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Disaster mitigation of smart structures in South Korea under complicated loads: state-of-the-art

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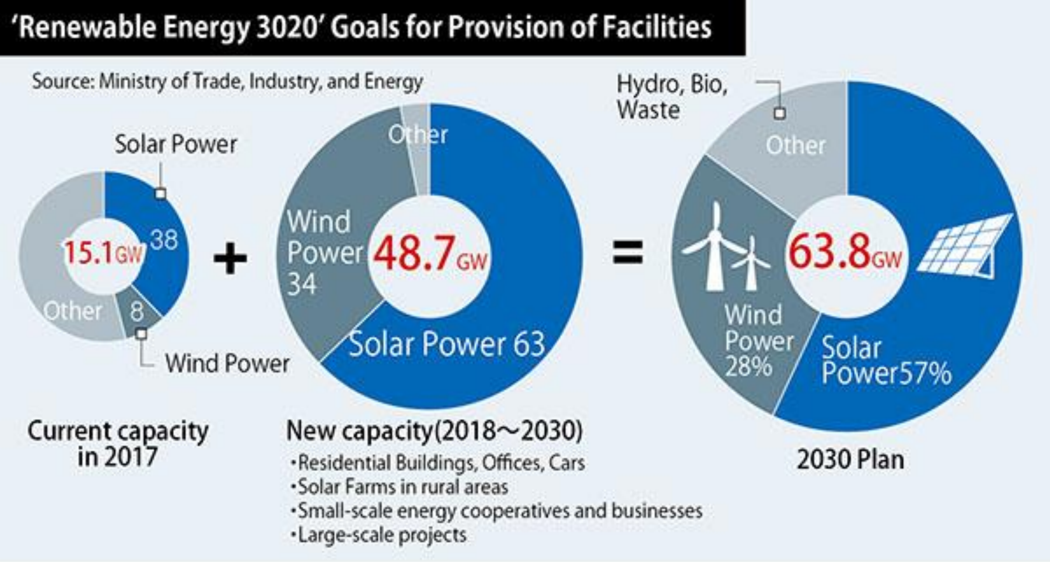


Renewable Energy 2030' Goals for Provision of Facilities

In 2010, 47% of the South Korean population lived in apartments that were constructed as early as in 1960. Approximately 8 Million buildings, containing more than 60% of all housing units, are apartments. Apartments have become an important element of the Korean housing development and economy starting from the National Housing Act of 1972, an ambitious plan for the construction of 2.5 Million housing units. The implementation of National Housing Act of 1972 and the construction of an immense amount of apartment buildings in a short time had significant influence on construction practices and the development of cost optimized building methods.

https://doi.org/10.3390/su10124494

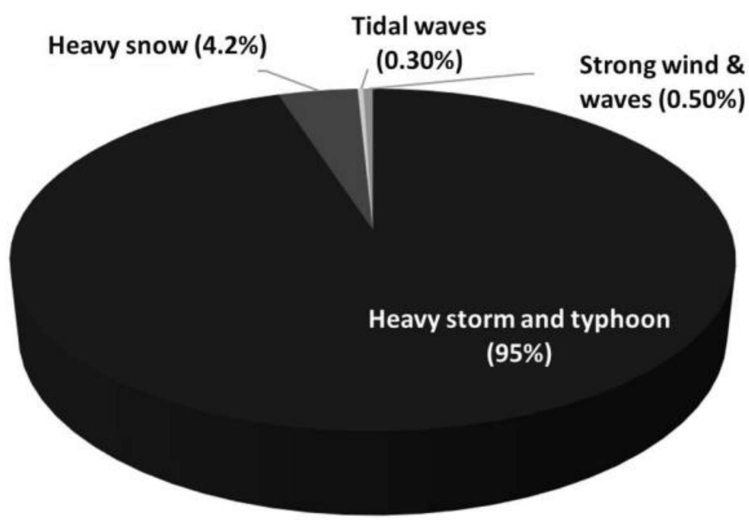
South Korea - High-technology exports

High-technology exports (current US$) in South Korea was reported at 118364816867 USD in 2016, according to the World Bank collection of development indicators, compiled from officially recognized sources.

Natural disaster effects and cost

Korea is relatively free from natural disasters caused by earthquakes and volcanic eruptions. However, it is often severely affected by other types of natural disasters such as floods, storms, and heavy snow. Among the most common hazards in Korea are floods caused by typhoons and heavy storms throughout the country. This is because the Korean peninsula is geographically located between the world's largest landmass, the Asian continent, and its largest body of water, the Pacific Ocean. Meteorologically, storms occur because the peninsula is situated in an atmospheric region that has low pressure air masses originating in the northwestern Pacific Ocean

Share of damage costs by cause (2010)

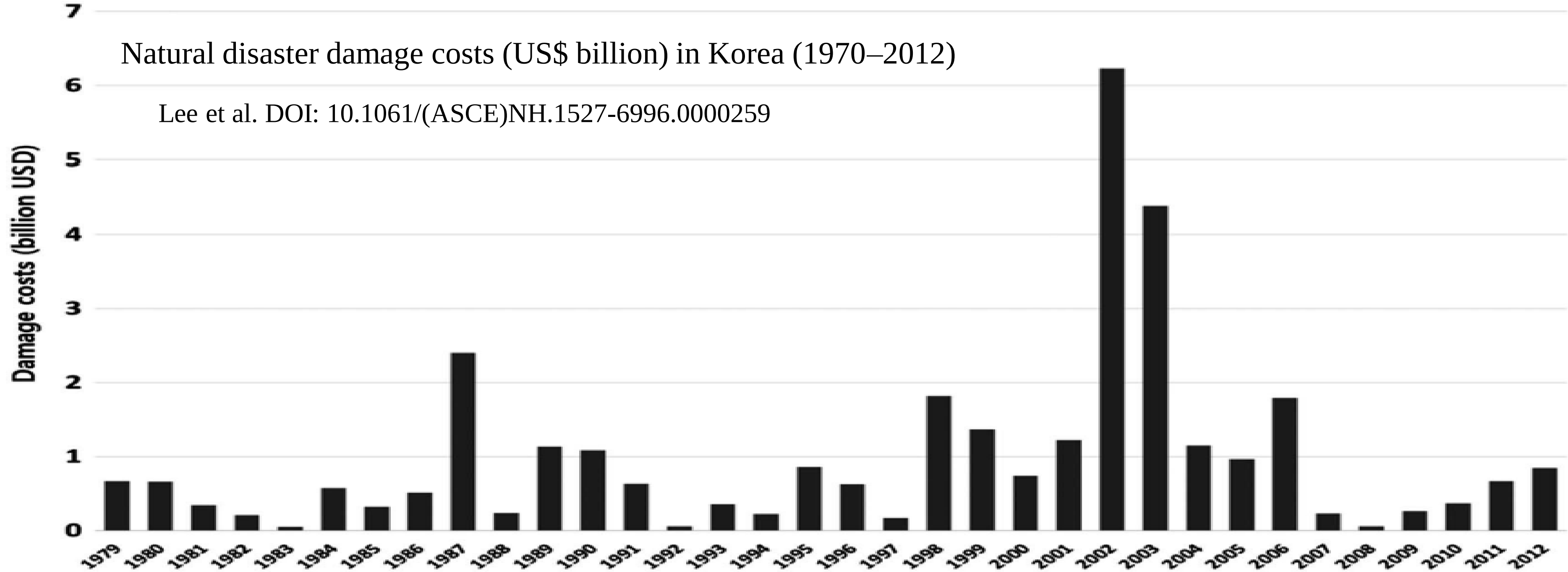


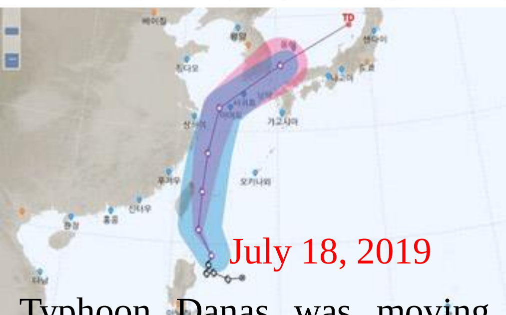
Estimated property damage by natural disasters, 2002–2013.

