An overview of Structural Health Monitoring Systems

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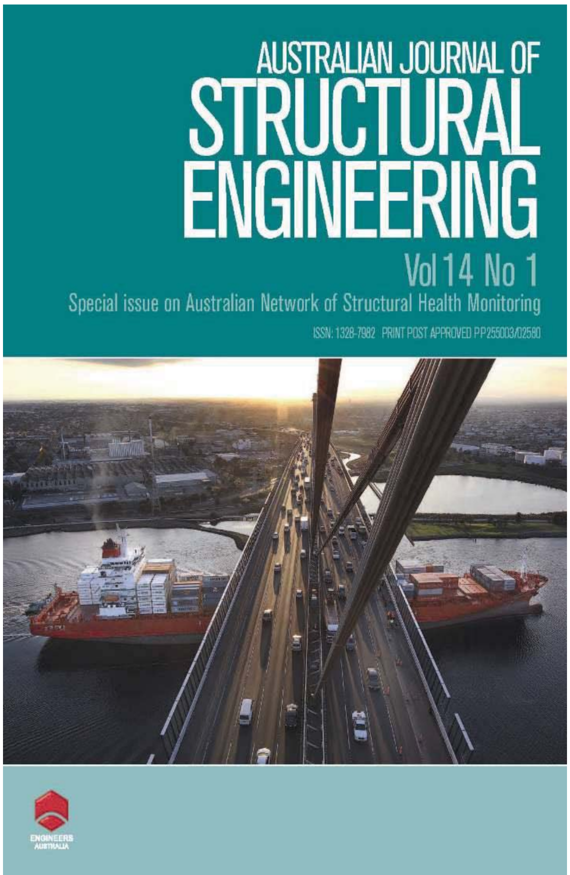
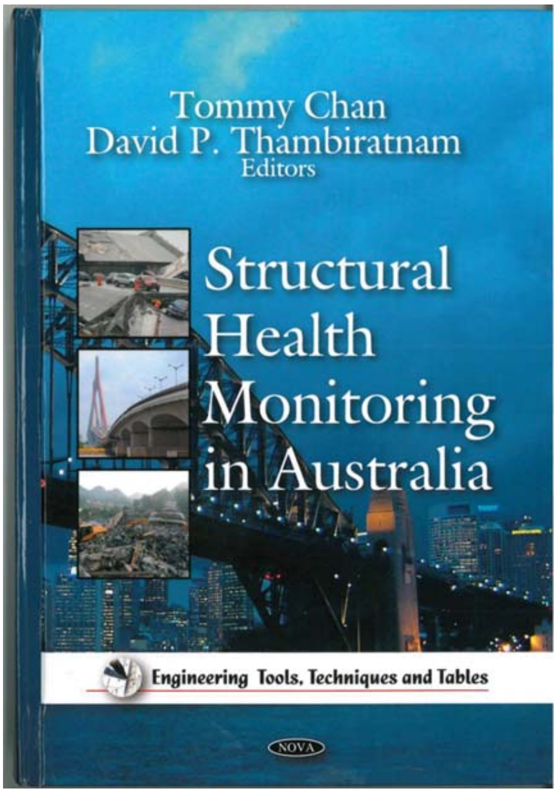


ANSHM

Outlines

- Definition of SHM
- Cost Benefits of SHM
- Examples of SHM Systems
- Hong Kong Example
- SHM Research and Development (at QUT)
- Summary of SHM A & A
- ANSHM (www.ANSHM.org.au)

Definition of Structural Health Monitoring



Definition of SHM

"the use of on-structure sensing system to monitor the performance of the structure and evaluate its health state"
(Chan & Thambiratnam, SHM in Australia)

"Structural Health Monitoring (SHM) involves the use of various sensing devices and ancillary systems to monitor the insitu behaviour of a structure to assess the performance of the structure and evaluate its condition."
(AS5100 Part 7 2017 March)

