Barge Collision/Impact Detection and Monitoring for Waterway Bridges Piers and Structures

with Resensys Wireless Solar Powered Cameras, Resensys Wireless Vibration/ Acceleration and Resensys Wireless Tilt/Inclination SenSpot™ Sensors

A **Barge** is a flat-bottomed boat for carrying freight, typically on canals and rivers or other inland waterways, either under its own power or towed by another. This shoal-draft boat is built principally for river and canal/channel transport of mass goods and is ideal for applications where navigation in shallow waters as well as deeper water stability is required. Nowadays, barges may be self-driven, usually with a slow-revving diesel engine and a large-diameter fixed-pitch propeller. Otherwise, "dumb barges" are towed by tugs, or pushed by pusher boats. In comparison with a towed barge, a pusher system has developed handling and is more efficient, as the pushing tug becomes "part of the unit" and it makes a contribution to the momentum of the entire.[1]

Barge Collision/Impact is a potential danger for piers of bridges located in navigation waterways. The dynamic impact process is influenced by many factors, including barge mass, impact velocity, oblique impact angle, water elevation, material properties of pier members, soil properties, etc. and is addressed in AASHTO design methods and specifications.[2]

While equally important to any country's economy, the domestic waterway system in the USA is an essential element of the country's entire transportation system and contributes to the success of the country's economy. The US has more than 11,500 miles of navigable waters used for transportation of commercial building block supplies. The figure below shows the paths of the navigable inland waterways system. Traversing about 38 states of USA, the inland waterway system functions are similar to the highway system with respect to transportation of commodities, goods and fuels. These inland waterway systems transport coal, gasoline, iron, steel, grain, chemical products, plastic, aggregates and other petroleum products across the USA heartland. So, USA inland waterways make a crucial contribution to the national economy.

The Department of Transportation (DOT) has planned for a rise in the annual traffic on the inland waterways system over the next 20 years. This occurs in conjunction with increasing pressure on the US highway system, because barge moving and transportation in waterways alleviates congestion/crowding on the highways. Barge transportation compares favorably to other modes of freight transportation in measures of capacity, congestion, emissions, and safety.

[1] https://en.wikipedia.org/wiki/Barge
[2] Wang, W., & Morgenthal, G. (2018). Reliability analyses of RC bridge piers subjected to barge impact using efficient models. Engineering Structures, 166, 485-495.

USA Inland Waterways[3]

So not only is barge transportation volume on waterways expected to increase, but also as the highways and roads in the USA continue to be improved, developed and modified, the number of bridges over the inland waterways and coastal waterways is expected to increase and to carry higher traffic volumes. Bridges not only span the gap, but in doing so, must resist potential hazards and dangers such as gravity, wind, floods and earthquakes to stay operational and safe. These bridges are usually huge structures that perform as key and fundamental routes for the local residents and the economy of the area. The local and national economy depends on the strength of these bridges to be operable even during or after extreme incidents/natural disasters. One of the important incident risks to bridges in waterways is the risk and hazard of barge and vessel collision/impact that causes significant damage to the river bridge's structure. Since, the highway system overlaps with the waterway system, the the risk of barge impact into bridge piers and structures affects both the waterway and highway systems and can be considerable. If collapse takes place, economic loss is suffered due to subsequent traffic rerouting and bridge replacement costs. Additionally, fatalities may occur if the roadway is occupied during or shortly after the collapse event.

In the vicinity of bridges that span navigable waterways, pre-specified vessel transit paths are indicated by navigation lights and physical barriers (fender systems) to guide the in-transit waterway traffic under a designated portion of the bridge. For a given vessel in transit, however, there is a risk that the vessel will become aberrant (e.g., as a result of pilot error or poor navigational conditions) and stray from the intended vessel transit path, striking a nearby bridge structural component.

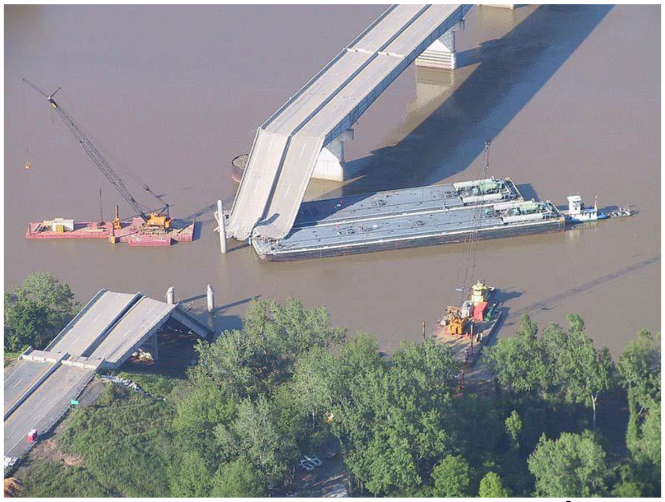
Accounting for waterway vessel collision is thus an integral component of structural design for any bridge spanning a navigable waterway.