Year	Typhoon	Rainfall	Snow	Storm	Wind and wave	Total
2002	5,185,728	929,564	0	0	0	6,117,294
2003	4,233,391	174,859	0	0	0	4,410,253
2004	341,561	214,977	673,897	0	0	1,232,439
2005	138,503	352,038	549,992	9304	0	1,051,842
2006	11,804	1,906,277	5175	14,039	5687	1,944,988
2007	160,869	43,492	7441	6879	33,128	253,816
2008	857	58,089	3,640,801	1115	0	3,702,870
2009	0	254,904	12,778	7035	24,089	300,815
2010	172,506	180,762	66,302	174	7036	428,790
2011	218,314	527,611	47,976	0	298	796,210
2012	1,003,715	38,430	20,351	932	0	1,065,440
2013	1689	158,128	11,342	932	44	174,148

Note: Unit = million KRW (about 900 U S. dollars as of 2015).
Source: NEMA (2013), Disaster Yearbook, p.581.

Lee et al. DOI: 10.1061/(ASCE)NH.1527-6996.0000259





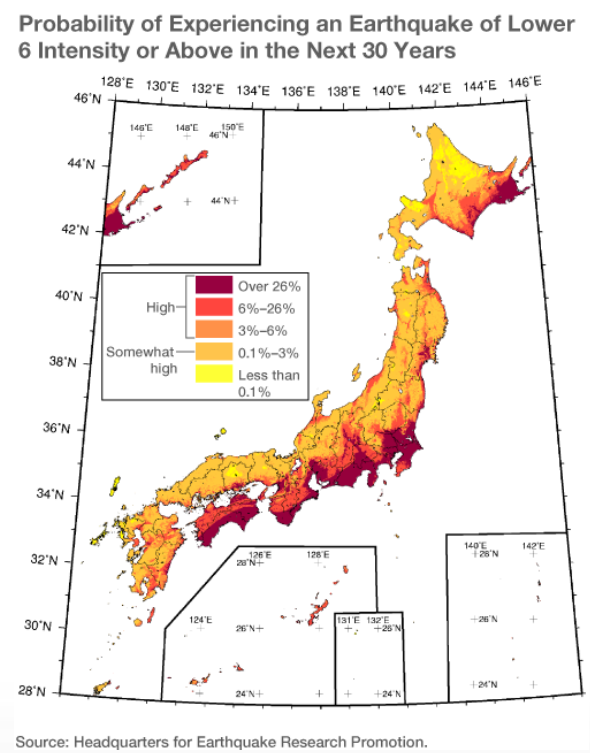
Typhoon Danas was moving north from waters 570 km northeast of Manila at a speed of 15 km/h as of 3 p.m. on Wednesday. It is a relatively small typhoon with a maximum speed of 18 m/s and central pressure of 996 hPa.

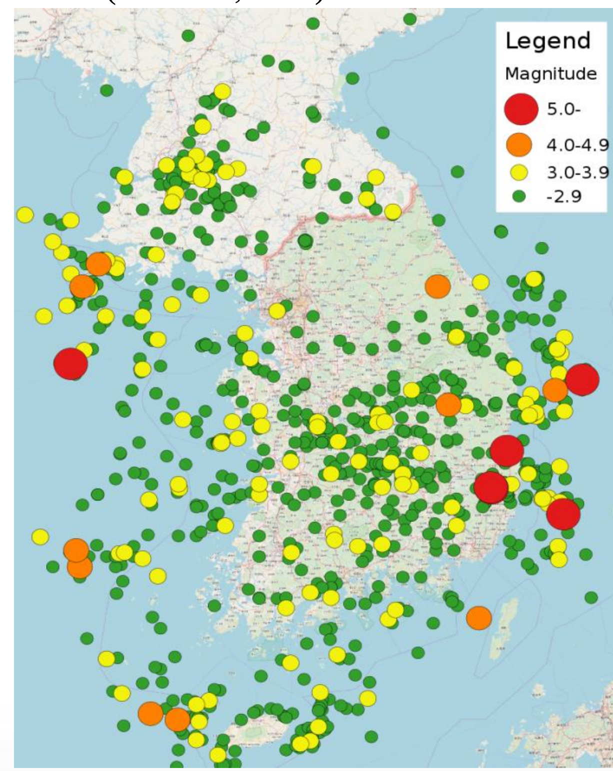
The fires were believed to have been started by sparks from an electric transformer that was shaken by strong winds on Thursday, according to officials at the National Fire Agency.

Disaster Type	Number of Disasters per Year	Total Deaths	Deaths per Year
Flood	10.85	17,800	445.0
Storm	9.65	184,063	4,601.6
Epidemic	2.28	7,294	182.4
Landslide	2.05	5,058	126.5
Forest Fire	0.45	310	7.8
Drought	0.98	1,337	33.4
Tsunami	0.15	92,021	2,300.5
Volcano	1.33	1,380	34.5
Earthquake	2.58	105,735	2,643.4

Disaster risk statistics during 1970-2009 in ASEAN (UNISDR, 2010)

The population of ASEAN and each of its member countries using 2012 World Bank data. (ASEANup 2014)

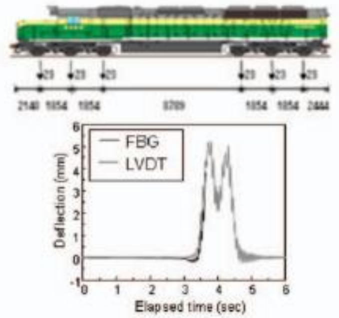




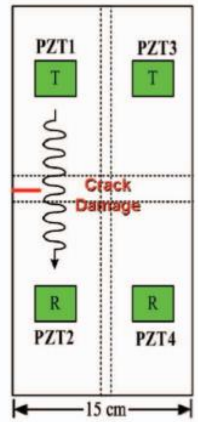
Earthquake map in South Korea 2000–2017

Extensive smart structures and disaster mitigation in South Korea

Recent research and development and application activities on Optical fibre sensors (OFSs) in Korea have been concentrated at, but not limited to, the following areas: (1) Development of data interrogation system for fibre Bragg grating (FBG) sensors using wavelength division multiplexing and code division multiple access methods; (2)Compact FBG sensor assemblies for various gauge lengths; (3)Damage localisation techniques using strain mode shapes and modal flexibility; (4) Retrofit of concrete structures using carbon fibre sheets with embedded FBG sensors;

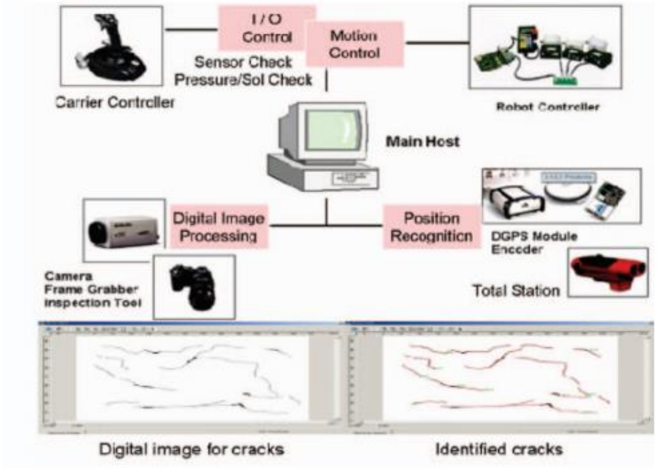


In addition, Piezoelectric (PZT) sensors are developed and utilized, here are some of the important examples related research and activities: (1)Smart active layers, consisting of PZT arrays, for monitoring defects on industrial facilities, steel and concrete structures; (2) Impedance-based damage detection on steel members; (3) Guided wave-based crack monitoring on critical steel structural components; (4)PZT-based crack detection on concrete structures.

