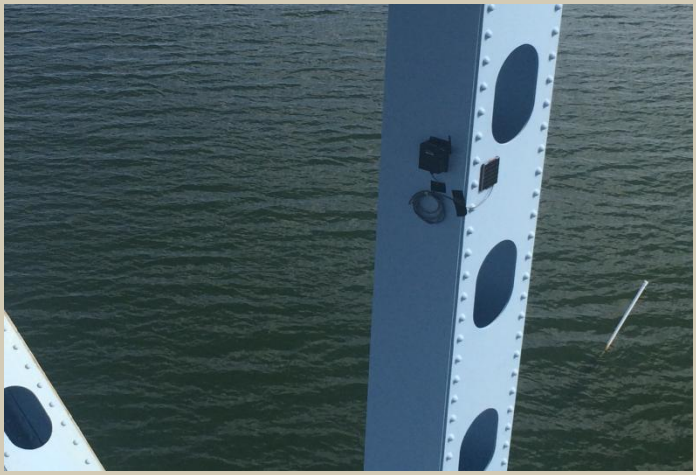
RESENSYS

Wireless Structural Health Monitoring

Small Sensors, **Big Difference**

Protecting Infrastructure with 21st Century Technology



Resensys SenSpot™ sensors monitor 10,000-foot Robert Norris Bridge, Virginia

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Resensys Wireless SenSpot™

Wireless SenSpot™ sensors offer a breakthrough technology for real-time and long-term structural health monitoring.

Sample applications of SenSpot™ sensors :

- **Bridge piers and abutments:** monitoring tilt, horizontal displacement, settling, deflection, instability of foundation
- **Structural elements:** monitoring strain (stress) in girders, beams, truss members, detecting overstrain, fatigue
- **Bearings and expansion joints:** monitoring bearing tilt, movement of joints, temperature response, detecting bearing malfunction
- **Bridge load rating:** fast, easy, reliable load carrying capacity calculation assisted by strain response of bridge elements
- **Other structures:** airframes, pipelines, tunnels, towers, buildings, cranes, etc.

Total wireless solutions for remote Structural Health Monitoring

SenSpot™ Features

- **Maintenance free, low-power:** minimum battery life of 10 years
- **Wireless communication:** IEEE 802.15.4, 2.4GHz
- **Small size and lightweight:** 2in × 2in × 1in, 5oz (50mm x 50mm x25mm, 142 gr).
- **Easy mounting:** quick installation, self-adhesive or flange mount
- **Wide working temperature:** -40 to +150°F (-40 to +65°C)
- **Long communication range:** 0.62mi (1.0Km) free space
- **Fully weather proof:** Ingress Protection of IP65

Types of SenSpot™ Sensors

- **Strain (stress)**, resolution: 1 µStrain
- **Vibration (acceleration)**, resolution: 1mg
- **Tilt & inclination**, resolution: 0.5 arc seconds (0.00016 degree)
- **Humidity**, resolution: 1% RH
- **Displacement**, resolution: 4mil (0.1mm)
- **Temperature** , resolution: 0.5 °C

Certification: MIL-STD-461F

RESENSYS PRODUCTS

- SenSpot™: attached to structure (as many as needed, typically 10-200 per structure)
- SeniMax™: collects SenSpot data on site of SenSpot™ and sends to remote server (one per structure)
- SenScope™: software package that analyzes data & generates alerts

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Resensys Remote Monitoring System

- **SenSpot™ sensors:** attached to the structure, any number, any combination
- **SeniMax™:** collects data from on-site SenSpot™ sensors and sends it to a remote server (one unit can cover up to 250 SenSpot™).
- **Repeater:** extends the range of SenSpot™ sensors when needed (in very large structures).
- **SenScope™:** software for sophisticated data analysis, visualization.

Displacement SenSpot™ (monitoring expansion, crack progression)

Tilt SenSpot™
(monitoring pier movements, foundation settling, bearing movement)

Strain SenSpot™ (monitoring stress/strain on members)

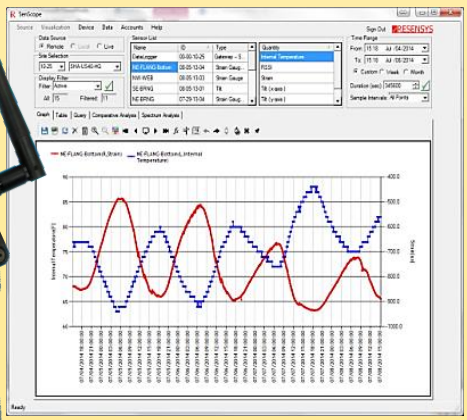
Cellular

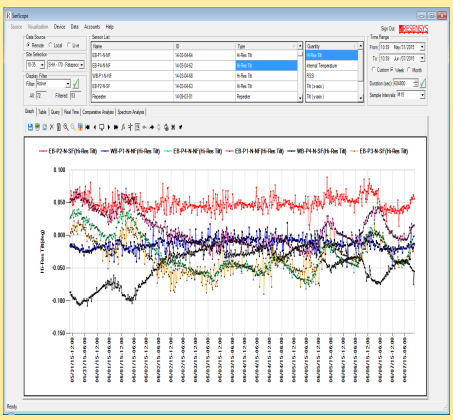
Cloud /
Server Storage

Internet

SeniMax™
Remote Transmission Gateway

SenScope™





RESENSYS

Resensys SeniMax™ Gateway

SeniMax™ receives data from SenSpot™ sensors and transmits data to a cloud based database system.

SeniMax™ is a high performance wireless data collector and remote communication gateway designed for years of uninterrupted and reliable monitoring.

SeniMax™ uses Resensys's proprietary breakthrough energy efficient communication and scheduling technology. As a result, even when it is disconnected from solar cells, it still has a full month of energy reserve for reliable operation.

SeniMax™ Dimensions:
150mm x 20mm x 100mm (6in × 8in × 4in)

SeniMax™ Features

Energy self sufficient: solar powered
Wireless protocols:
- IEEE 802.15.4
- HSPA (3G), GPRS
- IEEE 802.11 / Wireless LAN
- IEEE 802.3 / Ethernet

Low profile: small, easy to install
Weatherproof: IP66 protection
Coverage: up to 250 SenSpot™ sensors
Lightweight: 1.5Kg (3.0 Ib)

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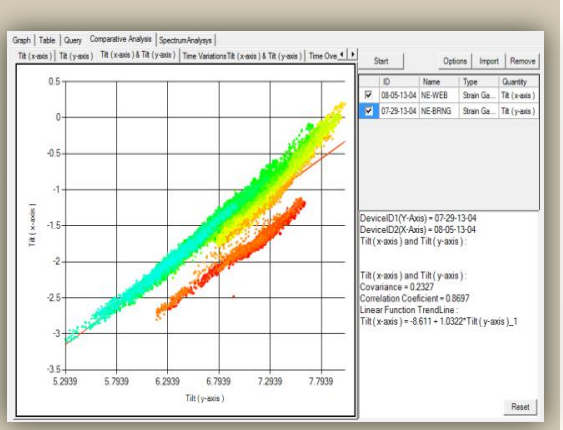
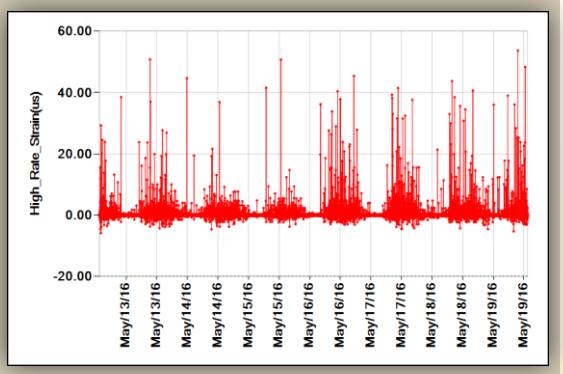


