Reference Station Networks: Beyond Surveying.

Structure Health Monitoring

Managing the nation's bridge infrastructure

Advance technology for safety, productivity, and low costs

James Stowell
A (very) Brief History

• Company Formed Jan 1997
Mission: Provide System Integration Services for Geotechnical Engineering Market with Integrated Software

• “Multilogger” released Nov 1997
• “MultiloggerDB” released 2001
• “MLWeb” released 2006
What Are We Doing?

• Building Campbell/Data Based Systems
• Developing Hardware Peripherals (control box)
• Developing Integrated Software (GPS/TPS/IPS)
• Connect over 800+ instruments “simultaneously” and alarming
Customers

Software: MultiLogger licenses 750+ (customers)

Hardware: Managing 3000 MCU’s, (box Controller)

Top 100 hundred Engineering Companies World Wide
Who Are We Doing It For?

- Government – USACE/ USA
- Consulting Engineering Firms
- Engineering Companies/ URS/ ARCADIS
- Utilities - TVA/PG&E/etc.
- State DOTs
y = 5E-07x - 0.0833
1 hour
Map Coordinates
Canary Connections

• Same instruments
  - GPS
  - TPS
  - IPS (inclinometers)
  - Weather stations
  + over 100 different types of Geotechnical Instruments

“Bridging the Gap Geodesy to Civil Engineering”
Chickamauga Lock Project Example

Instrumentation Includes (approximately):
- (44) Vibrating Wire Crackmeters
- (128) Vibrating Wire Extensometers
- (30) Vibrating Wire Growthmeters
- (180) Vibrating Wire Inclinometers and Tiltmeters
- (10) Vibrating Wire Jointmeters
- (12) Applied Geomechanics Tiltmeters
- (44) Vibrating Wire Piezometers and Uplift Cells
- (135) Vibrating Wire Stressmeters
- (258) Vibrating Wire Overcore Stress Cells
- (10) RXTX Optical Pendulums
- (13) CR10X & CR1000 Based Monitoring Systems
- (2) VW Comm Module Wireless Vibrating Wire Systems
- (1) Leica TCRP1201 Total Station with 20 Circular Prisms and 2 Reference Prisms
- (24) Manually Recorded Survey Markers
One of the key components to deliver the value of the investment in your monitoring system is the software to make it all work. With decades of collective experience working with instrumentation and systems of many types deployed at hundreds of projects worldwide, we have the experience to understand how the software should work to maximize this value. We develop in-house all of the software we sell. With the exception of the Firebird SQL database set, and we continuously enhance it to provide better value with each new version. We also understand that it isn’t just about developing world-class software, but providing support after the sale that further enhances the value of your investment. We stand behind our work and look forward to helping you with your monitoring systems and software.

Visit www.CanarySystems.com to find out more and download demo software.
Real Time Monitoring

• A Network Control Center
• Each GPS Station streams data to the Network Control Center via high speed data lines. Data integrity is monitored continuously. 3D precision ±10 mm.

Processing done at NOC on PCservers
Correlated Hemisphere

GPS Satellite

Bridge or structure

Spaced based Triangulation

Processing done at NOC on PCservers
Correlated Hemisphere
Data Sample

- Multiple structures per interface
- Selectable sensors
- Dynamic graphing based on date range desire
- Alarms by sensor
- Custom data display at sensor, structure, or structures levels
Real Time results unfiltered and resulting from a maximum displacement of 4 cm.
Reference Station Networks

- Perfect environment
- Perfect Tool
- WYSWYG
- Perfect Opportunity

- Yeah baby, we have been waiting a long time!
Structural Health Monitoring

• Start with a “GPS/IPS” (inclinometer positioning system) sensor system to clarify initial structural health concerns

• Additional sensor types can then be strategically added in suspect locations

• Structural engineers, using state-of-the-art analytics, can develop a final diagnosis quickly and efficiently with information from our sensor systems

• A definitive diagnosis leads to development of structure specific remedies and optimized Asset Management programs
Wikipedia

- Axiom VI: There is a trade-off between the sensitivity to damage of an algorithm and its noise rejection capability.
- Axiom VII: The size of damage that can be detected from changes in system dynamics is inversely proportional to the frequency range of excitation.

**SHM Components**

The sensory system consists of approximately 900 sensors and their relevant interfacing units. With more than 360 sensors on the Tsing Ma bridge, 360 on Ting Kau and 200 on Kap Shui Mun, the structural behaviour of the bridges is measured 24 hours a day, seven days a week.

The sensors include accelerometers, strain gauges, displacement transducers, level sensing stations, anemometers, temperature sensors and dynamic weight-in-motion sensors. They measure everything from tarmac temperature and strains in structural members to wind speed and the deflection and rotation of the kilometres of cables and any movement of the bridge decks and towers.

These sensors are the early warning system for the bridges, providing the essential information that help the Highways Department to accurately monitor the general health conditions of the bridges.

The structures have been built to withstand up to a one-minute mean wind speed of 95 metres per second. In 1997, when Hong Kong had a direct hit from Typhoon Victor, wind speeds of 110 to 120 kilometres per hour were recorded. However, the highest wind speed on record occurred during Typhoon Wanda in 1982 when a 3 second gust wind speed was recorded at 78.8 metres per second, 284 kilometres per hour.