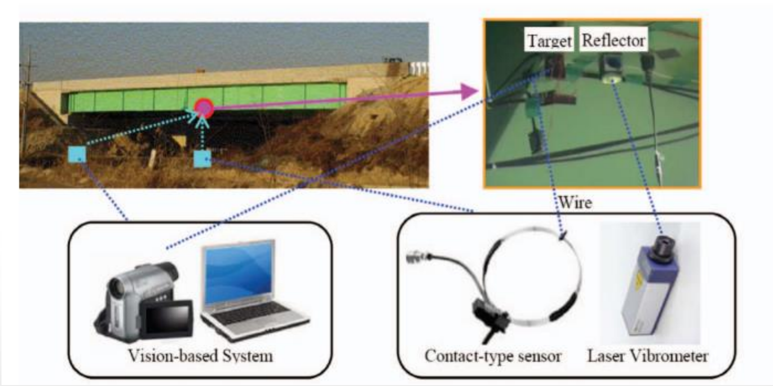


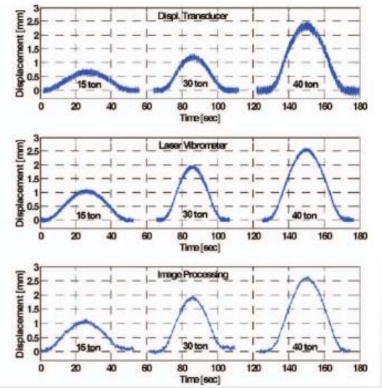
Wireless sensor systems have been developed to reduce the costs for installation and maintenance of the sensor cables. Korea Maintenance and Control (KMC) Cooperation developed a wireless data logger, which can transfer data from the conventional sensor via wireless communications. The maximum tractable distance is 120 m with standard antenna, and 1.0 km with patch antenna. Field verification for wireless data transmission was made on several bridges. Test results showed good agreement with the conventional cable-based sensor system. Various types of wireless data loggers developed by KMC Co. are now available on the market (www. kmctech.co.kr).

Digital image processing techniques have been studied for detecting and analysing cracks in the surface of concrete. Recently, a bridge inspection system for concrete slabs was developed using robot and digital image processing system by the KHC. The system consists of three parts: (1) a digital camera with a differential global positioning system (DGPS); (2) a remote controlled robot system with camera and boom; and (3) data processing, database management and crack identification system.



Recently, some promising advances have been made for displacement sensing including global positioning systems (GPS), laser Doppler vibrometers and vision-based systems. Lee and Shinozuka (2006) developed a real-time displacement measurement system using digital image processing techniques; this system can be deployed for accurately measuring structural displacements. A commercial video camera can take a motion picture of the target with known geometry that is to be placed at the measurement point. The system is cost-effective and easy to use, yet uniquely capable of measuring dynamic displacement with a high level of resolution. The camera-based displacement measurement system has been applied to estimate load carrying capacity of a steel girder bridge (Lee et al. 2007).



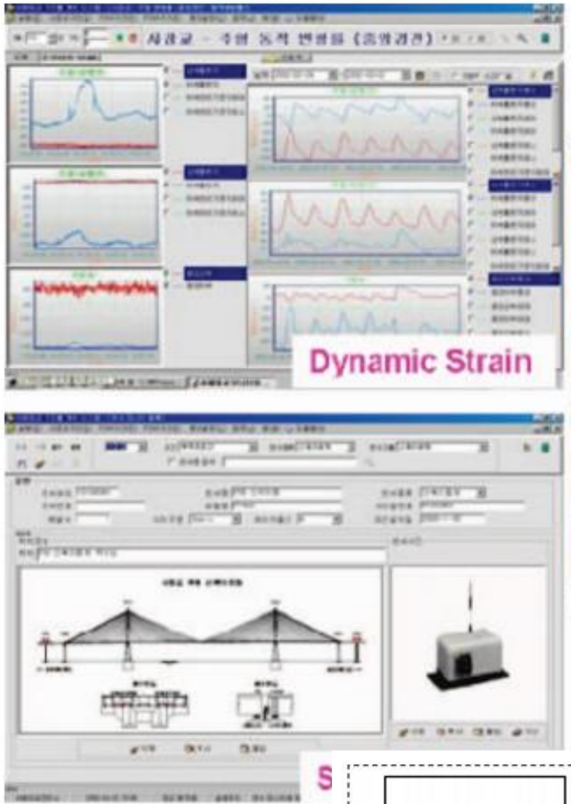


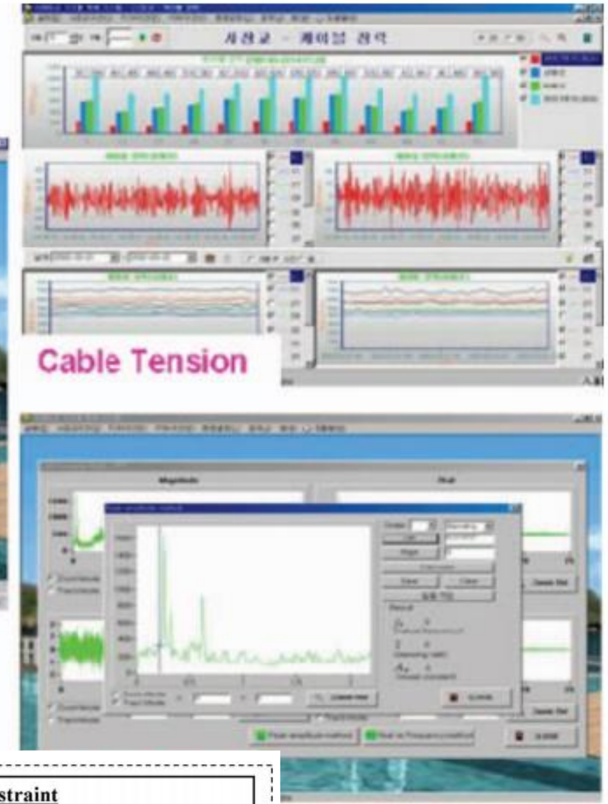
Bridge monitoring systems are in operation on most of the major bridges, especially on long-span bridges in Korea. The purposes of these systems are to monitor the structural integrity, based on the measured data, such as cable tension, tilting of main towers, vibration of girders and local strains, and to construct the database on the bridge responses and the characteristics under various loading conditions, such as traffic, wind, earthquakes and temperature. Data collected at each bridge are processed exclusively at each field station for real-time monitoring and alarming sudden abnormal behavior of the bridge.

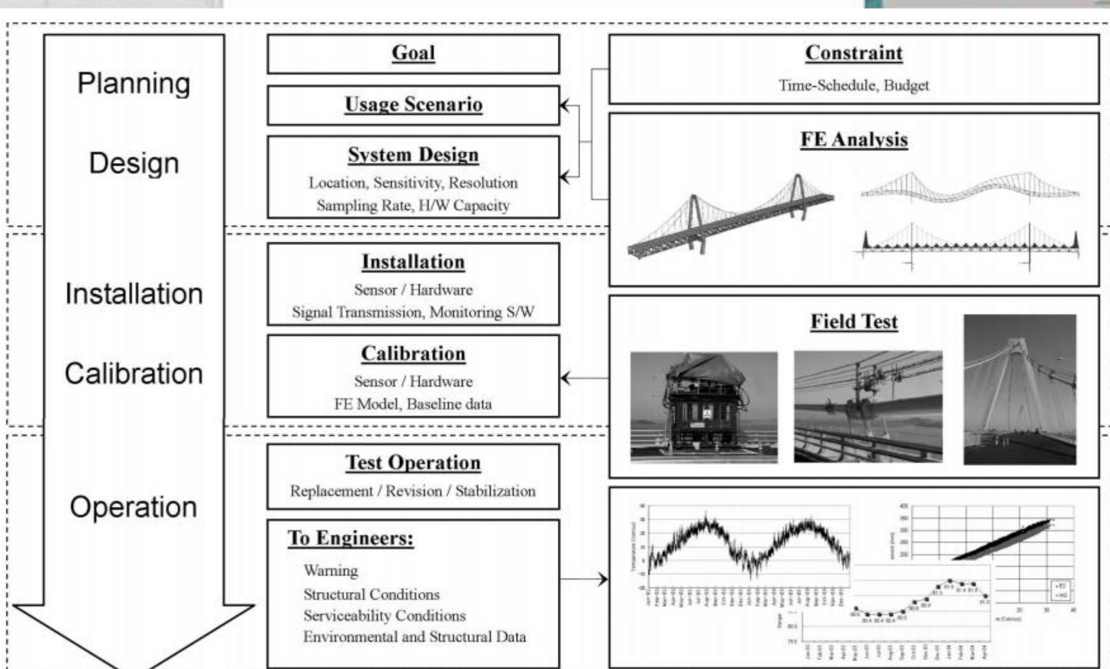
Once data are collected at the centre, the integrated bridge management software handles them to classify, store and retrieve. This integrated bridge management system itemizes bridge maintenance details; not only the physical information but also the knowledge, such as detailed rating category for all members. In addition, based on the inspection results, it manages status assessment, rating, repair and retrofitting activities. Current researches are focusing on implementing decision algorithms for repair and retrofitting methods, priority and budgeting, as well as improvement of the hardware performance of the health monitoring system.