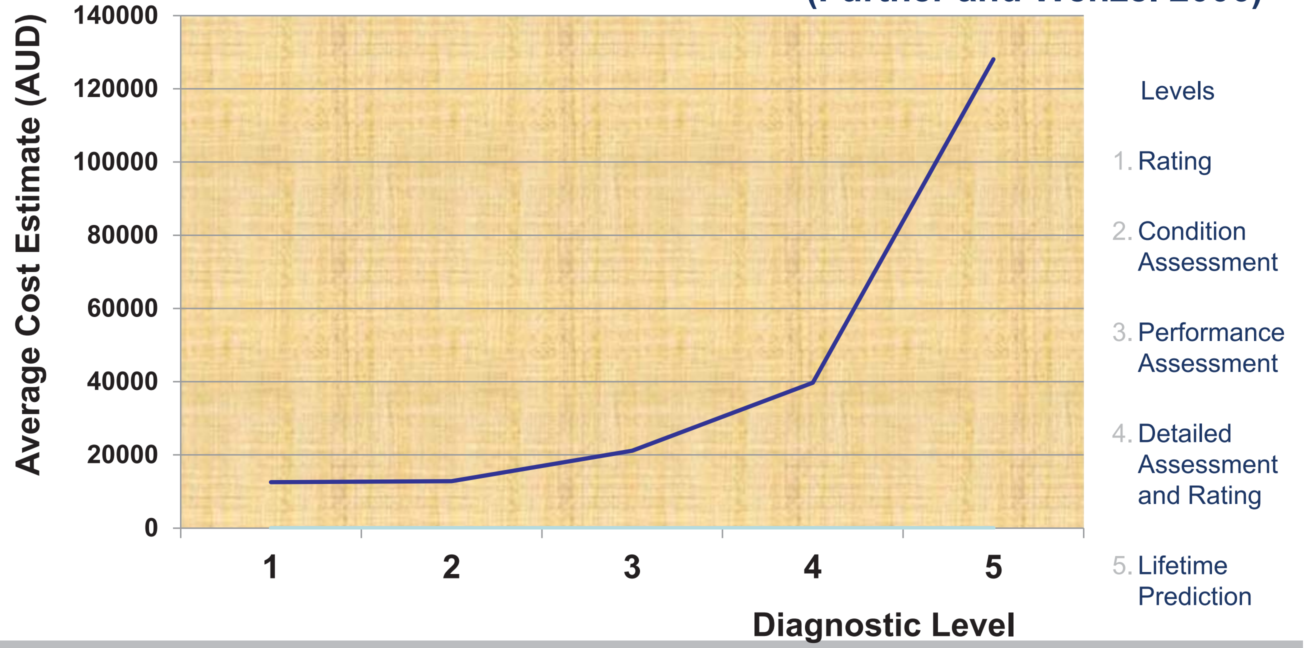
https://www.novapublishers.com/catalog/product_info.php?products_id=15996

Cost Benefits of SHM

Defining Costs for SHM

- Immediate Costs/capital investments
  - SHM design costs
  - Hardware costs
  - Installation costs
  - Costs for installation reporting, as-built documentation, system manuals
- Operational costs:
  - System maintenance, spare parts, consumables, energy, communication costs
  - Data management costs
  - Data analysis, interpretation and reporting costs

Cost Estimation of monitoring campaigns for a typical 3-span bridge (Furtner and Wenzel 2006)



Benefits – by Daniele Inaudi 2011

- Hard Benefits
  - benefits that can be economically quantified
    - immediate / deferred cost savings
    - increased value
    - etc
- Soft Benefits
  - benefits that the owner of a SHM system perceives and for which he/she is ready to pay a price, but that cannot be directly quantified
- Some are a mix of Hard and Soft Benefits

Increase in Capital Value (Hard Benefit)

More Efficient Use of Maintenance Budgets (Hard Benefit)

Increased availability of service to road users (Soft Benefit)

Reduction of Risk and Uncertainty & Increase of Safety and Quality (Hard/Soft Benefit)

Reduction of Risk and Uncertainty & Increase of Safety and Quality - Examples

- Safely extend the lifetime of aging bridges

Reduction of Risk and Uncertainty & Increase of Safety and Quality - Examples

- Early Detection of Construction Defects during construction (better quality assurance) or within the warranty period