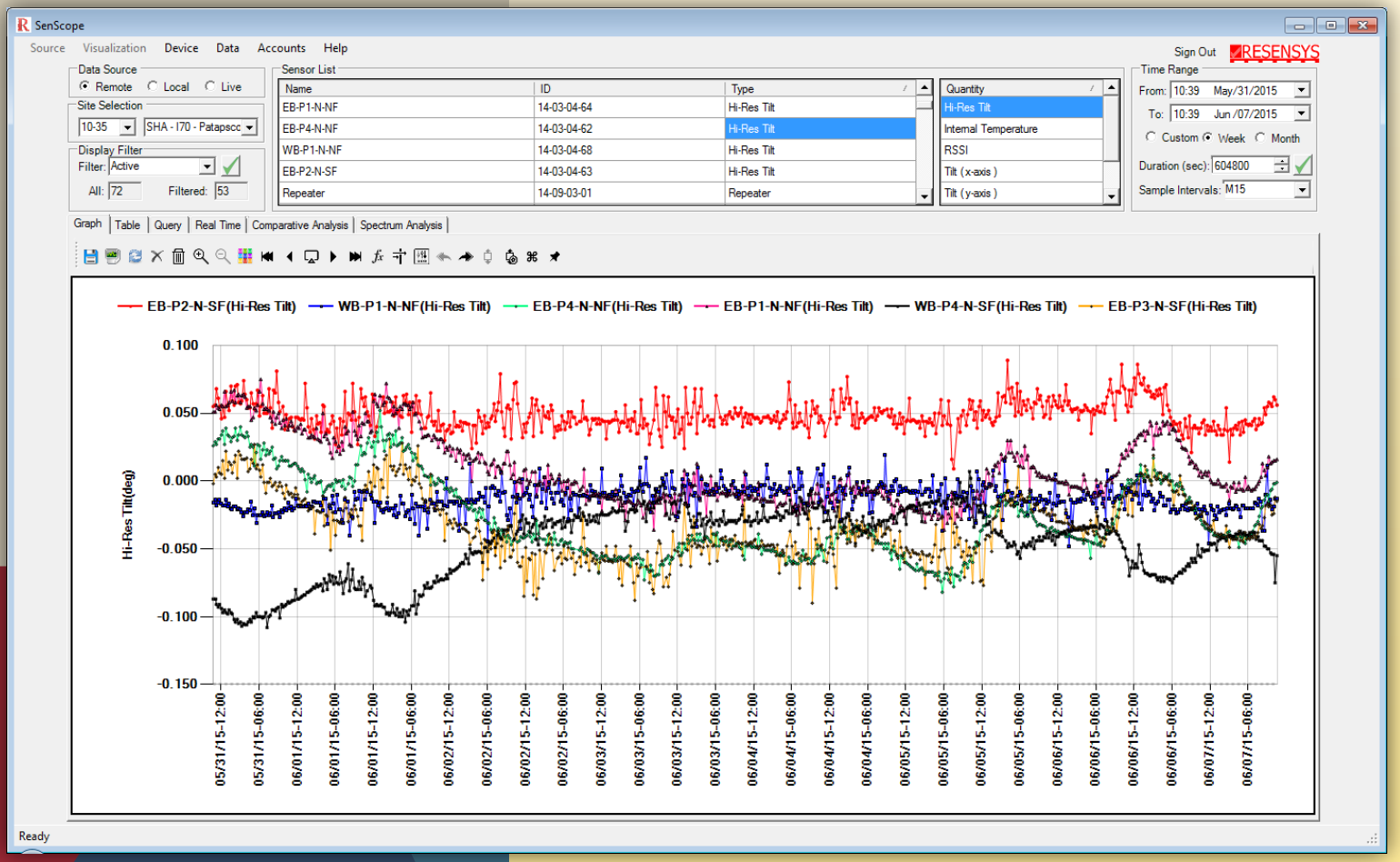


Resensys SenScope™ Software

SenScope™ is a software package for real-time monitoring and structural diagnosis. SenScope™ is capable of converting large volumes of data into specific structural diagnostics information. The information generated by SenScope™ facilitates decision-making and accelerates the course of action for maintenance/repair.

SenScope™ features

- Communication with Resensys SenSpot™ and SeniMax™
- Real-time data visualization and management
- Automated structural diagnostics, alert generation & management
- Alert generation with customizable alert levels
- Archiving of historical data of the structure
- Capability of adding user notes per SenSpot™ sensor
- Capability of providing e-mail or text message alerts
- Report automation