Korea Infrastructure Safety & Technology Corporation (KISTEC) developed safety-warning systems for infrastructures especially of small to mid-size, which are vulnerable to disaster (Lee et al. 2005). Each system is composed of two parts, which are the monitoring system at the site and the integrated software at the control centre. According to the target structure for monitoring, proper sensors and data loggers are chosen and installed. Wireless models and solar cells are used for data transmission and the power supply, respectively. Transmitted data are collected and analyzed at the server in the control centre.

Monitoring windows for Seohae Bridge.

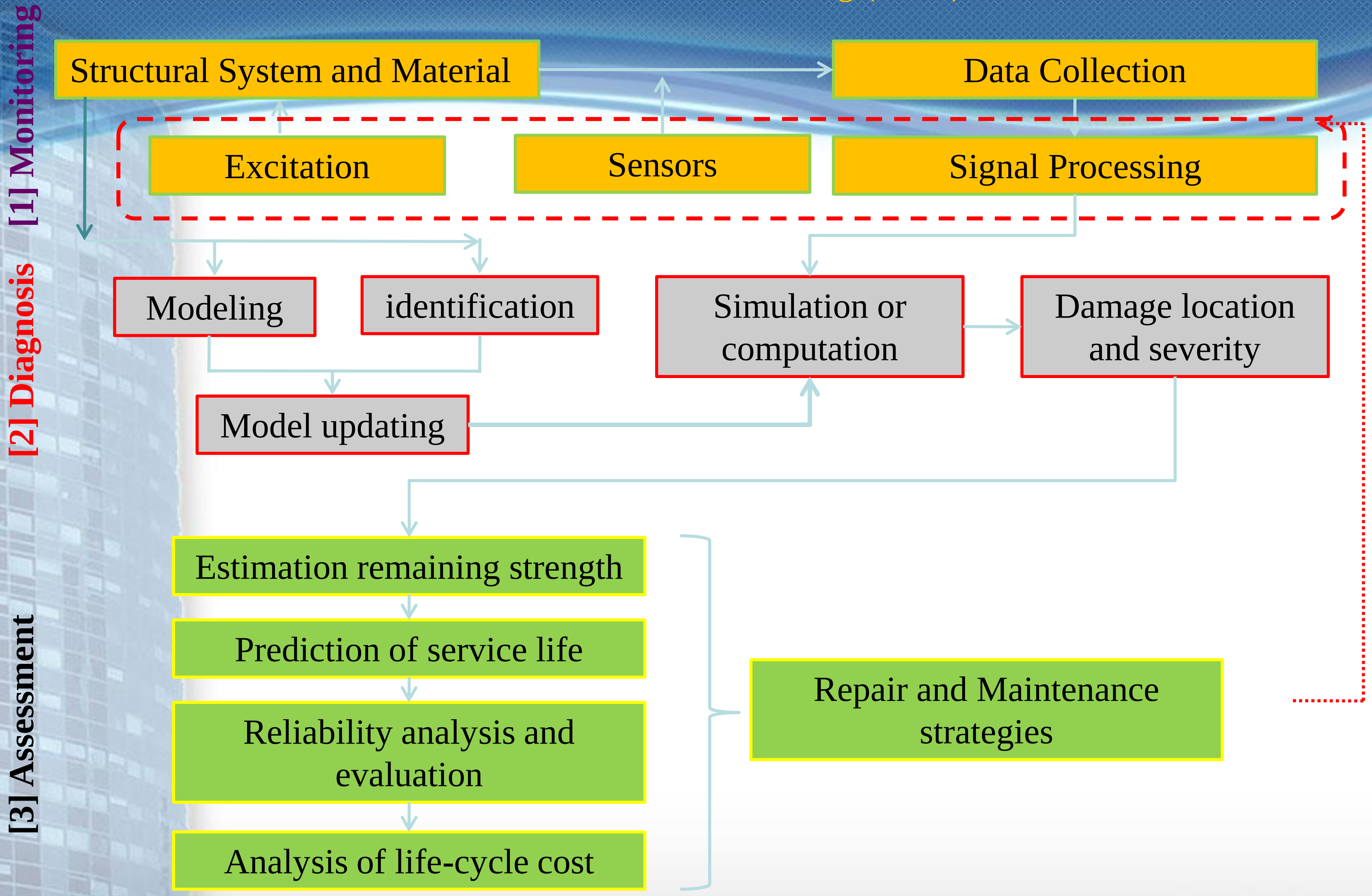


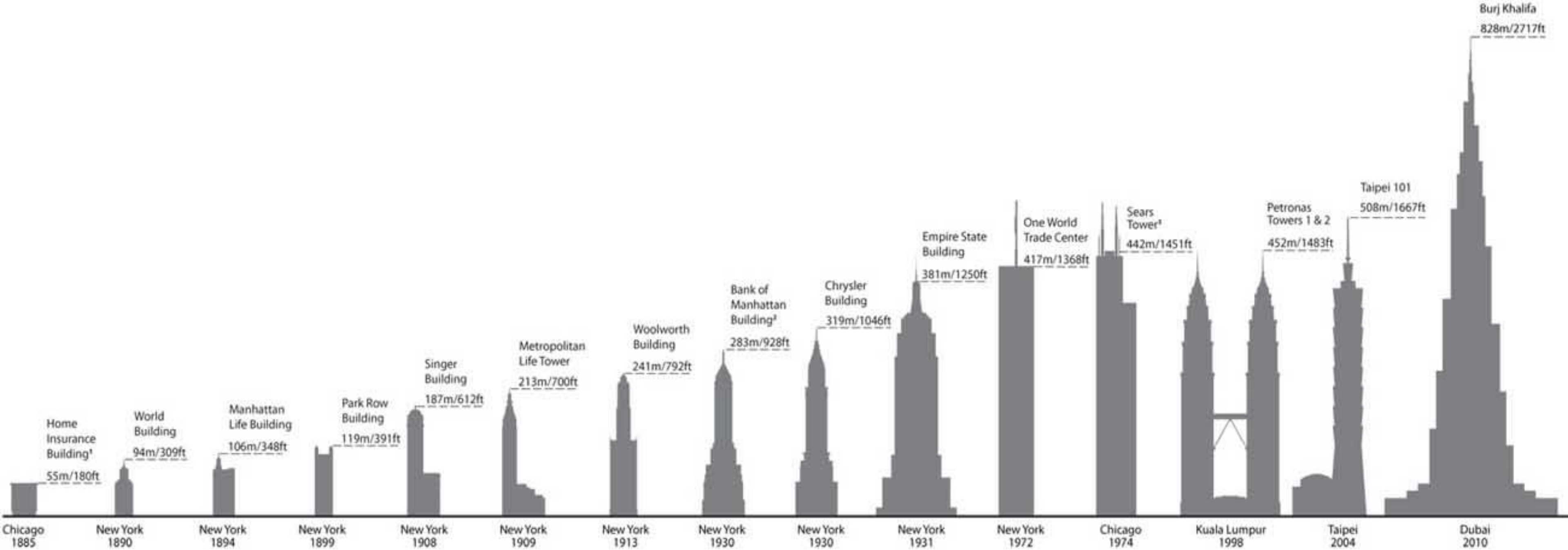




Development strategy of the monitoring system of Yeongjong Bridge