Reduction of Risk and Uncertainty & Increase of Safety and Quality – Examples (cont'd)

- Taking measurements even during construction
- Well aware of structural behaviour during initial years of a structure
- Reduce uncertainties include real state of materials, real loads, actual ageing behaviour

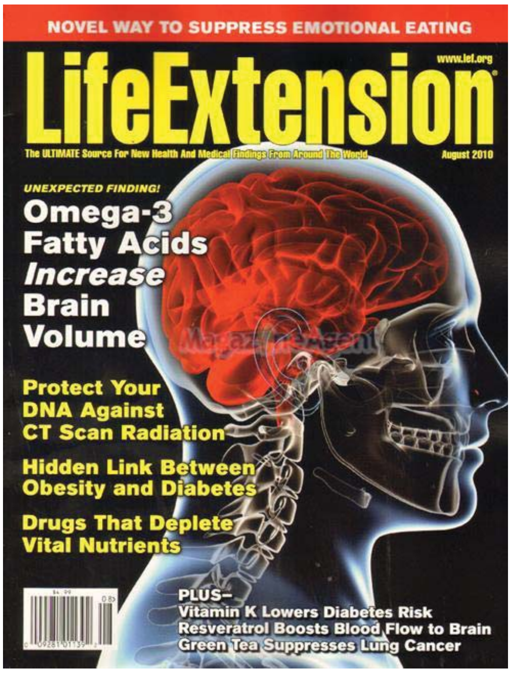
Reduction of Risk and Uncertainty & Increase of Safety and Quality – Examples (cont'd)

- Reduced incidence of damage
- Detect damage that cannot be identified by visual inspection
- Minimise human errors in inspection
- Perform "Maintenance on Demand" – Real Life Cycle Cost Management of Structures

Reduction of Risk and Uncertainty & Increase of Safety and Quality – Examples (cont'd)

- Detect damage that cannot be identified by visual inspection
- Minimise human errors in inspection
- Perform "Maintenance on Demand" – Real Life Cycle Cost Management of Structures

Extension of Lifetime (Hard Benefit)



"Experience has shown that basing condition assessment on visual inspection alone leads to an underestimation of a bridge's condition in a vast majority of cases.

This practice may be considered acceptable from a safety perspective, but is vastly inefficient from an economic perspective."

- Daniele Inaudi, 2011

Extension of Lifetime – Simple Calculation

- Assuming the costs for replacing bridges to be 100%
  - Installation Cost of SHM: 3%
  - Replacement of bridges that cannot be saved: 60%
  - Repair of bridges that can be rehabilitated: 30% cost for 20% of bridges = 6%
  - Cost for Bridges that do not need any action: 0% for 20% of bridges = 0%
  - **Total cost: 69%**

SHM can provide at least a 30% reduction in the overall investments for the owner

Increase of Know-how and Knowledge (Soft Benefit)

- Leads to Cheaper, Safer and more Durable Structures
- Advance the State-of-the-Art for the development of better structures in future

Conformance to Standards and State-of-the-Art (Soft Benefit)

EUROCODES
BUILDING THE FUTURE

BSi British Standards

Australian STANDARD

- Some structures require monitoring and regular assessment by law
- Other fields require monitoring during construction
- More and more considered as "standard practice" in many countries

Image, Prestige and Public Perception (Soft Benefit)