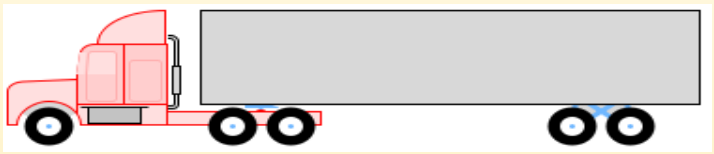
RESENSYS

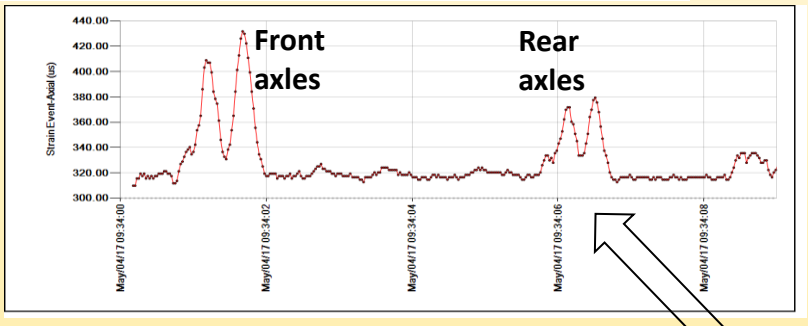
Strain SenSpot™

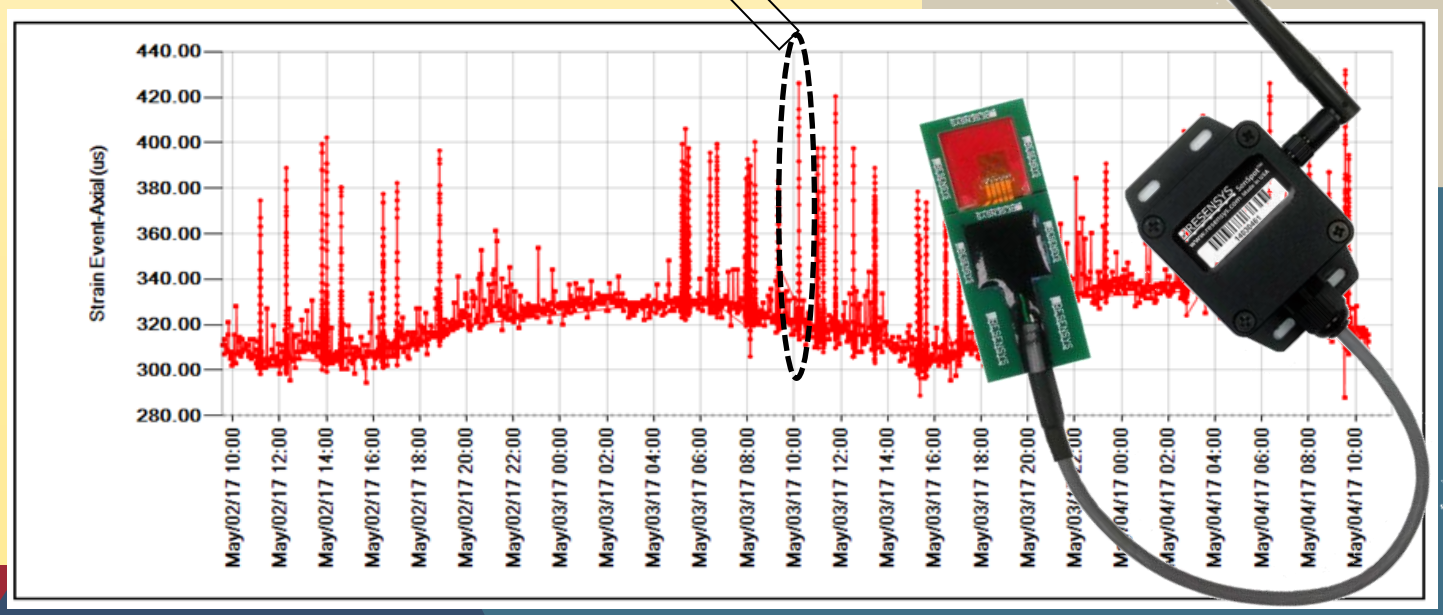
Game-changing technology for monitoring strain, fatigue damage awareness, and load rating

- Long- term and continuous monitoring of strain (stress)
- Detecting short-lived and transient high-strain events, e.g., caused by fast moving trucks on highway bridges or by turbulence on airframes
- Fatigue awareness, fatigue life analysis (remaining useful life estimation)
- Fast, easy-to-install adhesive mount
- Examples applications:
  - Highway bridges
  - Airframes
  - Pipelines
  - Machines, cranes, etc.
  - Truck tests, bridge load rating

The 8-second “zoomed in” data shows the loading effect of a single truck.
(Loading effects of front and rear axles can be seen)





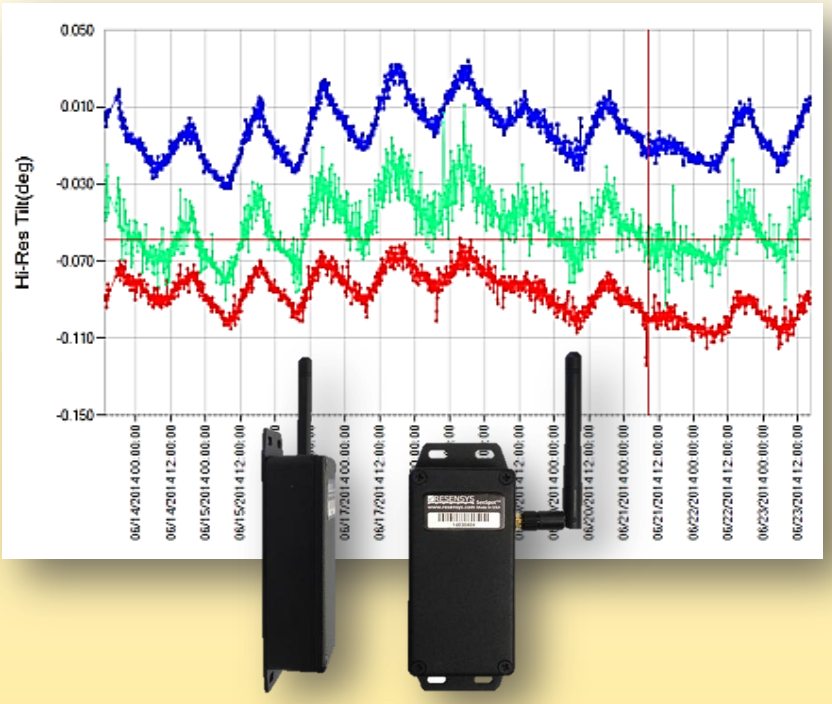


RESENSYS

Tilt/Inclination SenSpot™

A breakthrough tool for precise monitoring of tilt, inclination, settling, bending, deformation, and deflection

- Monitoring deflection, bending, settling of piers, abutments at high precision (resolution 0.00016 degree or 0.5 arc seconds)
- Monitoring vertical/ horizontal displacement in spans, pylons, piers using analytical model
- Detecting change in tilt caused by settling, deformation, or permanent change in loading.
- Detecting any over-tilting or unhealthy change in tilt that may affect overall safety of the structure.

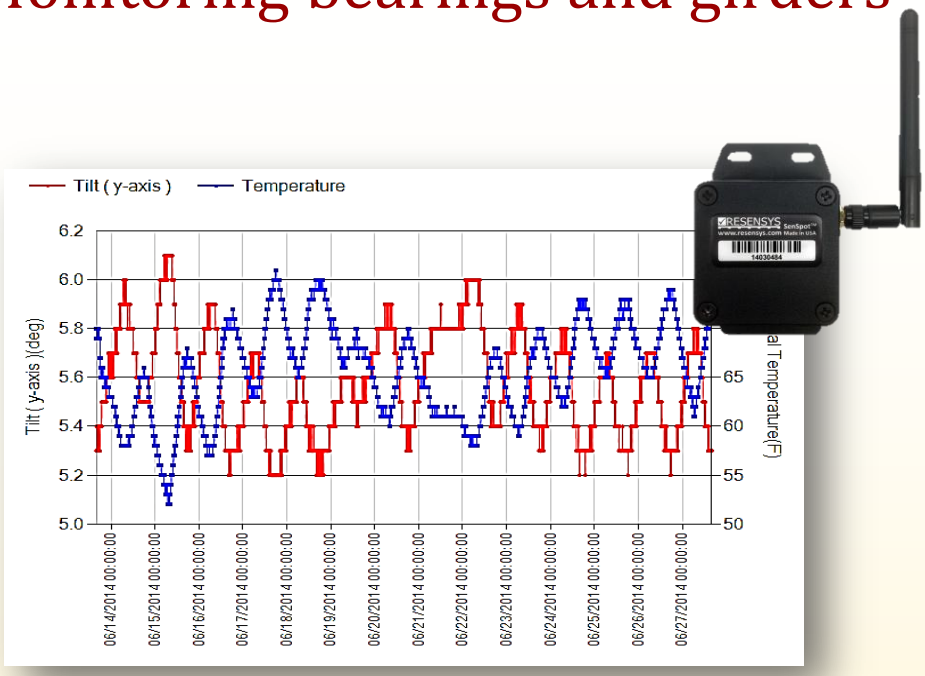


Using Resensys's high precision tilt SenSpot sensors, movement, settling, deformation and abnormal tilting of bridge piers are detected at an early stage, before such issues become major problems or lead to safety compromise and/or road closure.