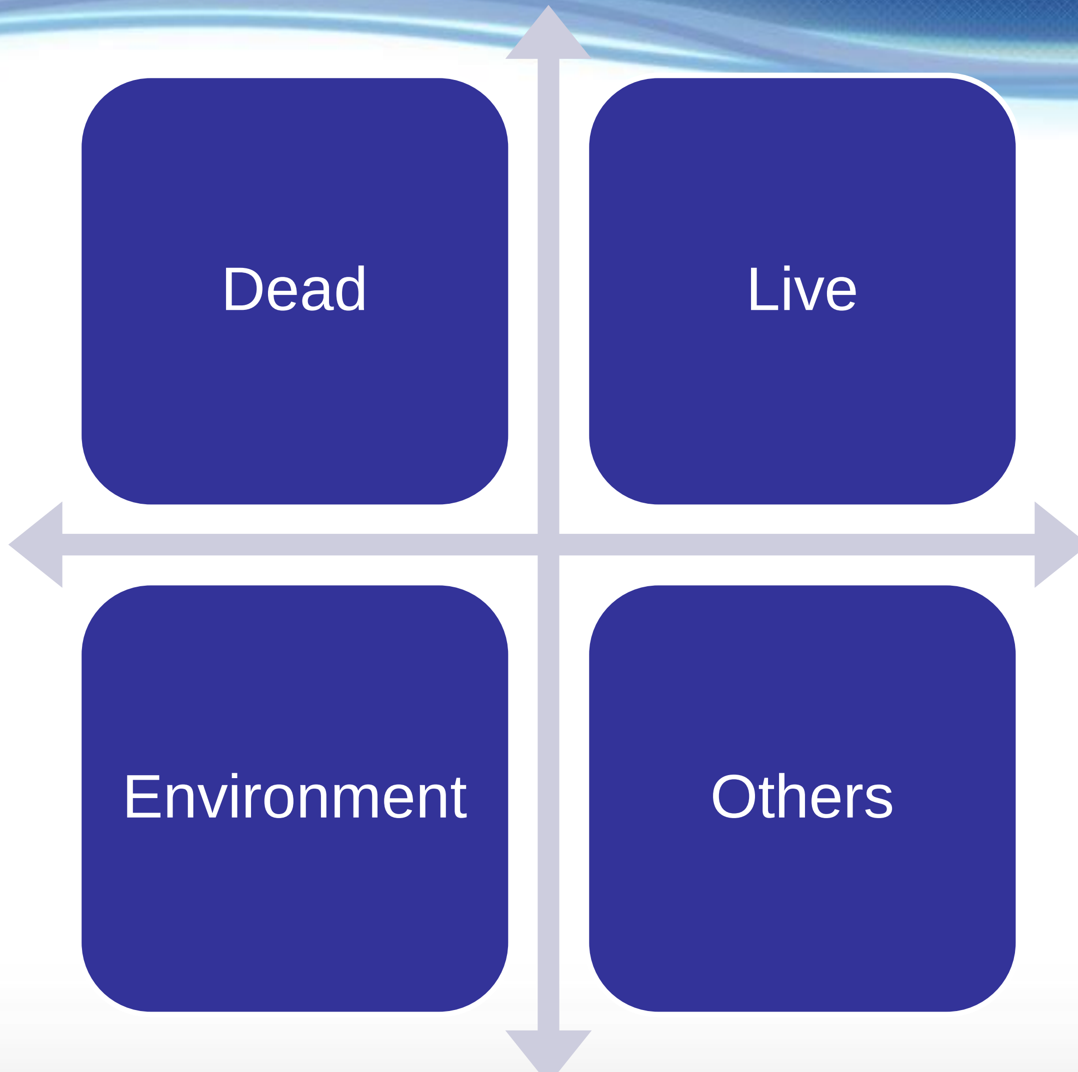
Structural Health Monitoring (SHM)



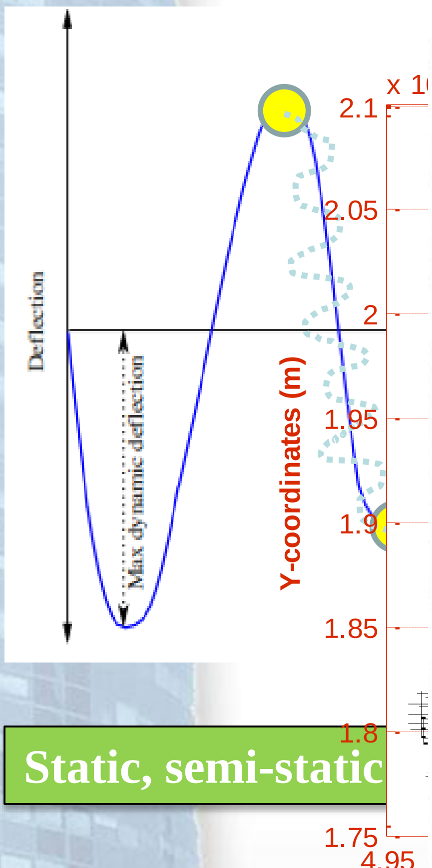


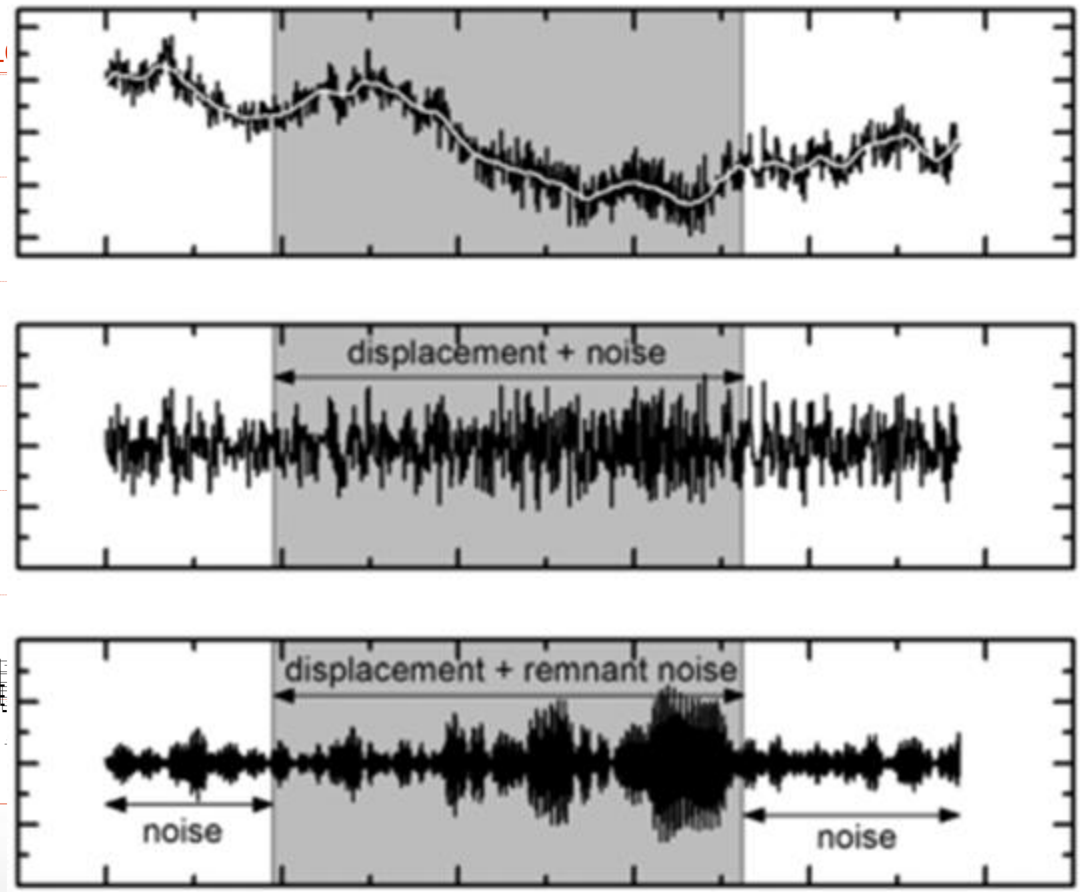
Home Insurance Building[1]
55m/180ft
Chicago 1885
World Building
94m/309ft
New York 1890
Manhattan Life Building
106m/348ft
New York 1894
Park Row Building
119m/391ft
New York 1899
Singer Building
187m/612ft
New York 1908
Metropolitan Life Tower
213m/700ft
New York 1909
Woolworth Building
241m/792ft
New York 1913
Bank of Manhattan Building[2]
283m/928ft
New York 1930
Chrysler Building
319m/1046ft
New York 1930
Empire State Building
381m/1250ft
New York 1931
One World Trade Center
417m/1368ft
New York 1972
Sears Tower[3]
442m/1451ft
Chicago 1974
Petronas Towers 1 & 2
452m/1483ft
Kuala Lumpur 1998
Taipei 101
508m/1667ft
Taipei 2004
Burj Khalifa
828m/2717ft
Dubai 2010

