Today’s TRB Webinar: **Obtaining Return on Investment from Structural Health Monitoring**

and the

Oct. 22, 2014 TRB Webinar: **Practical Structural Health Monitoring**

Have been organized by the TRB subcommittee on *Structural Health Monitoring*, which is a subcommittee of

* AHD30 Structures Maintenance,
* AHD35 Bridge Management, and
* AFF40 Field Testing and Nondestructive Evaluation of Transportation Structures

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The ROI Answer for State DOTs

- State DOT judiciously invests $500,000 in SHM solutions.
- Investment in SHM solutions provide $2,000,000+ in value from cost savings and deferrals.
- Given those type results, use of SHM technology is prudent and should be maximized.
- $500,000/year for a State DOT is an insignificant investment; <0.025% of an average State DOT budget.
DOTs Face Big Challenges......

- Federal bridge funding probably limited for decades.
- Local owners (States, Cities, Counties) also have limited funds.
- DOTs facing a prolonged “do more with less” environment.
- Knowledge “walking out the door” with boomer retirements.
- MAP-21 requires State DOT Asset Management Plans.
  - Bridge management now more complex.
  - Owners must optimize limited spending.
  - Owners must quantify and manage system risk.
  - Owners must avoid political prioritization of projects.
- Integrating SHM into State DOT Asset Management Program.
...So, Why Rely Solely on NBIS?

- Visual (bridge) condition ratings varied by +/- 2 states from the mean in a 2000 FHWA study. (1)
- “This methodology is highly subjective and produces variable results.” (2)
- “Visual inspection also does not capture hidden deterioration or damage.” (3)

2. Condition Assessment of Highway Structures, Past, Present and Future; TR Circular E-C104
3. IBID
Unintended Consequences

— **FUNDING:**
  - Inflated funding need for bridge projects.
  - Optimization of life cycle costs is impossible.

— **MANAGEMENT:**
  - Long-range planning and prioritizing spending difficult.
  - Risk management is reduced to guesstimating.

— **ECONOMIC DEVELOPMENT:**
  - Unnecessary load limitations and long detours for trucks.

“The actual performance of most bridges is more favorable than conventional theory dictates.” AASHTO MBE, Paragraph 8.2.1.
Why Should DOTs Use SHM?

• Because NBIS visual inspection is intentionally conservative, subjective and highly variable.
• Because SHM provides essential information, supporting safe deferral of repairs/replacement.
• Because SHM technology can provide enhanced safety by closely monitoring known defects.
• Because SHM meets “Standard-of-Care” for State DOTs and Professional Engineers.
How SHM is Used

Catalog Assets
- What?
- Where?

Asset Condition Assessment
- Macro: “Visual”
- Micro: “SHM”
  - Data-Driven

Manage Asset Performance
- Structural Analysis
  - Risk-Adjusted
- Life-Cycle Costs
  - Optimized

20th Century ↔ 21st Century
Intrinsic Value of SHM

- Objective, precise, and timely condition assessment results in:
  - Less expensive project options:
    - Rehabilitation vs. replacement
    - Safe deferral of replacement
    - Removal of unnecessary load restrictions
  - Realistic risk management
  - Safer operating conditions
  - Lower, long-term funding demand
  - Improved planning and prioritization
  - Lower life cycle costs
  - Optimized Asset Management Plans
  - Safely Extending Asset Life™
Example Projects with ROIs
**Safely Deferring Replacement**

- **Problem:** City can’t afford to replace 15 load-rated short-span bridges.
- **Customer:** Major City in Southwest
- **Project date:** 2008
- **Objectives:**
  - Conduct initial load test.
  - Stiffen bridge with CFRP wrap.
  - Verify repair using SHM technology.
- **Results:**
  - SHM proved repair worked as intended.
- **Conclusion:**
  - City spends $1 million, then in <18 months saves $3 million versus replacement costs.
Safely Deferring Replacement

- **Problem**: Replacement funds uncertain; need to verify structural adequacy.
- **Owner**: Class I Freight Railroad
- **Project date**: 2012-Ongoing
- **Objectives**:
  - Monitor in-service truss stresses.
  - Monitor substructure displacements.
- **Results**:
  - Highly stressed, but safe to use.
- **Conclusion**:
  - RR spends $500K; analysis supports safe deferral of $75 million bridge replacement.
  - Deferral value >$300,000 per month @ 5%
Safely Deferring Repair

- **Problem:** Is the third party recommended repair program necessary?
- **Customer:** Northeastern Toll Road
- **Project date:** 2005
- **Objectives:**
  - Monitor key tensile and compressive strains.
  - Calibrate a finite element model to analyze current condition and recommended repair program.
- **Results:**
  - Recommended safe deferral of $875,000 steel repair program.
- **Conclusion:**
  - Owner spends $150,000; analysis supports net savings of $725,000 in <18 months.
**Problem:** Will severe corrosion require an expensive structural repair program?

