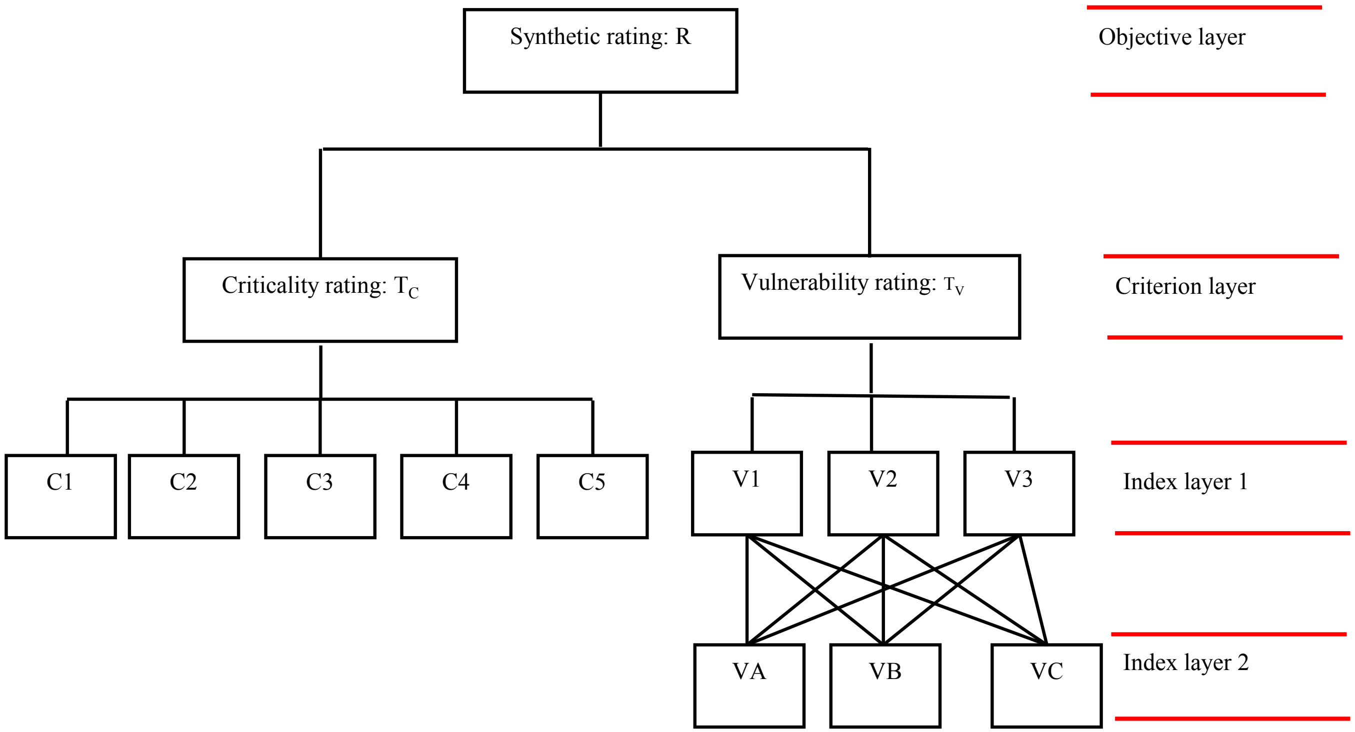
(1) Dynamic stress analysis of long suspension bridges under multiple loading

(2) Fatigue assessment of multi-load suspension bridges over design life

(3) Fatigue reliability analysis of multi-load suspension bridges

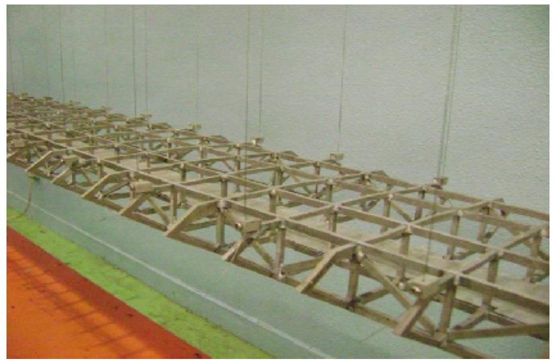
4.4 Research Milestones

A new bridge rating method has been proposed. The associated numerical value of each factor for a given structural component is determined using SHMS-based computation simulations and engineering judgments.