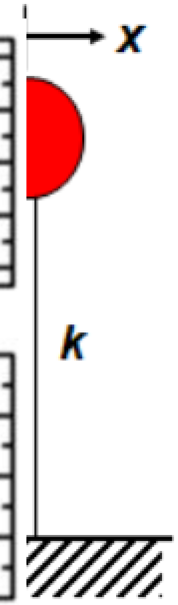
Loads effects and structures performances



Static and Dynamic deflection





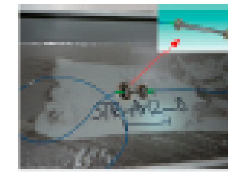
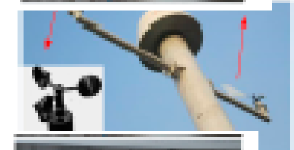
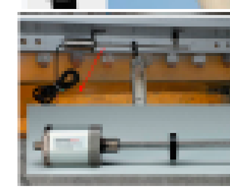


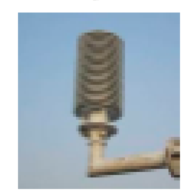
Static, semi-static

Structural Health Monitoring Sensors

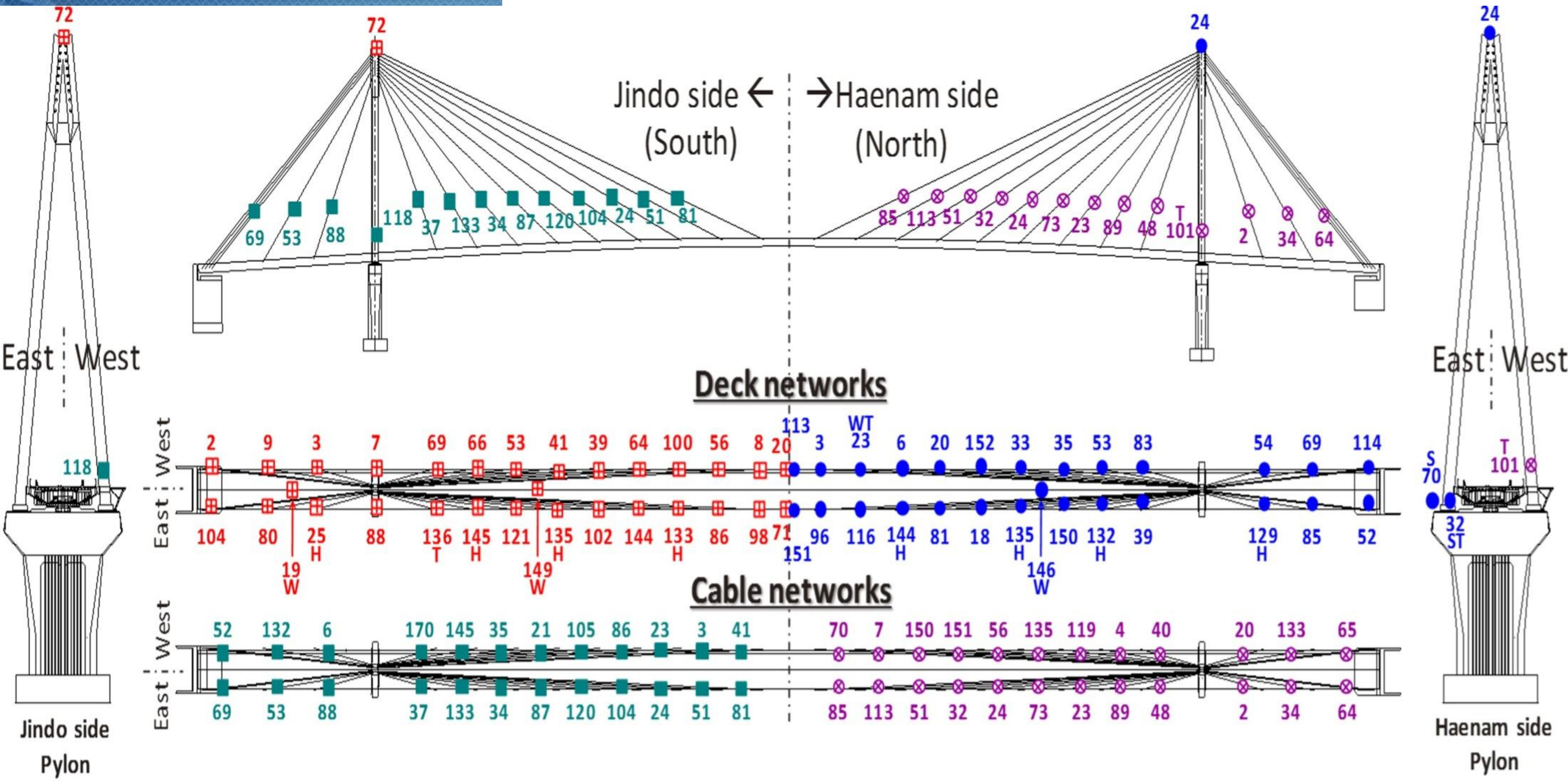
		Weigh-in-motion (WIM)
Global Response	Vibration	Accelerometer
	Displacement	Pressure transmitter sensor/GPS
	Strain	Optical fiber Bragg grating (FPG) strain sensors
Loads and Environmental actions		Mechanical anemometer
Local Response	Bearing displacement	Magnetostrictive displacement sensors
	Hanger rod/Cable force	Fiber brag grating test-force rings
	Temperature and humidity	Temperature and humidity sensor



Jindo Bridge wireless smart sensor (113 sensors)



⊞ : Jindo Deck network (single hop)

■ : Jindo Cable network (multi hop)

● : Haenam Deck network (single hop)

⊗ : Haenam Cable network (single hop)

W : Anemometer (SHM-DAQ)

T : Temperature

WT : Wind Turbine power

H : High-sensitivity (SHM-H)

S : Strain sensor (SHM-S1)