The information from these hundreds of different sensors is transmitted to the data acquisition outstation units. There are three data acquisition outstation units on Tsing Ma bridge, three on Ting Kau and two on the Kap Shui Mun.

The computing powerhouse for these systems is in the administrative building used by the Highways Department in Tsing Yi. The local central computer system provides data collection control, post-processing, transmission and storage. The global system is used for data acquisition and analysis, assessing the physical conditions and structural functions of the bridges and for integration and manipulation of the data acquisition, analysis and assessing processes.

- Monitoring Hong Kong's Bridges Real-Time Kinematic Spans The Gap

**Structural Health Monitoring for bridges**

In order to oversee the integrity, durability and reliability of the bridges, WASHMS has four different levels of operation: sensory systems, data acquisition systems, local centralised computer systems and global central computer system.

The sensory system consists of approximately 900 sensors and their relevant interfacing units. With more than 350 sensors on the Tsing Ma bridge, 360 on Ting Kau and 200 on Kap Shui Mun, the structural behaviour of the bridges is measured 24 hours a day, seven days a week.
Monitoring Applications
Tunnelling and Buildings

- Construction site near by the tunnel
- Deformation risk in bad soil
- Urban areas
- Multiple total stations needed
- GNSS used for reference point stability
- Geotechnical sensors
- Railways and Highways
- Construction
- Maintenance of structures
Monitoring Applications
Dams and Landslide

- Safety and risk management of important transport links and urban areas
- Landslide areas near by dam
- Glacier above water reservoir
Monitoring Eastside GPS/TPS

460 prisms

- Typical Setup

Reference Points
Monitoring

• Typical Setup

Reference Points

GPS

Critical Zone?
MultiLoggerDB Project Interface

• Insite, the MLDB client software, is designed to present a project as a series of Project Views. This application includes extensive functionality in the viewing of the project and the output of data.

  • Readings Box showing current reading & status (yellow or red = alarm)
  • Project Status
  • Legend Box showing instruments and managing the display
  • Thumbnail viewer for selecting Project View.
Monitoring Applications
Open Pit Mining

- 3D deformation for slope stability control (prediction)
- Safety and risk management for staff and machinery
- Long term 3D survey as reference for other monitoring tools
- Total stations used for cost effective wide area coverage
- GPS, geotechnical and other monitoring systems used for added safety
Example – Mine

- First signs of movement
- Second signs of movement
- Danger signs
- Crack Visible
- Action taken
- Move workers

Movement detected 2 weeks before visible Crack
• Data Acquisition Systems for Demanding Environments

Note: UDS-1100’s use default

GeoMos Database

Firebird Database

MORAPPROC

MLDB/Insite Console

MFL

Current 402 Tower Temp

Max Wind Speed

24HR RAINFALL

Average Wind Speed

MTD RAINFALL

Humidity

YTD RAINFALL

FOR CANARY ALARM ON DISPATCH SCREEN
1. Double click on RED CIRCLE ABOVE
2. Locate flashing icon on next screen and double click on blue writing of alarming icon
3. Follow instructions that come up

ROBOT01

FO Interface

ROBOT02

FO Interface

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Morenci – Total Stations
Monitoring Applications
Seismic and Subsidence

- Measurement of tectonic movement, earthquakes, isostatic rebound, glacial flow, subsidence due to extraction of groundwater or mining

- 1D or 3D deformation for understanding risks to infrastructure and for scientific study

- Measurement of movements over wide areas

- Often use a combination of GNSS and geotechnical instrumentation
Monitoring Applications
Bridges and Structures

- Safety and risk management of important transport links and urban areas
- Construction near by buildings (high rise buildings)
- Maintenance of Structures
- Insurance and Bonds
Continuous Beam Deflection Monitoring Using Precise Inclinometer Data

\[ L = \text{Length} \]

\[ a \]

\[ x \]

\[ P = \text{Load} \]

\[ E = \text{Module of Elasticity} \]

\[ I = \text{Inertia} \]

\[ V(x) \text{ is deflection} \]

\[ p(x) \text{ is the tangent} \]
Integrated Monitoring System

- Ground Map coordinates
- Traditionally a laser beam coupled with a ZNL is used to materialize the main verticale.
- The observed deviations are reported on the map coordinates.

- GPS
- TPS
- IPS
External Recognition of

GPS World Magazine
Feature Article and Cover
Sept 2003

How did we get there?