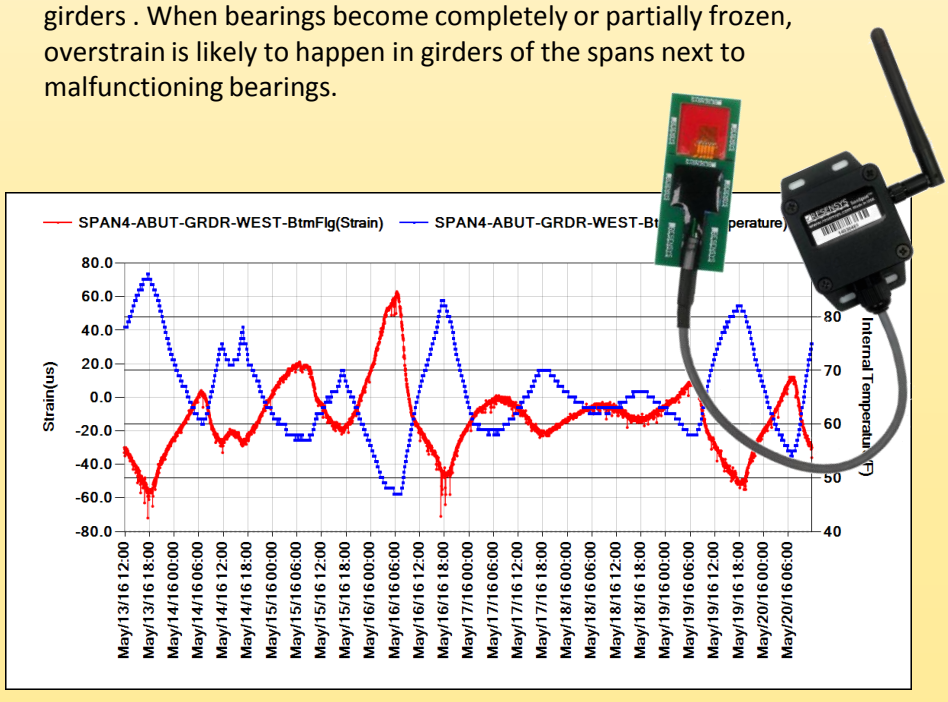
High precision tilt data helps calculate vertical/horizontal displacement of piers, pylons and spans.

RESENSYS

Monitoring bearings and girders



- Bearings are designed to accommodate the expansion and contraction of a bridge deck and superstructure as a result of temperature change.
- Accumulated stress as a result of malfunctioning bearings can damage a structure by forming fatigue cracks in steel, piers, and abutments.
- Resensys SenSpot™ sensors provide accurate information about tilt, temperature and strain on bridge bearings; the system can detect instances where the bearings are partially or completely frozen.
- As a secondary measurement, in addition to the tilt SenSpot™ sensors on bearings, strain SenSpot™ sensors can be used to monitor stress on girders . When bearings become completely or partially frozen, overstrain is likely to happen in girders of the spans next to malfunctioning bearings.



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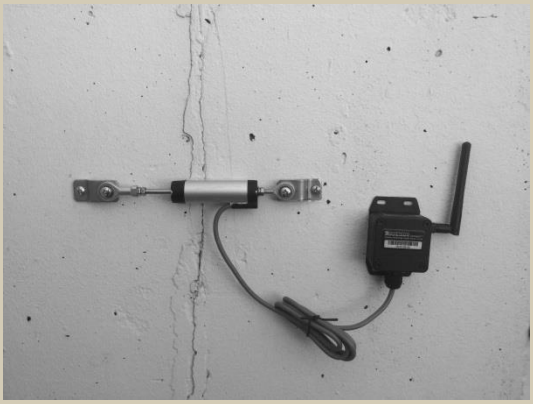
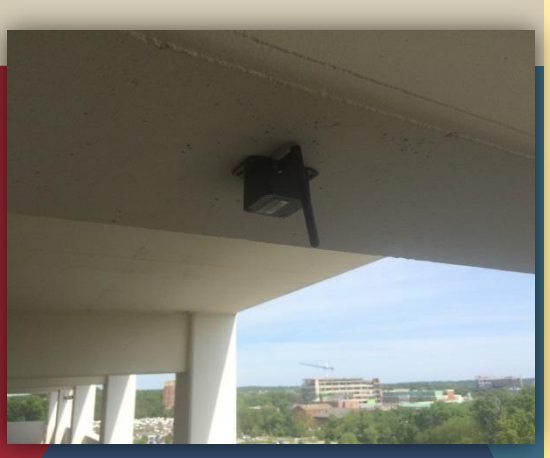


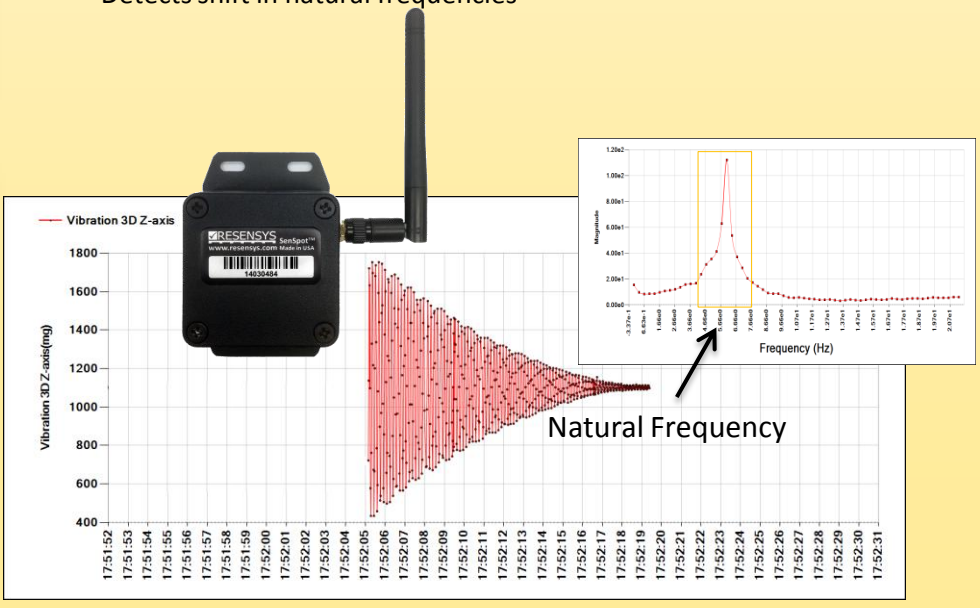


Displacement SenSpot™

- Monitors expansion joints
- Monitors activity / propagation of existing cracks.
- Monitors movement

Vibration SenSpot™

- Monitors single axis or tri-axial acceleration
- Calculates natural frequencies/ modal analysis
- Detects shift in natural frequencies