The new I35W Bridge in Minneapolis is monitored with an extensive SHM system

Some SHM Systems in the world

- Skarnsundet Bridge in Norway

- Storck's Bridge in Winterthur, Switzerland

- Sutong Bridge in Mainland China

- Millau Viaduct Bridge in France

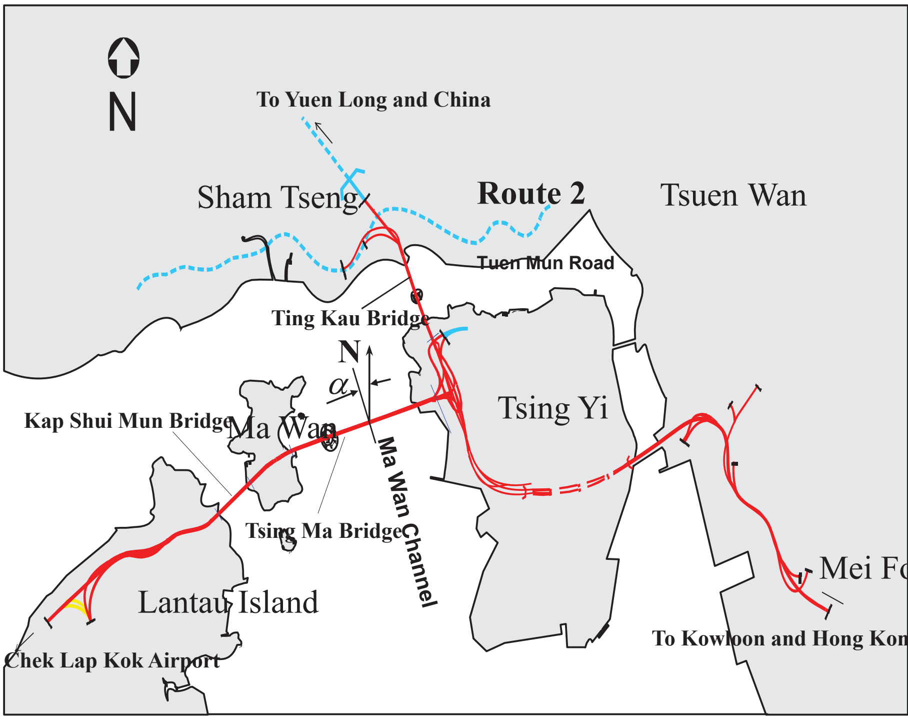
Hong Kong Example

WASHMS

WASHMS

- The Wind and Structural Health Monitoring System for
  - Tsing Ma Bridge
  - Kap Shui Mun Bridge
  - Ting Kau Bridge

Location plan of the 3 Bridges



Structural Health Monitoring

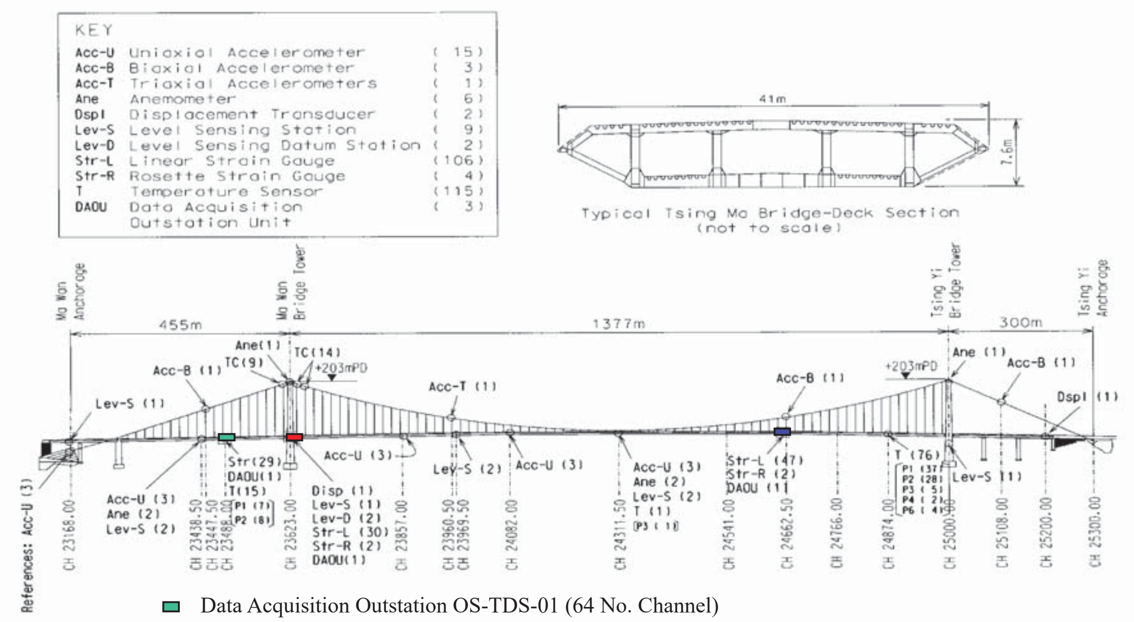
- Load Monitoring
  - Wind Loading
  - Seismic Loading
  - Temperature Loading
  - Highway Loading
  - Railway Loading