In the event of a vessel-bridge collision, large lateral forces can be transmitted to the impacted bridge structure. Furthermore, as an impacted bridge absorbs dynamic collision load, significant inertial forces may develop that, in turn, produce additional structural demands. Vessel-bridge collision forces can, therefore lead to severe structural damage and even catastrophic failure of the impacted bridge, or of roadway spans in the vicinity of the impact location.[4]

[3] https://www.infrastructurereportcard.org/wp-content/uploads/2017/01/Inland-Waterways-Final.pdf
[4] Davidson, M. T. (2010). Probability assessment of bridge collapse under barge collision loads. University of Florida.

Data shows that bridge collisions are not infrequent. Bridge lateral collision forces from barges/vessels resulted in around 2% of the total bridge failures in USA from1987-2011. From 1960–2002, 31 major bridge failures happened worldwide totally as a result of barge/ship/vessel collision and impact (AASHTO 2009). These incidents cost more than 342 lives and caused significant economic loss. The U.S Coast Guard marine casualty database further cites 1,054 collisions/ impacts (42% of all collisions) from towboats and tugboats between 1992 -2000, and 828 collisions from freight barges (33% of all collisions) during the same period. [5]

The figure below shows one of the big recent barge collisions in the USA. On May 26, 2002 on the Arkansas River in Oklahoma, a barge turned away from the main channel and hit the unprotected and exposed bridge piers, resulting in catastrophic damage.



Barge collision with I-40 Bridge in Oklahoma[6]

In the event of a collision, catastrophic damage could occur immediately, in which case immediate notification of this damage is important so that appropriate action can be taken in a timely manner throughout the transportation systems, or else damage could be undetected until conditions are such that failure occurs at a future date. Sensing technologies can be put in place for initial damage detection/assessment and also ongoing monitoring of bridges that have been evaluated as likely to have a high probability of barge collision. By allowing early warning that collision impact has occurred and providing information to support the timely assessment of the damage cause by this impact, authorities can take action to mitigate the economic and safety implications of these collisions.

The applicable, measurable and monitorable quantities and qualities in Barge Collision/Impact Detection and Monitoring are tilt, vibration (single axis acceleration or tri-axial acceleration; X, Y and Z axis), ambient temperature and visual feedback.

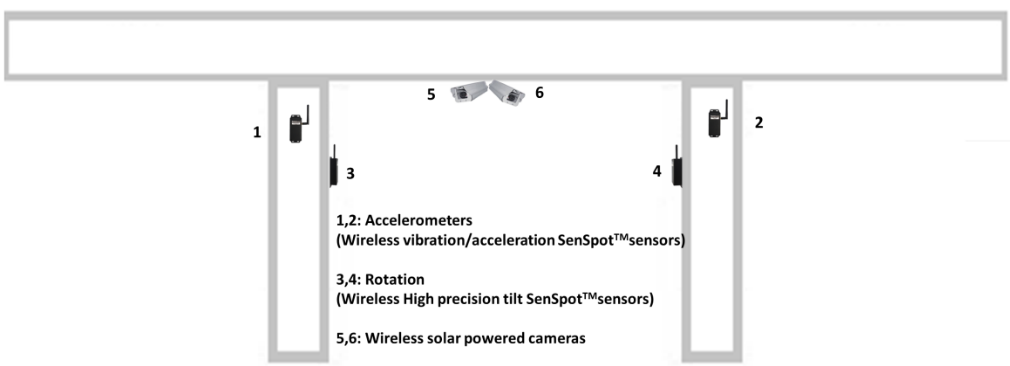
Sensors that monitor acceleration and rotation on the piers/ abutments provide information regarding vibration and tilt, allowing for investigation and decision support regarding damage detection and quick structural assessment after barge collision to determine negative impact on structural integrity.

[5] Ribbans, D. A. (2015). Structural Vulnerability Assessment of Bridge Piers in the Event of Barge Collision.
[6] http://en.wikipedia.org/wiki/I-40_bridge_disaster

Resensys' unique wireless structural health monitoring solution (SHM) is well-suited for barge collision/impact monitoring and detection. The Resensys Wireless Vibration/Acceleration SenSpot™ sensors are installed on bridge piers, and they are capable of monitoring acceleration on the pier constantly. Depending on the situation, these Wireless Vibration/Acceleration SenSpot™ sensors information and data must be combined with sub-arc second accuracy tilt measurements using Wireless High Precision Tilt SenSpot™ sensors for pier rotation monitoring, and corresponding visual feeds from the Wireless Solar Powered Camera for in-depth and thorough monitoring of the barge collision on a bridge. This allows complete condition awareness and remote monitoring on bridges for barge collision, and is particularly useful to allow quick assessment of conditions after barge collision. This can be particularly important when timely physical access to these assets for inspection is challenging.