BRIDGES Magazine
Feature Article and Cover
April 2006

Structural health monitoring using GPS
Example Hong Kong

Monitoring Hong Kong's Bridges
Real-Time Kinematic
Spans the Gap

WASHMS Computer System
Global Data Acquisition Station
GPS

Local Data Acquisition Station - Ting Kau Bridge
1. GPS Reference Station
Local Data Acquisition Station - Kap Shui Mun Bridge
2. GPS Reference Station
Local Data Acquisition Station - Tsing Yi Bridge
3. GPS Reference Station
GPS Base Reference Station

Ma Wan Tower
Tsing Yi Tower

Rotation (degrees)

MVB
MVB
MVB
MVB
MVB
MVB
MVB
MVB

MVB
MVB
MVB
MVB
MVB
MVB
MVB
MVB

AllSafe Engineering
Almost 27%, or more than one in four, of the nation’s bridges are considered structurally deficient or functionally obsolete. In real numbers, this means that of the 600,905 bridges listed by the U.S. Department of Transportation in December 2008, 72,868 (12.1%) were categorized as structurally deficient and 89,024 (14.8%) were categorized as functionally obsolete. Even though the number of deficient rural bridges declined by 8596 from 2005 to 2008, the number of deficient urban bridges increased by 2817 during the same time period. Considering the higher level of passenger and freight traffic on these urban bridges, the impact is significant.

- 72,868 (12.1%) structurally deficient
- 89,024 (14.8%) were categorized as functionally obsolete.

- One in four, (1/4) count your bridges every 4th one could fail.
6 Dead in Minn. Bridge Collapse

(Newser Summary) – A four-lane bridge over the Mississippi River in Minneapolis collapsed during the evening rush, killing at least 6 people and injuring dozens. Witnesses say there were up to 100 cars on the bridge at the time, and as many as 50 were hurled into the river and onto the banks. Rescuers rushed to triage victims and put out massive fires.

The FBI and Homeland Security have ruled terrorism—the Minneapolis Star-Tribune reports construction crews had been repairing the section of the I35W bridge that buckled for several weeks. One semi reportedly burst into flames, while some witnesses said that a school bus full of children was on the bridge while it collapsed, though it appears none of the children were injured.

—Gregg
At 7:25 a.m. on May 9, 1980, with the Greyhound bus approaching the Pinellas Skyway for a few more miles on the northbound trip from St. Petersburg, Capt. J. H. M. Grace was at the helm of a freight boat. As the boat entered Tampa Bay, it suddenly disappeared as long as the unforgettable scene.
SKYWAY SCHEMATIC
SKYWAY PHOTOS
REAL TIME SNAPSHOT PLOTS
POST PROCESSED SNAPSHOT PLOTS

30-DAY SERIES

AllSafe Engineering
Diurnal effects

Solar effects: A simplified schematic showing more realistically the motions, red arrows, caused by the towers bending because of temperature differences through the towers caused by solar heating and forces, green arrows, transmitted through the cables.

Wind Loading: A simplified schematic showing the motions, red arrows, caused by the towers bending because of temperature differences through the towers caused by solar heating.

Deck expansion: A simplified schematic showing the motions, red arrows, caused by thermal expansion of the bridge deck spans and the resulting separation of the towers. Opposing forces are represented by the green arrows.

Wind Loading: A simplified schematic showing the motions, blue arrows, caused by wind loading.
4 Hurricanes ....... Structure Impact?
FLORIDA BLOWS!

Hurricane Jeanne visible satellite image, taken on September 22, 2004 at 11:15 AM EDT.

Hurricane Ivan, September 14, 2004
4 AM CDT Tuesday
NWS TPC/Iational Hurricane Center Advisory
Maximum Sustained Wind: 185 mph
Current Movement: NW at 8 mph
Forecast Center Positions:
1. Sustained wind > 73 mph
2. Sustained wind 119-156 mph
Potential knowledgeable Track Area

Structural Health Monitoring Services
AllSafe Engineering
Canary Systems
Crossing tracks of Frances, Jeanne, Charley
Hurricane Frances

TNTH

Up (cm)

Along (cm)

Cross (cm)

Sep 4  Sep 5  Sep 6  Sep 7  Sep 8 2004

Up (cm)

Along (cm)

Cross (cm)

Sep 4  Sep 5  Sep 6  Sep 7  Sep 8 2004

delta T (C)       wind (normalized)

delta T (C)       wind (normalized)
Hurricane Jeanne

TNTTH

- delta T (°C)
- wind (normalized)

Up (cm)

Along (cm)

Cross (cm)

Sep 26 2004

Sep 27 2004

Skyway

AllSafe Engineering
“Reference Stations have allowed this technology to be enhanced tremendously.”

Objective and quantitative information on exact structural asset condition and management- increase life cycle

Reduced costs, delays, and risks in maintaining its Building/ Bridge infrastructure- Safety enhanced

Improved use of cash and capital resources from making “just-in-time” repairs and replacement

Enhanced maintenance practices “objective criteria” instead of subjective
Valued 24/7 health Monitoring Solutions

Higher accuracy and Precision
Funding?

How to influence people and get money

- Educate
- Solicit
- Influence
- Show off your work
New Instruments

- **TPS**
  - 1 second/remote

- **Visual Targeting**
  - Reflectorless
    - Reduced prisms
    - Coaxial optics
    - Reduces risk
    - remote

- **Visual Scanning**
  - Exceed Tolerance
    - Automatic Scanning
      - Course 10 x 10
      - Fine 1 x 1

3 in 1

1. TPS
2. Scanner
3. Coaxial Camera
• Ask yourself

• Are you ready for a failure?
Thank you

www.canarysystem.com