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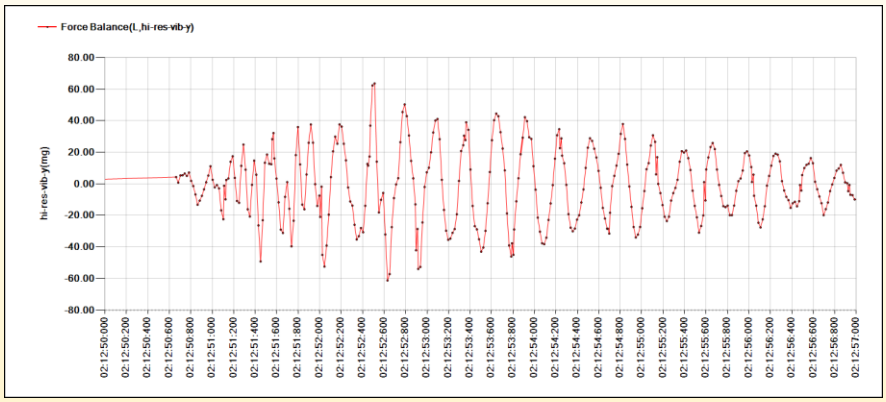
Monitoring buildings: settling, vibration, crack

- Displacement SenSpot™ is used for measurement and progress of the existing cracks in a structure. This device has a sliding element which moves with displacement of structure or growth of a crack.
- Inclination/Tilt SenSpot™ is used to monitor smallest movements in walls or floors caused by settling in foundation.
- Humidity/Temperature SenSpot™ reports environmental conditions.



Seismic activity waveform reported by a Resensys vibration SenSpot™. The device detected an earthquake on December 30, 2015 in British Columbia, Canada.

Other Applications: Tunnels, towers, pipelines, and cranes are more examples of structures that can use Resensys Structural Health Monitoring Systems.

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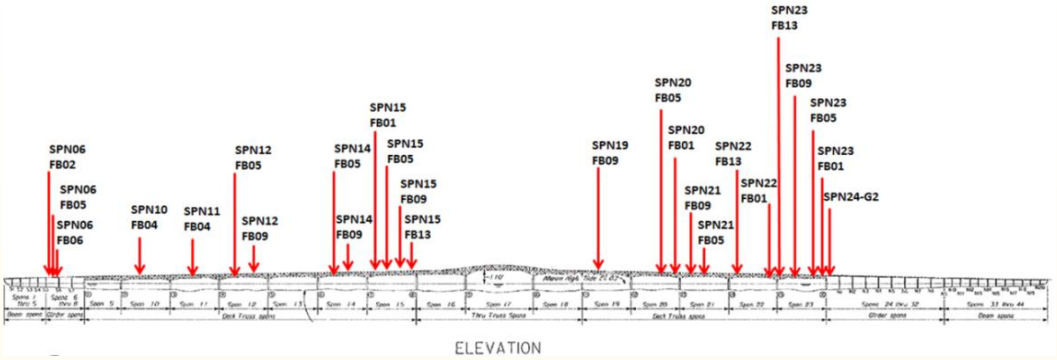
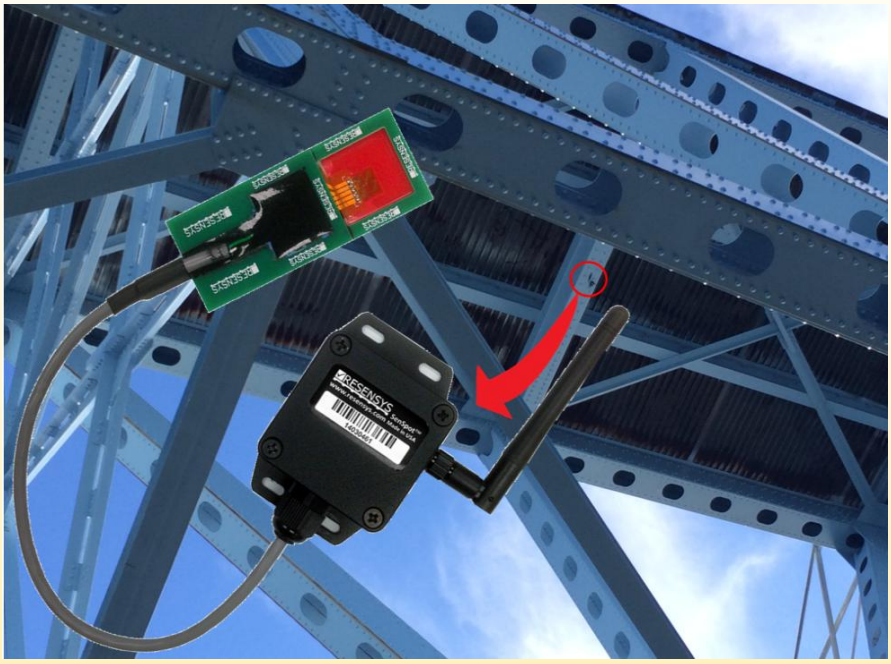
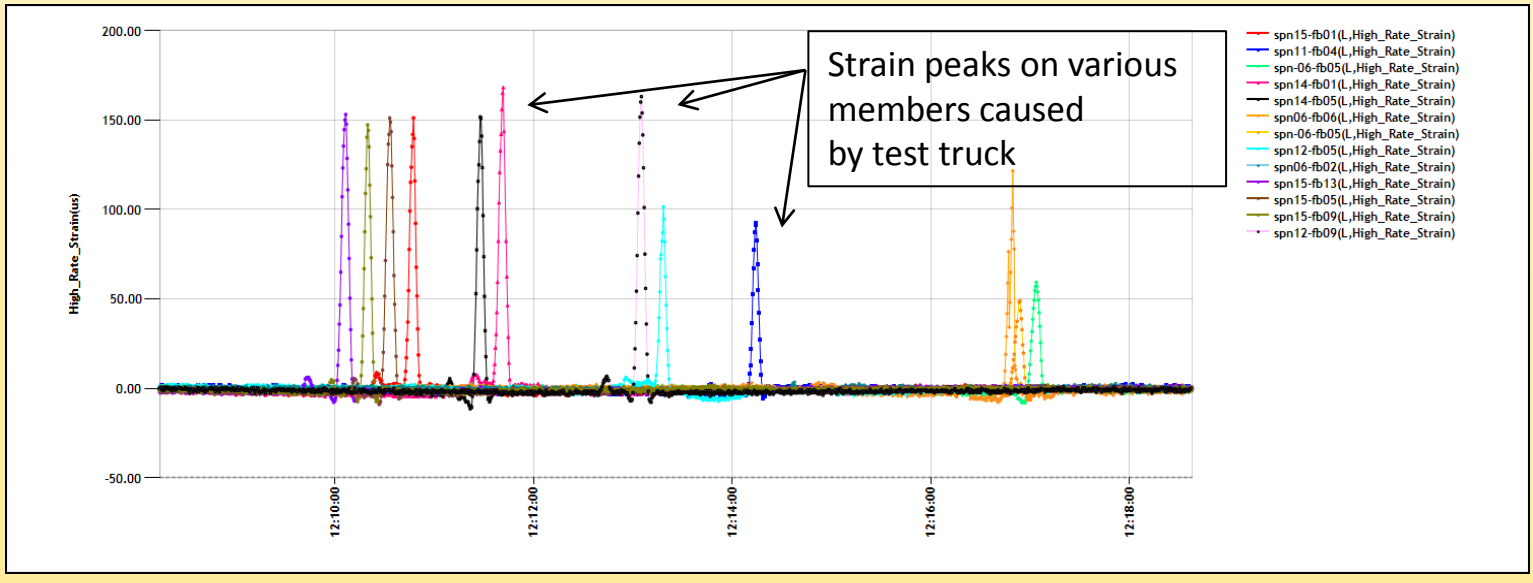
SenSpot™ for Bridge Load Rating





