What is Structural Health Monitoring?

Applying instruments to a structure that monitor and evaluate the on-line or in-service performance in an automated manner.
What is the purpose of SHM?

- Detection of sudden or progressive damage to the structure
- Monitor performance under normal and extreme loading events
- Provide real-time evaluation of the effects of damage and the current serviceability of the structure
How does SHM benefit ODOT?

• Enhances the ability to extend the service life of an aging infrastructure
• Provides feedback to the structure design/load rating/retrofit process
• Enhances mobility by allowing owners to safely increase service demand on structures
# Examples of Damage Detection

<table>
<thead>
<tr>
<th>Type of Damage</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatigue Cracking</td>
<td>Strain, crack growth indicators, AE, vibration</td>
</tr>
<tr>
<td>Corrosion</td>
<td>Half Cell electrical potential, AE</td>
</tr>
<tr>
<td>Foundation settlement</td>
<td>Tilt meters, vibration, soil pressure</td>
</tr>
<tr>
<td>Gear/bearings in machinery</td>
<td>Torque, vibration, temperature</td>
</tr>
</tbody>
</table>
Fatigue Cracking
Corrosion
Machinery
A fault is when the structure can no longer operate satisfactorily.
Taxonomy of Damage Identification

“Damage is when the structure is no longer operating in its ideal condition but can still function satisfactorily, i.e. in a sub-optimal manner”

2. Structural Health Monitoring 2004:3:85
Taxonomy of Damage Identification

“
A defect is inherent in the material and statistically all materials will contain some unknown amount of defects.”

2. Structural Health Monitoring 2004:3:85
Defect

Photograph C: Magnification 1.6X
Typical fracture surface features on an “outboard” leg of an angle pointing to a fracture initiation site at the bolt or rivet hole.

Photograph D: Magnification 12X
Higher magnification view of an apparent fracture initiation site at a location of smeared metal at a punched hole.
Hierarchical Relationship

- Defects lead to damage
- Damage leads to faults
Faults are to be avoided and are usually obvious once they occur.
Early detection of damage can prevent faults from occurring.
Damage Identification Problem Hierarchy ³.

1) Detection
2) Localization
3) Classification
4) Assessment
5) Prediction

Damage Identification Problem

Hierarchy

• Ideally all five stages can be performed online, in real time and in an automated manner

• Practically, only the simplest problems can be fully automated at this time
ODOT’s approach automates the stages that can be practically and reliably automated and performs the remaining stages manually or off-line.
As technology progresses, more components can be automated.

Wavelet analysis applied to AE data from OSU Concrete Beam Testing.
The end result of the analysis of the SHM data can have several outcomes:

1) Improved understanding of the nature of the damage mechanisms
2) Assessment of repairs or retrofits
3) Forecasting of remaining service life
4) Provide warning of serious problems to owners
5) Activate automated shut down systems (petroleum industry) or active motion control systems (active seismic protection systems)
The majority of ODOT’s SHM systems have been designed for the purpose of developing a better understanding of an existing state of damage or performance deficiency.
Components of SHM

- Sensors that can make measurements that can be correlated to the performance parameters or damage condition of interest
- Signal conditioning and data collection
- Achieving of data on a centralized computer
- Analysis of data
- Warning or other active responses when required
Sensors for SHM

- Strain and displacement transducers
- Tiltmeters
- Temperature transducers
- Pressure transducers (soil and hydraulic)
- Weather parameter measurements
- Vibration measurement
Signal Conditioning and Data Collection

- regulated power supply and conditioning of the output signal
- Digitization and temporary storage
Signal Conditioning and Data Collection

- All SHM systems have one or more Master Control Units on the structure to provide this function.
- Sensors are typically hardwired to the MCU.
Transfer of data for Achieving

- Once the data is conditioned, digitized and temporarily stored in the MCU it must be transferred to the central computer server for achieving and retrieval for analysis.

- Each SHM application uses the most effective method for the transfer which is dependent on the location of the system and the type and quantity of data to be transferred.
Transfer of data for Achieving
Archiving SHM data

Data are stored on a dedicated central computer server located in Salem into a common data base application.
Analysis of SHM data

- Once the SHM data is on the server, several different analysis programs are used to explore and analyze the data.
- The particular analysis software used depends on the type of SHM data being analyzed.
Warning Systems

- All SHM systems can be configured to provide notification to the owner of a current or impending fault if desired.

- The implementation of such systems can range from a simple pre-recorded phone call to actively shutting down facilities.

- Currently ODOT has only one structure with a warning function implemented.
ODOT’s SHM Program

- ODOT has been instrumenting and testing bridges since the 1970’s
- Most bridge monitoring up to 2000 were temporary applications
- In 2000 the Isthmus Slough bridge was the first bridge to receive a permanent SHM system
- In 2005 a formal SHM program was implemented under ATA 24723
Engineered Monitoring Solutions Inc. was selected from an RFP process as the consultant to help implement the SHM program.

ODOT identifies the deficiencies on specific bridges that need monitoring, what to measure and how to analyze the data.