- Response Monitoring
  - ☐ Displacements
  - ☐ Stresses and Strains
  - ☐ Temperature
  - ☐ Cable Forces

Sensory System

- Anemometers
- Temperature Sensors
- Weigh-in-motion Sensors
- Accelerometers
- Strain Gauges
- Displacement Transducers
- Leveling Sensing Stations

Layout of Sensory System in TMB

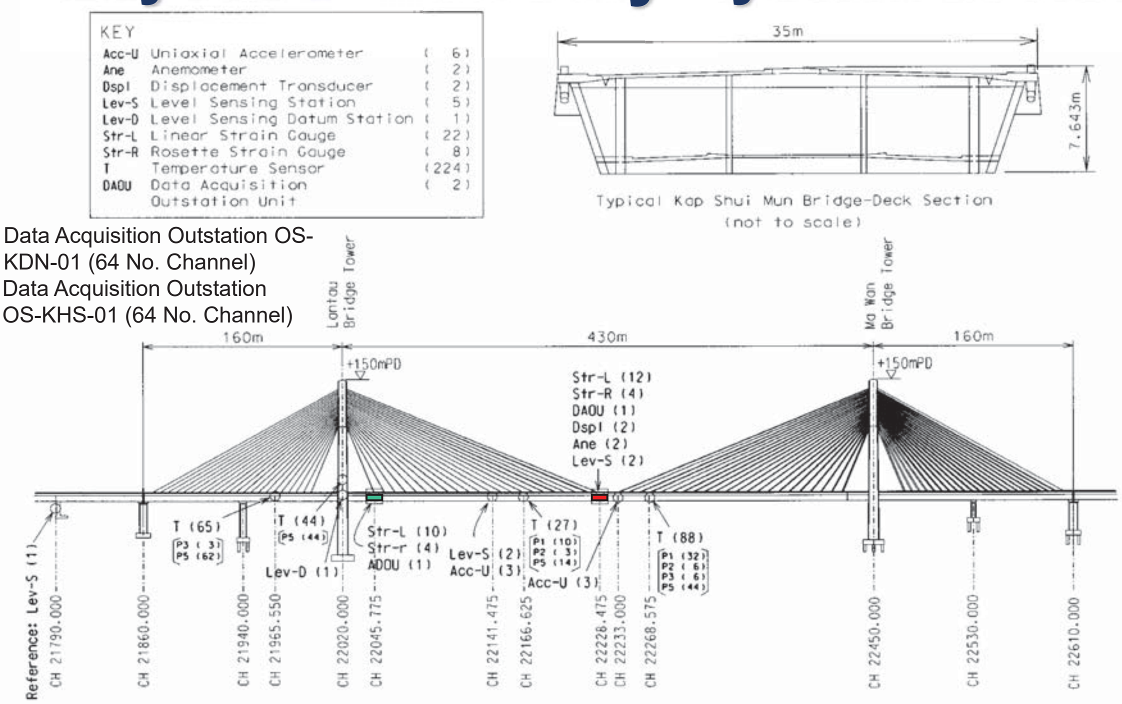


Data Acquisition Outstation OS-TDS-01 (64 No. Channel)

Data Acquisition Outstation OS-TEN-01 (64 No. Channel)

Data Acquisition Outstation OS-TLS-01 (128 No. Channel)