A breakthrough method for fast and accurate bridge load rating:

1. Attach adhesive mount wireless strain SenSpots™ to critical members (e.g., beams, girders, truss members, gussets);
2. Drive truck of known weight over the bridge;
3. Calculate load carrying capacity using the responses



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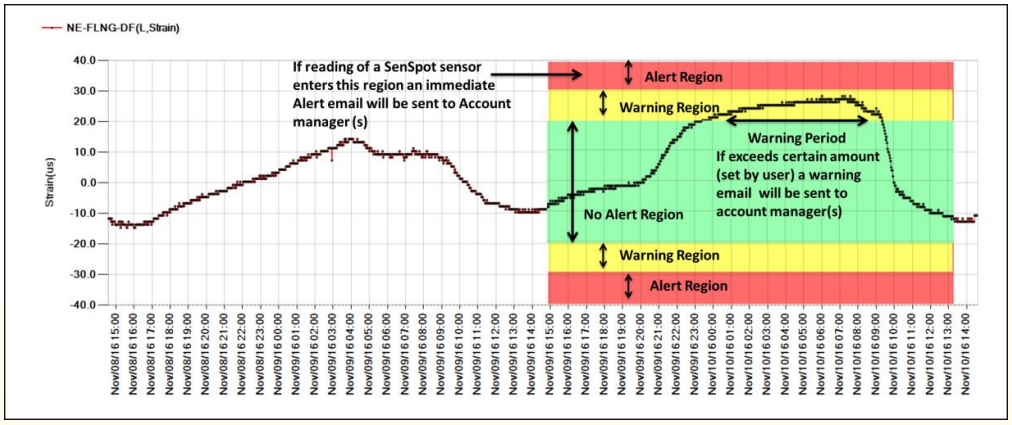
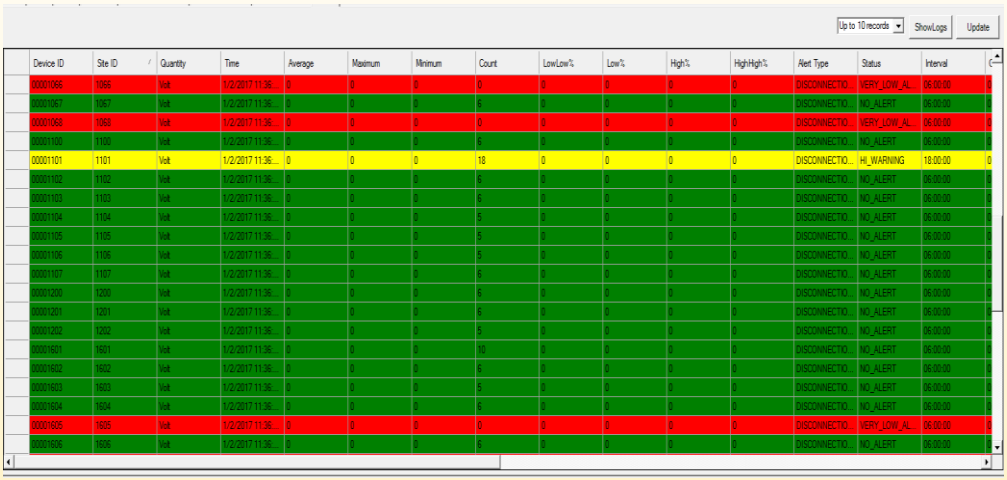
Resensys Monitoring Services

Immediate Alert Services: Facilitate detection of critical failures, when immediate action is needed. Alert administration is conducted through text message and email notifications.

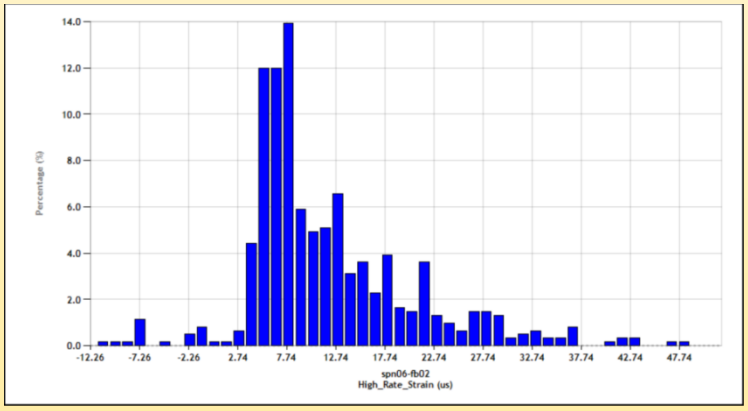


Regular Alert Services: Facilitate detection of non-critical failures, when immediate action is not needed. Emails with detected alerts are administered regularly (daily, weekly, or monthly).



Data Analysis Services:

- ***Statistical analysis:*** statistical properties of the readings of a single or a group of SenSpot sensors (e.g., maximum, minimum, median, standard deviation in a time range).
- ***Comparative Analysis:*** sophisticated regression and correlation analysis tools to compare the relative behavior of time series with respect to each other.
- ***Spectral analysis*** Fast Fourier Transform (FFT) calculations on SenSpot acceleration data for modal analysis, finding natural frequencies.



Data Hosting Services: Data is stored in Resensys's secured cloud servers and backed up periodically. Data can be accessed using Secure Sockets Layer (SSL) from anywhere. Data can be exported to Excel, TXT, CSV, and XML formats.

Featured Monitoring Projects

- **Gold Star Memorial Bridge, Connecticut (I-95 Over Thomas River):** monitoring girders, bearings, gusset plates, and truss members.
- **I-70 Bridge over Patapsco River, Maryland:** monitoring bearings, girders, piers.
- **Robert Norris Bridge, Virginia:** monitoring floor beams, girders.
- **Portage Creek, Victoria Island, Canada:** monitoring piers, abutments, expansion Joints.
- **East Capitol Bridge over Anacostia River, Washington DC:** monitoring piers, abutments.
- **I-495 over Northwest Branch Bridge, Maryland**: monitoring bearings, girders.
- **Soekarno Bridge, Indonesia:** monitoring vibration, temperature, humidity, wind speeds and direction, and strain on pier, pylon, girders, abutments.
- **US40 Bridge over Licking Creek, Maryland:** monitoring bearings, girders.
- **I-81 Bridge over Potomac River, Maryland.** monitoring piers .
- **US Air Force C-130 military airplane:** monitoring cargo ramp.
- **US-522 over Potomac River, Maryland**: monitoring bearings, girders.
- **Calgary Airport Tunnel, Canada:** monitoring temperature, displacement across the tunnel.
- **SR-16 Clay County Culvert, Florida:** monitoring strain on concrete culvert pipes.