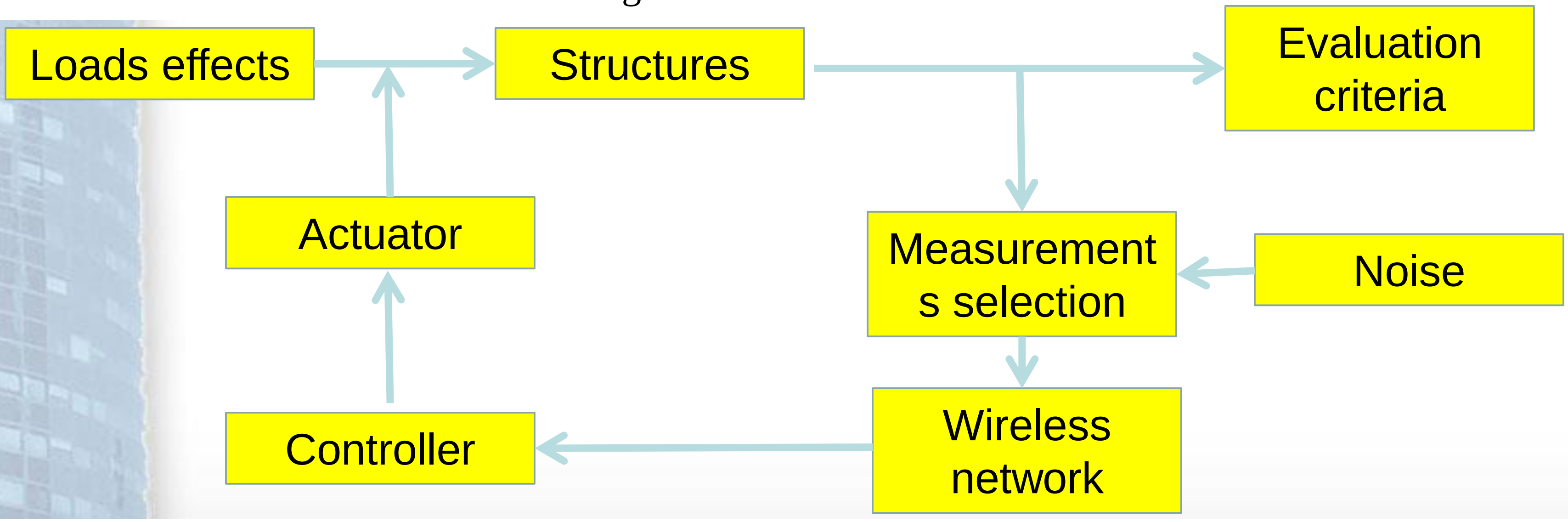
ST : Strain + Temp correction (SHM-S2)

Benchmark of SHM

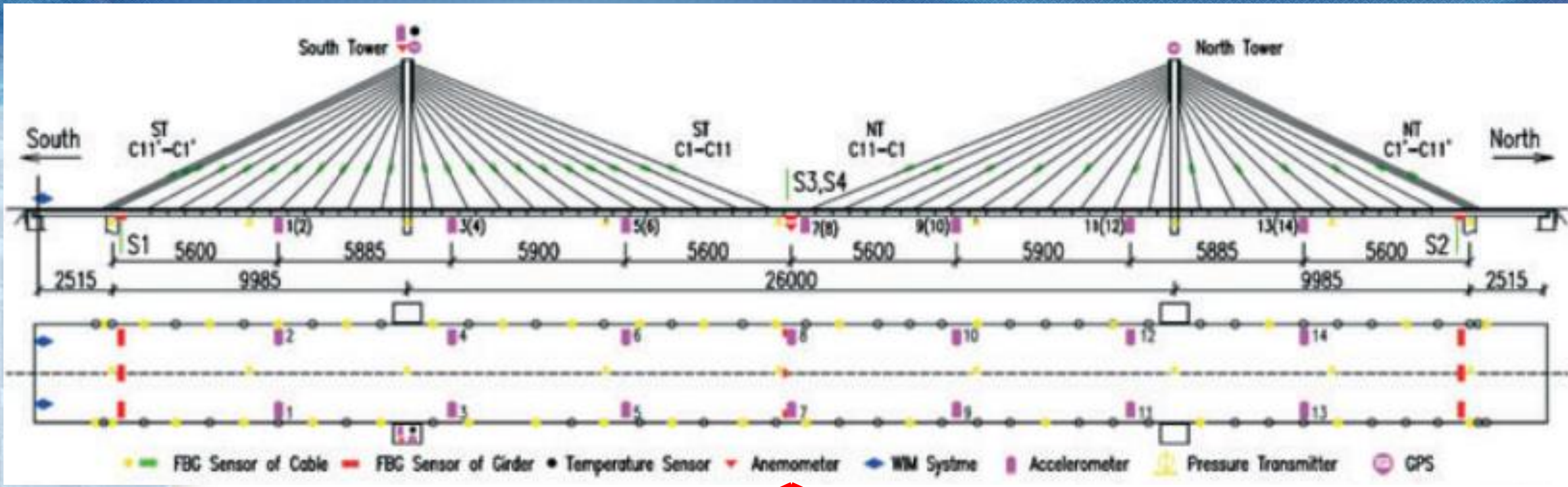
Relative measurements of sensors

In evaluation stage

SHM system provides an efficient way to diagnose the condition of critical and largescale structures such as long-span bridges and tall buildings. With the development of SHM techniques, numerous condition assessment and damage diagnosis methods have been developed to monitor the evolution of deterioration and long-term structural performance of such structures, as well as to conduct rapid damage and post-disaster assessments. However, the condition assessment and the damage detection methods described in the literature are usually validated by numerical simulation and/or laboratory testing of small-scale structures with assumed deterioration models and artificial damage, which makes the comparison of different methods invalid and unconvincing to a certain extent.