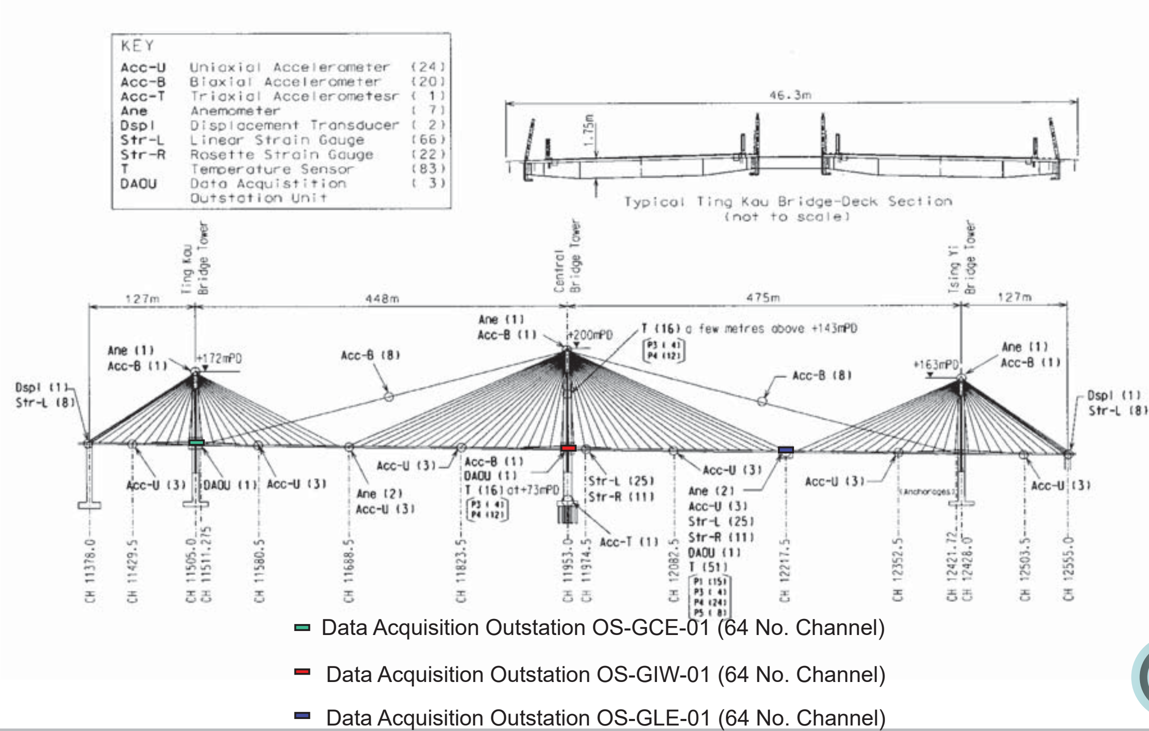
Layout of Sensory System in KSB



Data Acquisition Outstation OS-KDN-01 (64 No. Channel)

Data Acquisition Outstation OS-KHS-01 (64 No. Channel)