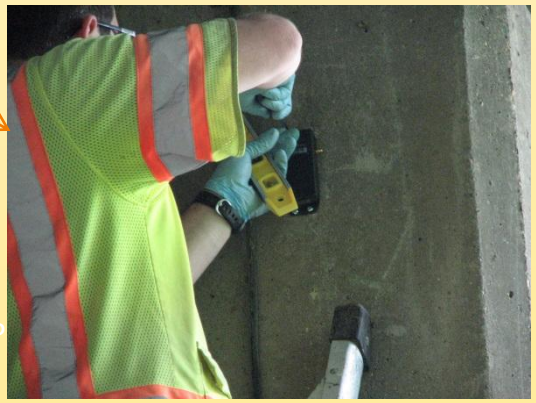

RESENSYS

Monitoring Scour-Critical Bridges

East Capitol Bridge over Anacostia River, District of Columbia

In June 2014, Resensys SenSpot sensors were used on piers of East Capitol Bridge across Anacostia River to monitor their movement, settling and deflections. Piers of highway bridges over rivers are vulnerable to bridge scour caused by fast moving water from around bridge abutments or piers. Deep bridge scour removes the riverbed materials beneath the piers and abutments footings which results in deflection, movement and settling of the piers and compromise of bridge's stability and safety.

Resensys High Precision Tilt SenSpot sensors provide an ideal solution for structural health monitoring of scour critical bridges by monitoring tilt (inclination) on piers and abutments with a resolution of 0.00016 degree (0.5 arc seconds).



RESENSYS

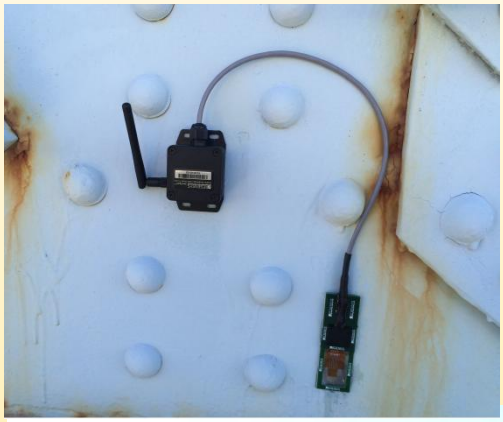
Monitoring Major Structures

Gold Star Memorial Bridge, Connecticut

In December 2015, a Resensys structural health monitoring system was deployed on Gold Star Memorial Bridge which carries Interstate 95 over Thomas River.

The 6000-foot, 27-span bridge consists of 16 girder/floor-beam/stringer spans and 11 main deck truss spans composite with a reinforced concrete deck, supported by abutments and piers. The Resensys remote monitoring system installed on the Gold Star Memorial Bridge included high rate strain SenSpot sensors, tilt SenSpot sensors, SeniMax data loggers and remote communication gateways, and auxiliary signal repeaters.

In addition to continuous monitoring of girders, bearings, gusset plates, and truss members, load rating tests were conducted on Gold Star bridge by Connecticut Department of Transportation using Resensys high rate strain SenSpot sensors.



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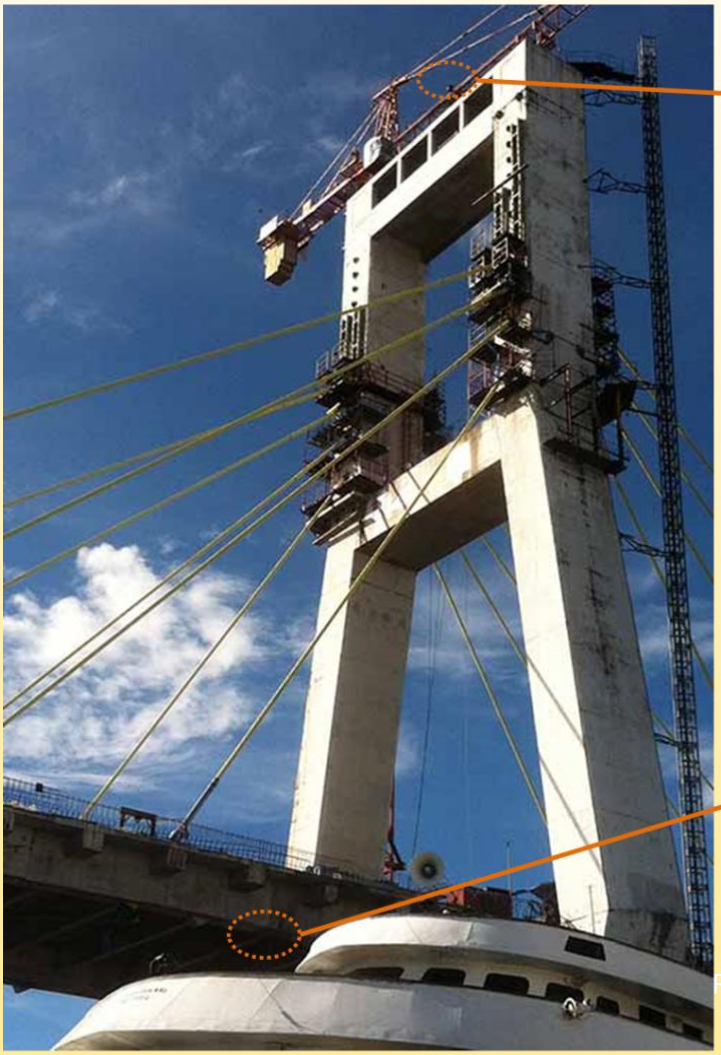
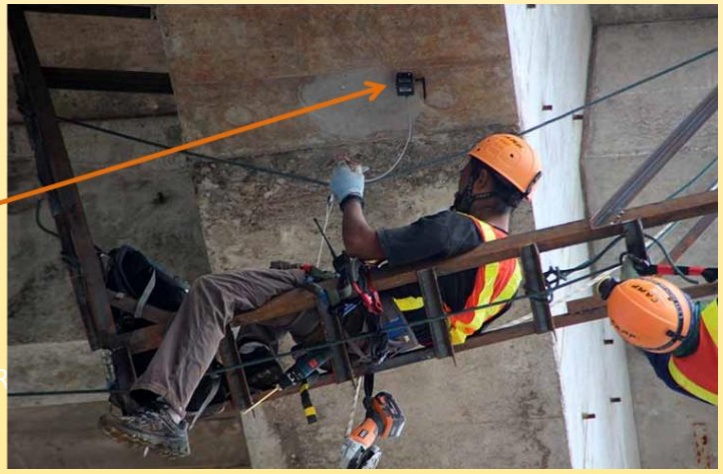
Monitoring Major Structures

Soekarno Bridge, Indonesia

In December 2015, Soekarno Bridge in Manado, Indonesia was instrumented with a network of 90 Resensys wireless SenSpot sensors. The wireless SenSpots included vibration SenSpots, high precision inclinometer SenSpots, strain gauge SenSpots, temperature SenSpots, and anemometer SenSpots.

All SenSpots sensors are wireless and transmit data to a SeniMax gateway data logger, which streams live data to a secured cloud based server, accessible through the internet from everywhere in the world.