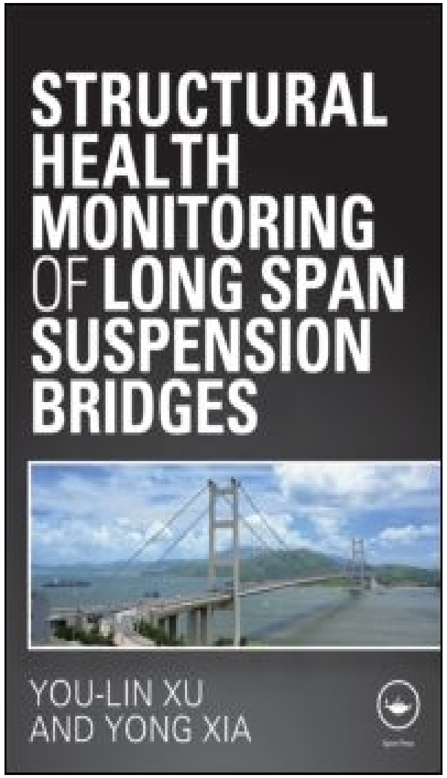


4.4 Research Milestones

Many key issues still remain unsolved and many difficulties are encountered in pursuing the tasks and utmost goals of SHM. It is desirable to establish a laboratory-based test-bed (benchmark).



4.4 Research Milestones



1. Introduction
2. Long-span Suspension Bridges
3. Structural Health Monitoring Systems
4. SHM-Oriented Modeling
5. Monitoring of Highway Loading Effects
6. Monitoring of Railway Loading Effects
7. Monitoring of Temperature Effects
8. Monitoring of Wind Effects
9. Monitoring of Seismic Effects
10. Monitoring of Other Effects
11. Structural Damage Detection
12. Bridge Rating System
13. Establishment of Test-beds
14. Epilogue: Challenges and Prospects

4.5 Future Infrastructure

Structural Vibration Control Technology: Equip an important structure with semi-active, active or hybrid control devices, a sensing network and an information technology-based data analysis system in order to:

- Reduce excessive vibration
- Enhance structural functionality, safety, and sustainability
- Retrofit historic buildings and structures

4.5 Future Infrastructure

4.5 Future Infrastructure

- At present, the areas of structural health monitoring and vibration control have been treated separately according to the primary objective pursued.

- However, both technologies require the use of sensors, data acquisition, signal transmission, data processing and data analysis.

4.5 Future Infrastructure

- The next step shall be to integrate the two systems together to create a smart structure with the sensors (nervous system), processors (brain system), and actuators (muscular system) so that the smart structure can mimic biological systems to function themselves properly at all levels of specified performance and to protect themselves against all kinds of natural and man-made hazards.

4.5 Future Infrastructure

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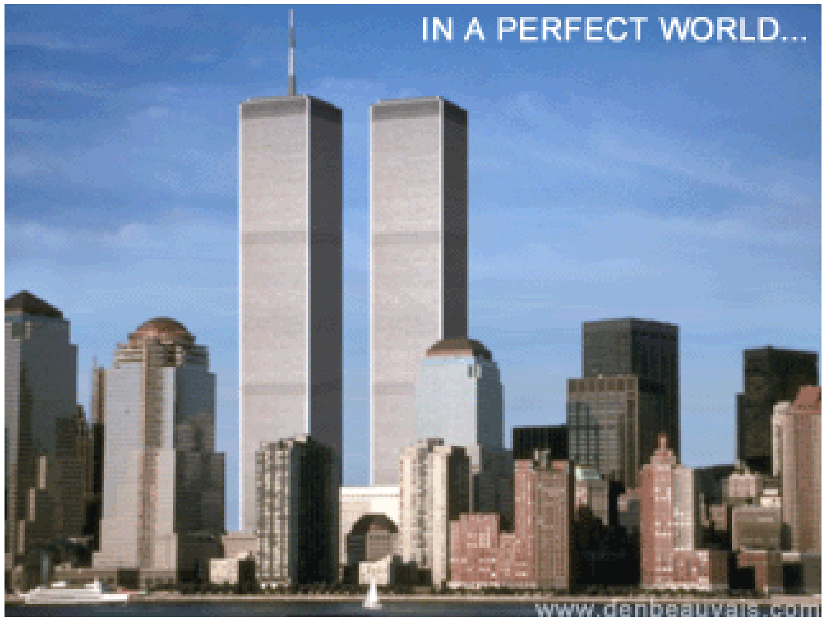
Smart Buildings

Smart VAWT

4.5 Future Infrastructure

- This is a spectacular idea of our structural engineers. The idea may be turned into reality in the decades ahead.



Acknowledgments

Financial Sponsors:

- The Hong Kong Polytechnic University
- The Hong Kong Highways Department
- The Hong Kong Research Grants Council

Thank many co-workers and students. Without their helps and supports, it is impossible to deliver this lecture.

Thank you for your attention

Welcome you to visit the Hong Kong Polytechnic University!