- **Owner:** Southeastern DOT
- **Project date:** 2009
- **Objectives:**
  - Monitor key locations for strain and temperature.
  - DOT monitored strains so they would not exceed certain maximum values.
- **Results:**
  - Bridge safely handled truck traffic.
  - Overweight vehicles identified and stopped.
- **Conclusion:**
  - Owner spends $125,000, then saved $700,000 in <18 months by monitoring vs. repair.
**Problem:** Deck framing reaching end of life; unexpected steel cracking.

**Owner:** Upper Midwest Toll Bridge

**Project date:** 2012-Ongoing

**Objectives:**
- Measure displacements at as-designed locations and proposed repairs.
- Monitor for several months to confirm repairs worked as expected.

**Results:** Repair method worked as intended.

**Conclusion:**
- Owner spends $75,000; analysis supports safe deferral of ~$25,000,000 repair program.
- Deferral value >$100,000 per month @ 5%.
Load Rating; Deferred Repair

- **Problem:** Truss bridge does not load rate from visual inspection; repair estimated at $2 million.
- **Owner:** Regional Railroad
- **Project Date:** 2014
- **Objectives:**
  - Evaluate stress in load bearing members.
  - Rate for intended load and speed.
- **Results:** Bridge rates; no repair needed.
- **Conclusion:**
  - Owner spends <$100,000 to get proper load rating; avoids $2 million dollar repair project in <2 months.
When to Use SHM for ROI

- When the owner needs options due to funding constraints.
- Superstructure condition is problematic per NBIS, e.g.:
  - Significant section loss
  - Visible cracking
  - Out-of-plane bending
- Scour critical conditions.
- When repair estimates exceed $300,000.
- When replacement estimates exceed $2 million dollars.
When to Use SHM for ROI

- To optimize an Asset Management program:
  - Data-driven
  - Risk-adjusted
  - Objective prioritization
- For more realistic load ratings.
- To monitor heavy truck permit crossings to confirm damage for insurance recovery.

- **Probabilities for SHM success:**
  - Improved load rating >50%
  - Safe project deferral >40%
Takeaways To Remember

• For Manual SHM Solutions:
  – 50+% of current load ratings are too restrictive.
  – Detours cost truckers nearly $2.00 per mile.
  – DOTs can conduct load ratings in-house at low cost.
  – ROI easy to calculate knowing ADTT and detour length.

• For Automatic SHM Solutions:
  – Plan customized SHM projects with experienced solution providers and analytical experts.
  – Most SHM equipment can be re-used, lowering per use cost.
  – The larger the bridge project, the higher the expected ROI.
Don’t Avoid SHM – Embrace It!!
Structural Health Monitoring (SHM) Technology - An Owner’s ROI -

by:

Richard “Lee” Floyd, PE
State Bridge Maintenance Engineer
Management Challenges

- Safety is Job 1
- Bridge conditions
- Visual and tactile
- Long term funding
- Embracing change
- Developing and evaluating options
- Long term solutions and program
- Benefits to Costs
- Asset management
Limitations of NBIS Data

- NBIS is a safety system - not a management system
- Subjective and variable (per 2001 FHWA study)
- General component qualitative data - vs - specific element/material level quantitative data
- No effective predictive analyses
- Difficult-to-explain bridge classifications:
  - Structurally Deficient & Functionally Obsolete
Bridge Element Data

- Qualitative and quantitative issues are minimized
- Quantitative and element specific data:
  - Provides detailed data and reporting
  - Detailed analytical modeling
  - Effective predictive analyses
SHM Technology Basics

- Precise and timely assessment of structural response
- Strain, especially peak
- Temperature
- Known defects
- Information via Internet
- System reliability
- Out-of-tolerance alerts
SHM Benefits

- Improved safety
- Safe deferrals of actions as necessary
- Rehabilitation -vs- replacement
- Prevention/removal of some unnecessary restrictions
- Return on investment
Pee Dee River Bridge

- Last 18 to 24 months of service
- Needed open for legal loads - approximately 46 mile bypass
- Truck ADT = 488
- Option #1: Fix steel for $825,000
- Option #2: Monitor for $125,000
- Saved $700,000 based on normal decision making protocols
North Santee River Bridge

- Both SB bridges over the North and South Santee Rivers slated for replacement based on NBIS visual inspection findings, however the North Santee bridge was in the more critical condition
- Funding was available to replace but the local political environment was not conducive at the time
- Only option: monitor -vs- possibly restrict until replacement
- Have safely deferred replacement actions for 5 years with an expected 3 to 5 additional years
Other Bridges

- Used SHM technology to evaluate load demand and structural response
- Some bridges did not need restricting
- One steel truss swing bridge had its safe load restriction increased based on structural response thus benefitting 3 sea islands - sole access route
An Owner’s ROI Considerations

- **Not just benefits for the Owner:**
  - Deferred capital expenditures-savings
  - Risk and safety management
  - Prioritization within Asset Management

- **And not just benefits for the User:**
  - Minimize detours and therefore user cost
  - Enhanced safety