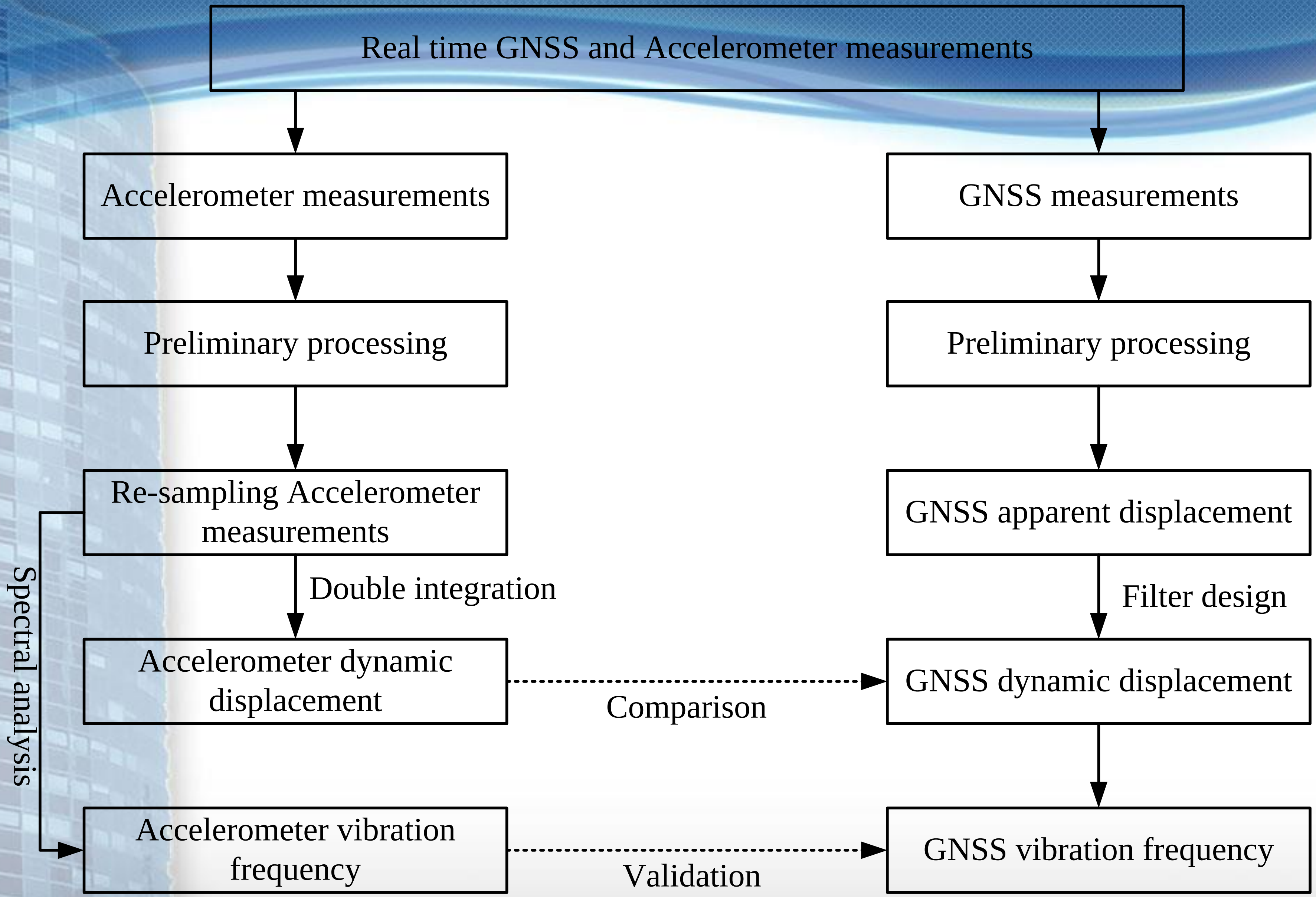
Updating models throughout SHM data

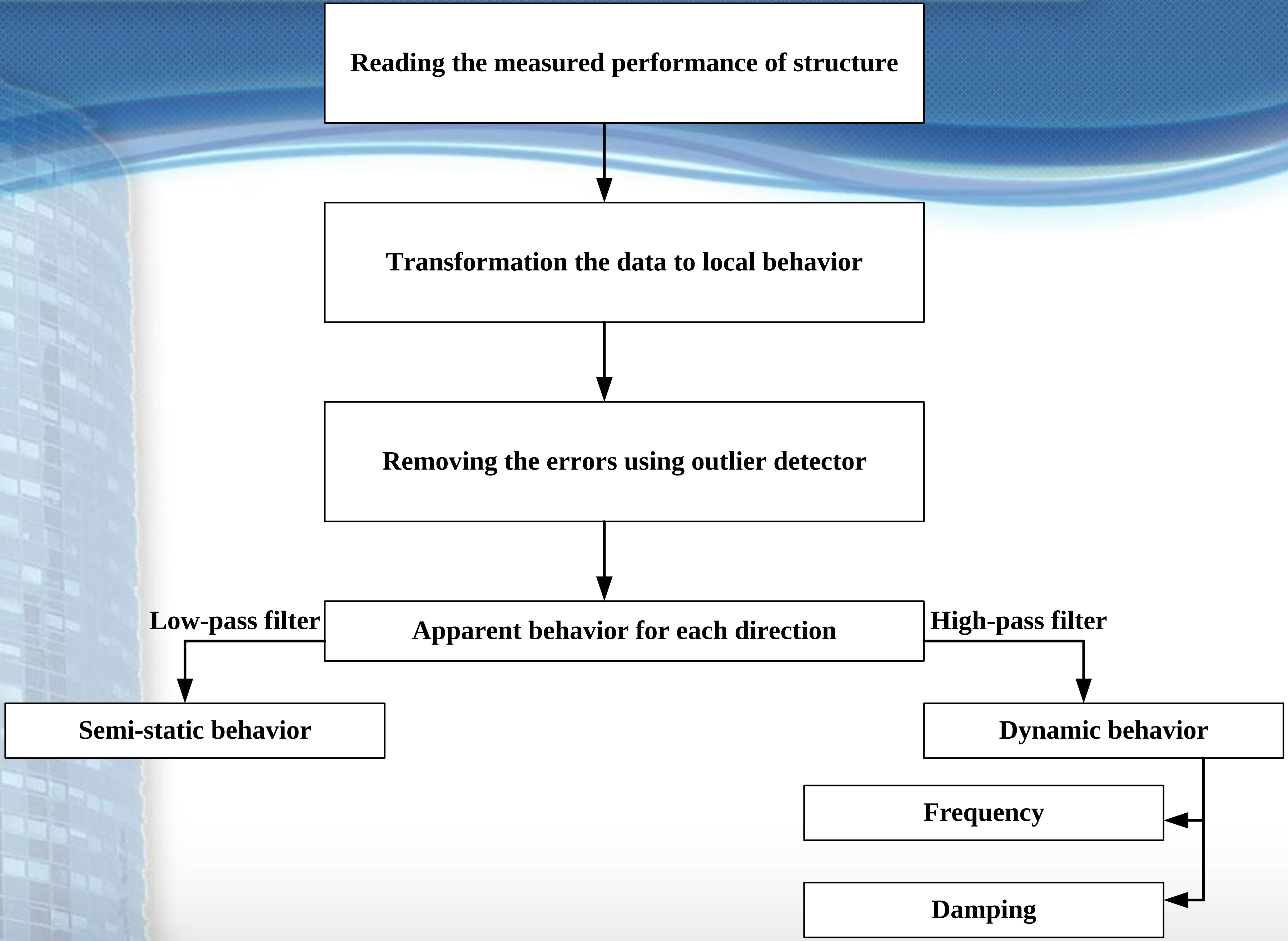


benchmark problem 1: condition assessment of stay cables

benchmark problem 2: damage detection of bridge girders

Evaluation tools




Reading the measured performance of structure
Transformation the data to local behavior
Removing the errors using outlier detector
Apparent behavior for each direction
Low-pass filter
High-pass filter
Semi-static behavior
Dynamic behavior
Frequency
Damping

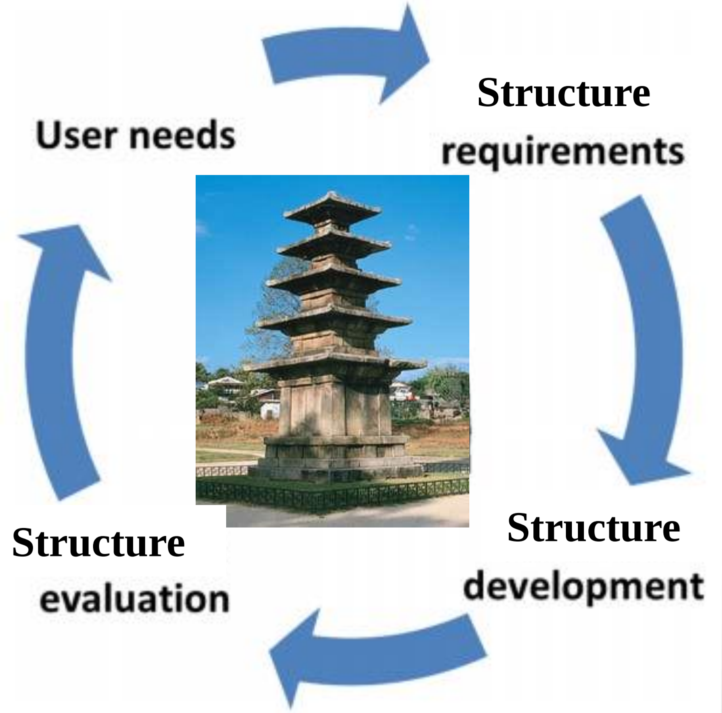
Settlement study: The increasing demand for underground infrastructure should be supported by innovation in monitoring and damage assessment solutions to minimize damage to surface structures caused by ground settlements. Most previous studies evaluated the structures behaviors under settlements using simplifying assumptions; they neglect the influence of the soil–structure interaction on ground and building deformations and they tend to produce over-conservative results.

Multi-hazard including settlement effect was not considered in the research challenges in structural health monitoring and control systems. At the core of these future research activities will require transformative advancements in sensors and sensing systems. The mimicking of biological systems to enhance the performance of sensors and civil infrastructure systems must be a part of any future research agenda in these areas.

Integrated sensors: The findings from the mixed-methods systematic review showed that accelerometer data can be used to detect the acceleration which used to detect the dynamic behavior; other sensors are same that used to evaluate one direction for structures behavior.

Benchmark solution is still limited in the evaluation, sensors measurements and in the updating structures models, this needs more specific solutions in real and experimental works.

Evaluation tools in time and frequency domains, as well as in the filtering tools.



Thanks for your attention

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