Layout of Sensory System in TKB



Anemometers

Temperature Sensors

Weigh-in-Motion Sensors

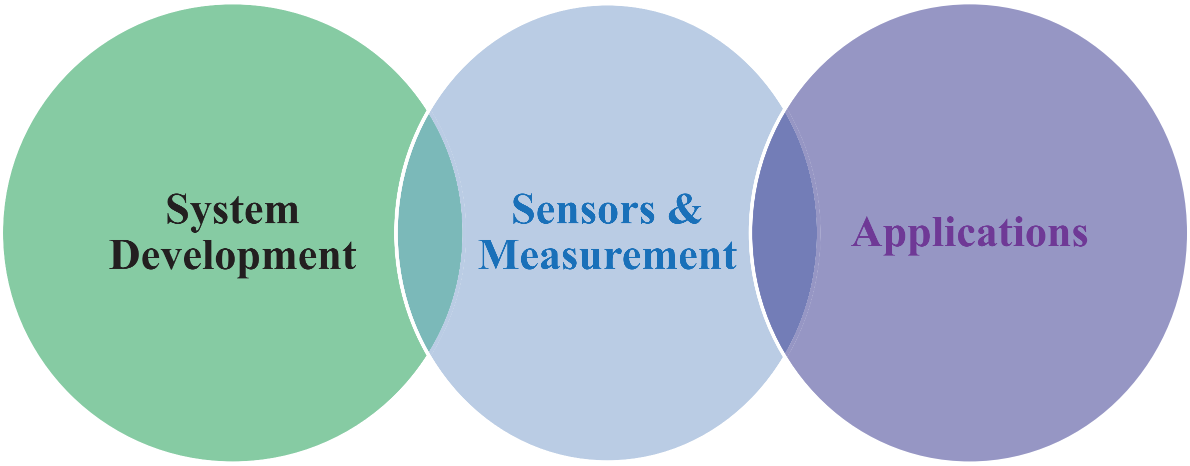
Displacement Transducers

Accelerometers

Strain Gauges

Leveling Sensing Stations

SHM Research and Development (at QUT)



Summary

Structural Health Monitoring Aims & Applications

Aims

- Ensure Safe Structures
- Obtain rational and economic maintenance planning
- Attain safe and economic operation
- Identify causes for unacceptable responses

Applications

- Design Verification
- Data for Future Design
- Maintenance Planning
- Safety Provisions
- Trouble Shooting
- Monitoring Systems

Australian Network of Structural Health Monitoring (ANSHM)

Australian Network of Structural Health Monitoring

- To promote and advance the Field of Structural Health Monitoring in Australia
  a) To coordinate and integrate efforts for better development and application of SHM techniques in Australia;
  b) To showcase achievements, exchange ideas and disseminate knowledge nationally and internationally;
  c) To promote and facilitate national and international collaborative research and development; and
  d) To raise general community awareness on the need for and value of SHM research and application

www.ANSHM.org.au

Thank you for your attention!

www.ANSHM.org.au

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Please refer to http://eprints.qut.edu.au/view/person/Chan,_Tommy.html

for research output

Contact your local university partner to find out how you can participate

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This initiative is supported by the Australian Network of Structural Health Monitoring (ANSHM).

ANSHM was established to promote and advance the field of SHM in Australia, and to:

- coordinate and integrate efforts for better development and application of SHM techniques in Australia
- showcase achievements, exchange ideas and disseminate knowledge nationally and internationally
- promote and facilitate national and international collaborative research and development
- raise general community awareness on the need for and value of SHM research and application.

ANSHM has members from 19 universities (including QUT), six government authorities, 11 private companies and three research organisations in Australia.

ANSHM members are working on a range of SHM-related research projects and have successfully completed many others. The network jointly holds 27 ARC Discovery projects, 23 ARC Linkage projects, 12 ARC Linkage Infrastructure-Equipment-Facilities projects, two ARC Industrial Transformation Training Centre projects, two ARC Discovery Early Career Research Award projects and two CRC/CSIRO projects.

Learn more at www.anshm.org.au

Universities and industry working together on structural health monitoring research and training

Australia's leading universities are seeking participation from industry partners to form an Australian Research Council Training Centre for Infrastructure Safety and Operations (ATCISO) to provide research and training for ongoing structural health monitoring of civil infrastructure.

Why it matters

Civil infrastructure such as buildings, bridges, dams and multi-purpose towers are built to last several decades. However, during their service lives progressive deterioration and sudden damage can occur due to changes in load patterns, environmental effects and random events such as impacts. For example, increases and changes in traffic loads can accelerate the deterioration of ageing bridges resulting in structural failure and causing economic loss and interruption to traffic.

All infrastructure has a limited lifespan which cannot be determined in advance due to uncertainties about structural condition and performance. Recent accidents have raised concerns about the lack of effective condition assessment of structures.

The retrofit and reconstruction of failed infrastructure involve large costs for infrastructure owners. It is reported that Australian bridges built decades ago are subject to an additional load of about 5.6% annually. The annual maintenance expense for 33,500 bridges in Australia is around $100 million and the replacement cost of faulty bridges could run to billions of dollars.

Top right: In 2018, the collapse of the FIU pedestrian bridge in Miami, USA a few days after it was installed killed six people and injured 10 others.

Bottom right: The 2007 collapse of the I-35 bridge in Minneapolis, USA killed 13 people and injured 145 others.