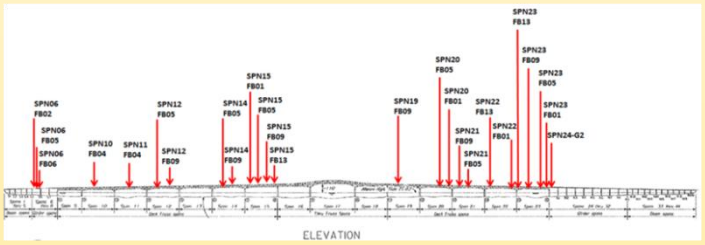
RESENSYS

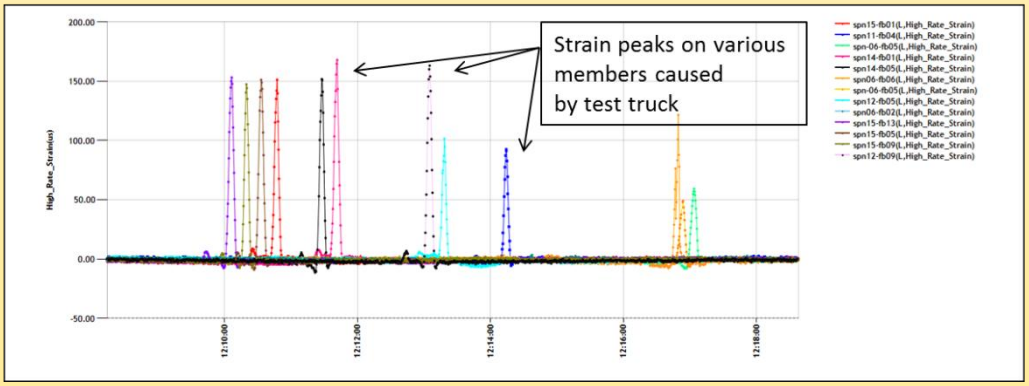
Monitoring Major Structures

Robert Norris Bridge, Virginia

The Robert O. Norris Jr. Bridge which carries Route 3, spans the lower Rappahannock River from Grey's Point to White Stone, Virginia. This structure has a total length of 9,985 ft consisting of 44-spans of varying construction. In October 2015, a Resensys structural health monitoring system was deployed on the structure for monitoring floor beams and girders. The system includes High rate strain SenSpot sensors, SeniMax gateways, and signal repeaters.

Resensys technology offers a breakthrough method for long term monitoring and fast and accurate bridge load rating. By attaching adhesive mount wireless strain SenSpots to critical members (e.g., beams, girders, truss members, gussets) and driving a truck of known weight over the bridge load carrying capacity will be calculated using the responses of the members.





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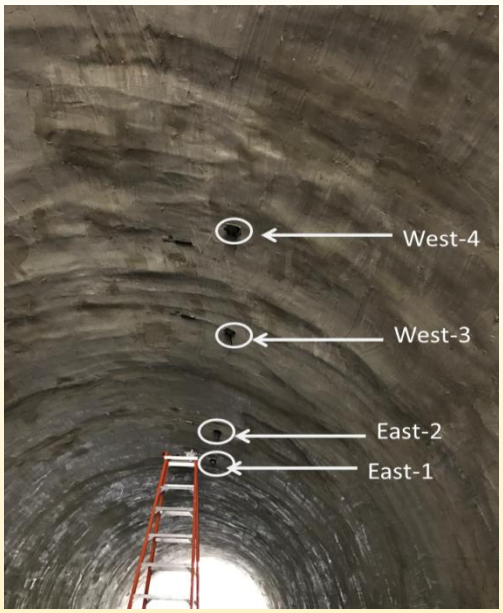
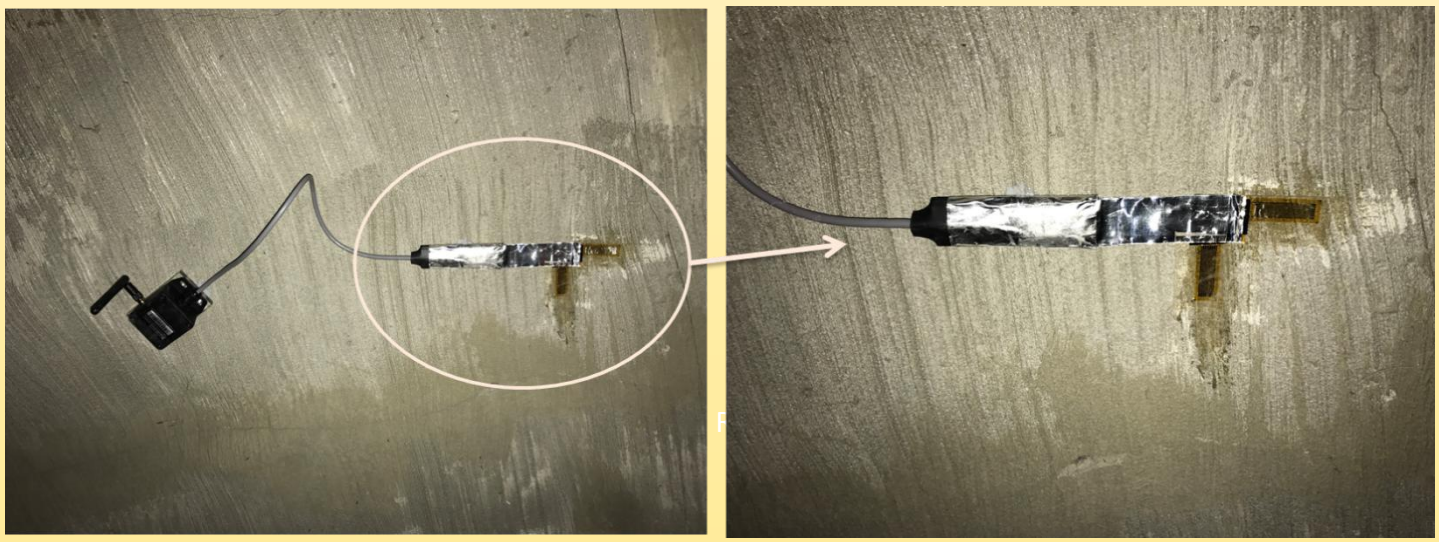
Monitoring Stress on Concrete Culvert Pipes

SR-16 Clay County , Florida

In November 2016, a Resensys structural health monitoring system was deployed on a culvert running under Florida SR-16 in Clay County. The system consists of four high rate strain SenSpot sensors and one SeniMax data logger and remote communication gateway.



Using the system, live load test was used to confirm structural integrity of the structure and to ensure its capability to withstand its rated load.



RESENSYS LLC

Resensys was founded in 2008 with the mission of protecting infrastructure systems against aging, deterioration, and collapse. For this purpose, Resensys offers a range of structural monitoring solutions based on its award winning ultra low power wireless sensor network technology, known as SenSpot™. Resensys wireless SenSpot sensors provide a versatile platform for remote monitoring of structures on a wide range of structural quantities; examples include strain (stress), vibration, tilt, inclination, temperature, humidity, and acoustic emission events. Having monitored all these important structural quantities in real time, SenSpot sensors provide reliable tools to measure overstrain, metal fatigue, formation of cracks, movement and stability of foundation, as well as monitoring vibration and performing modal analysis. Currently, Resensys's SenSpots are the world's most energy efficient wireless monitoring sensors and a SenSpot sensor provides a minimum of 10 years of monitoring using a small ½-AA battery.

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RESENSYS

Protecting Infrastructure with 21st Century Technology