- **Benefits for both should be considered!!!
An Owner’s ROI Estimate

- Total SHM expenditures to date: $510,000
- Estimated benefits for owner to date: $3,200,000
- Estimated benefits for users to date: $3,400,000
- Total Benefits to date: $6,600,000
- \( \text{ROI} = \frac{B}{E} = 12.9 \)

- This makes our users VERY happy!!!
Future SCDOT SHM Program

- Expand SHM on Ravenel Bridge
- Increased use of SHM for structural performance on other bridges
- Increased load testing of other bridges for structural performance
- Integrated analytics
Closing Thoughts

- SHM is fully commercial – it’s very effective!!!
- Work with experienced SHM firms
- Don’t shortchange monitoring periods
- Use appropriate analytics for project
- Plan and ensure a return on investment
- You can be creating value - just do it!!!
Asset Management

Engineering Assessment of Infrastructure

Economics

Modern/Effective Management Practices
Questions?
Utilization of Structural Response Monitoring for the Pulaski Skyway

Andrew J Foden, PE, PhD
Parsons Brinckerhoff
Pulaski Skyway Bridge
Pulaski Skyway Project Limits

- 3 ½ miles long
- Direct Link to Holland Tunnel via Route 139
- Links Newark at Raymond Blvd. & Jersey City at Tonnele Ave Circle
- SB Entrance, NB Exit to Jersey City at Broadway Ramp
- SB Exit, NB Entrance to Kearny @ Kearny Ramp
Total Estimated Rehabilitation Cost

- Rehabilitate Existing Bridge – Approx. $1 Billion
  - Deck Replacement - $400 M
  - Painting - $250 M
  - Seismic Retrofit and Substructure Rehab - $75 M
  - Superstructure Steel Rehab - $125 M
Deck Design

• Design Considerations
  • Original deck had relief joints at each floorbeam
    – Supported on crossbeams
    – Rehabilitation in 1978 eliminated relief joints
    – Shrinkage substantially completed
  – New deck composite with stringers
    – Shrinkage effects
    – Structural behavior modified
Analytical Models

- Global model including the truss
Analytical Models

- Detailed model of the floor system
Detailed Floor System Model
Floorbeam Connection Forces

- Thermal effects
  - Uniform temperature change
  - Temperature gradient
- Shrinkage
- Live Load
Floorbeam Forces (Continued)

- Uniform Temperature
  - Cold Climate (−30° to 120°F)
- Temperature Gradient
  - Zone 3 - 30 degree differential

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Floorbeam Forces (Continued)

- Shrinkage
  - AASHTO criteria vs. CEB-FIP 90

![Shrinkage vs. Time, 0-10000 days](image)
Analysis Results

• Initial Results
  – 40% of connections inadequate for assumed loads
  – Expensive retrofit

• Refined Modeling/Analysis Approach
  – Reduced to 5%, however, condition not eliminated

• Refinement required on the loading side
Floorbeam to Truss Connection
Structural Response Monitoring

- **CX1 Structural Response Monitor**
  - 3 accelerometers, 2 inclinometers and 1 temperature sensor.

- **Key parameters measured**
  - Tilt along the direction of the bridge
  - Ambient temperature corresponding to the tilt.

- **Real time data**
  - Accessed via website

- **Tilt data measured from the sensors used to verify model behavior and calibrate model loading**
Sensor Installation

• 12 sensors installed
  – 6 on the floorbeam at the west end of Section 5
  – 6 on the floorbeam at the east end of Section 6
Sensor Installation (continued)
Sensor Results

- Good correlation between temperature and floorbeam rotations
Analysis of Results

- Sensors 5A and 5B have higher rotations compared to sensors 5D, 5E and 5F
- Relative movement between the truss & deck
- Reasons:
  - Difference in coefficient of thermal expansions
  - Temperature differential
Sensor Results – contd.

- Rotations similar in the same vertical plane - Minimal curvature webs
Analytical Results – Floorbeam Deformations
Calibration of Analytical Models

- Conservatively assumed entirety of rotations were caused due to temperature differential.
- Models were analyzed with temperature differentials corresponding to 10, 20 and 30 degrees respectively.
- Deflected shapes in the model agreed with the observed data.
- Rotations computed from the analytical 3D model were higher than those measured from the installed sensors.
Comparison of Results
Results of Calibration

• Temperature gradient used in the analytical model was conservative and could be reduced significantly.
  – Assuming a temperature differential of 10 degrees for future analysis is reasonable
• Based on the results of the analysis, retrofit of floorbeam to truss connections is not warranted.
• Significant savings in construction costs based on results of Structural Response Monitoring.
Future Use

- Support during construction
- PB has developed several 3D analytical models to verify structural movements during various construction stages
- Strategically placed sensors are being used to monitor rotations in the floorbeams as well as truss members during demolition operations and during construction activity

Snapshot of partial demolition loading case
Construction SENSRR Location Schematic
THANK YOU