The consultant is responsible for designing the system, procuring equipment, installing the system and annual maintenance.

The consultant is not allowed to have any financial relationship with equipment vendors and is required to select the most appropriate equipment for each application.
ODOT Bridges with SHM

• 12 bridges with SHM systems installed
• 2 bridges with SHM in design phase

• 6 bridges have **structural** monitoring
• 3 bridges have **mechanical** monitoring
• 2 bridges have **foundation** monitoring
• 3 bridges have **corrosion** monitoring
<table>
<thead>
<tr>
<th>Br. #</th>
<th>Name</th>
<th>Hwy. #</th>
<th>M.P.</th>
<th>Concern</th>
</tr>
</thead>
<tbody>
<tr>
<td>06635A</td>
<td>Luckiamute River</td>
<td>99W</td>
<td>68.13</td>
<td>Concrete Cracking</td>
</tr>
<tr>
<td>03146A</td>
<td>Banzer</td>
<td>102</td>
<td>59.58</td>
<td>Concrete Cracking</td>
</tr>
<tr>
<td>02529</td>
<td>Fremont</td>
<td>I-405</td>
<td>3.32</td>
<td>Fatigue</td>
</tr>
<tr>
<td>09743B</td>
<td>Kamal</td>
<td>I-205 SB</td>
<td>1.04</td>
<td>Fatigue</td>
</tr>
<tr>
<td>07949C</td>
<td>Astoria</td>
<td>US101</td>
<td>2.41</td>
<td>Aero/fatigue</td>
</tr>
<tr>
<td>02164</td>
<td>Quartz Creek</td>
<td>US26</td>
<td>24.23</td>
<td>Load Capacity</td>
</tr>
<tr>
<td>Br. #</td>
<td>Name</td>
<td>Hwy. #</td>
<td>M.P.</td>
<td>Concern</td>
</tr>
<tr>
<td>---------</td>
<td>--------------------</td>
<td>---------</td>
<td>-------</td>
<td>-------------</td>
</tr>
<tr>
<td>07333</td>
<td>Columbia River SB</td>
<td>I5 SB</td>
<td>308.38</td>
<td>Lift Span</td>
</tr>
<tr>
<td>01377</td>
<td>Columbia River NB</td>
<td>I5 NB</td>
<td>308.38</td>
<td>Lift Span</td>
</tr>
<tr>
<td>01822</td>
<td>Reedsport</td>
<td>US101</td>
<td>211.11</td>
<td>Swing Span</td>
</tr>
</tbody>
</table>
# Bridges with foundation monitoring

<table>
<thead>
<tr>
<th>Br. #</th>
<th>Name</th>
<th>Hwy. #</th>
<th>M.P.</th>
<th>Concern</th>
</tr>
</thead>
<tbody>
<tr>
<td>01132</td>
<td>Isthmus Slough</td>
<td>241</td>
<td>0.42</td>
<td>Bascule Piers</td>
</tr>
<tr>
<td>06510</td>
<td>Spencer Creek</td>
<td>US101</td>
<td>133.86</td>
<td>New Design</td>
</tr>
</tbody>
</table>
# Bridges with Corrosion Monitoring

<table>
<thead>
<tr>
<th>Br. #</th>
<th>Name</th>
<th>Hwy #</th>
<th>M.P.</th>
<th>Concern</th>
</tr>
</thead>
<tbody>
<tr>
<td>01182</td>
<td>Cummings Creek</td>
<td>US 101</td>
<td>168.44</td>
<td>CP system</td>
</tr>
<tr>
<td>01172</td>
<td>Patterson</td>
<td>US 101</td>
<td>327.70</td>
<td>CP system</td>
</tr>
<tr>
<td>01181</td>
<td>Ten mile</td>
<td>US 101</td>
<td>171.44</td>
<td>CP system</td>
</tr>
</tbody>
</table>
Example SHM System
NOTE:
This view is looking east. The sensor I.D. numbering always begins in the lower left corner when looking east and increases around the cross section to the lower right corner.

LEGEND
• TS01 Strain Gage
  (ST01) Temperature Sensor
• Temperature Sensor

Fremont Bridge SHM
Fremont Bridge SHM
Fremont Bridge SHM
SHM System Costs

- Installed system costs range from $40k to $240k per bridge
- System design is 10% of total cost
- Equipment and materials is 30 to 50% of total cost
- Installation including traffic control is 30 to 50% of the cost
- Central server and software is $110k
Conclusions

An aging infrastructure has forced owners to use new technologies to extend the service life of bridge structures.
Conclusions

- SHM is providing a key function in this adaptation of technology.
- Costs of SHM are greatly offset by providing enhanced reliability to our aging bridge structures and increased mobility on critical trucking routes.
Conclusions

ODOT has found applying SHM to specific problems opposed to general monitoring to be the most effective and efficient use of limited resources.
Conclusions

As you can see ODOT is using SHM the way it serves us best, by identifying potential damages before they become a fault.
Conclusions

With this strategy we can extend the service life, performance and reliability of our bridge inventory.