Figure below illustrates the approach for barge collision detection:

- Sensor group 1, 2: These are wireless vibration SenSpot™ sensors (accelerometers). These devices constantly monitor acceleration on the pier, taking up to 400 samples of tri-axial acceleration per second. Barge collisions are reliably detected using the 3-dimesional acceleration data.
- Sensor group 3, 4: These are wireless high precision tilt/inclination SenSpot™ sensors. These devices constantly monitor rotation on the piers, producing sub-arc second accuracy tilt measurements and data.
- Sensor group 5, 6: These are wireless solar powered cameras. While barge collision and assessment of the damage upon an impact is initially done using vibration and tilt, a confirming and surrounding visual assessment and identification of the responsible source can be provided using cameras.



Barge collision detection approach using Resensys accelerometer, high resolution tilt SenSpots and Image monitoring

Resensys Wireless SenSpot™ sensors measurement responses and collected data have the capability of high rate data transmission, and adjustable triggering threshold and sampling interval. They are suitable for barge collision monitoring and detection due to their accurate, reliable, and repeatable results, without need for calibration in the field. The system delivers precise and detailed data. Resensys SenScope™ software provides data visualization, data analysis and live "image monitoring". Resensys monitoring software can be set to provide alerts notifications when pre-established thresholds have been exceeded to allow proactive and timely action to be taken.

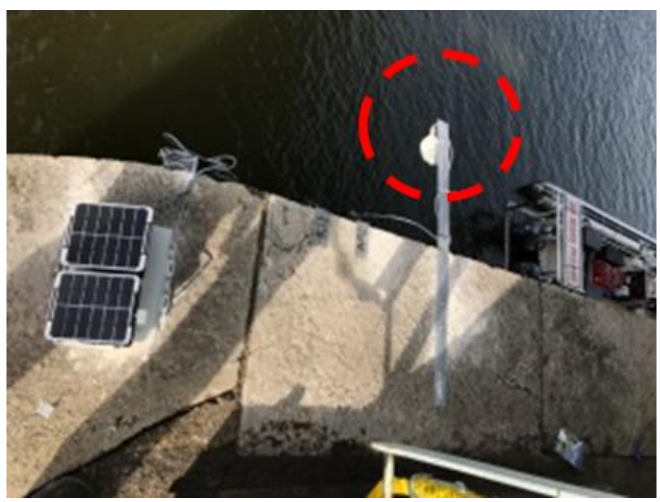
Another key benefit of Resensys sensors is their wireless ultra-low power design, which provides a great deal of flexibility. Resensys' wireless products are quick,easy and convenient to install, which lowers implementation costs and time because there is no additional wiring required. This means that Resensys solutions are a cost-effective way for owners to get the quality data they need for barge collision detection. Resensys' ultra-low power design means that the sensors have a 10-yr battery life. This allows for both short and long term use, without the need for battery replacement (for long term installations) and intra-test charging (for short term installations/ assessments). After installation, SenSpot™ does not need battery replacement or any other maintenance during its whole service life.

Resensys Wireless SenSpot™ sensors and devices monitor structural quantities such as vibration, tilt and ambient temperature in concrete, steel and composite materials under wet, humid and extreme weather conditions (-40°C to +65°C or -40°F to +150°F). The products are corrosion resistant and can withstand salty environments. They are small in size and lightweight.

A Resensys Barge Collision/Impact Monitoring and Detection system for bridges and other structures solution comprises the following components:

- SenSpot™ sensors and Wireless Solar Powered Camera (for vibration, tilt and image monitoring): which are attached to a bridge/structure and its piers. The required number of sensors per structure depends on design and barge collision monitoring needs).
- SeniMax™: gateway/ data logger, which collects SenSpot™ data at the site and sends it to a remote server (one unit can cover as many as 100 SenSpot™ sensors).
- Repeater: may be used to extend the range of the SenSpot™ sensors.
- SenScope™: software for data analysis, visualization and image monitoring results.

Resensys Wireless Solar Powered Camera on a bridge for barge collision detection and monitoring



Resensys Wireless Solar Powered Camera on a bridge for barge collision detection and monitoring

Resensys Wireless Vibration/Acceleration SenSpot^{TM} sensor on pier of a bridge for measuring pier acceleration and barge collision detection and monitoring

Resensys Wireless Tilt/Inclination SenSpot^{TM} sensor on pier of a bridge for measuring pier rotation and barge collision detection and monitoring

Resensys Wireless SenSpot^{TM} sensors are easily placed/installed on critical elements (specific pier, abutment, etc. that are under possible risk of barge collision) as determined by inspection (before or after barge collision) or authority's/client's suggestion. Since they are wireless, no additional wiring is required, and the sensors are mounted with adhesive or flange mounted depending on the application. A SeniMax^{TM} data acquisition unit is conveniently mounted nearby (within 1.0Km (0.62miles) free space of the SenSpot^{TM} sensors) and a SenScope^{TM} module is installed on the client's/authority's laptop or PC.

A complete Resensys SHM system includes software and hardware components for (1) the reliable collection of SenSpot™ data, (2) aggregation of the data, (3) the addition of timestamps, (4) communication of encrypted data to a remote server, and finally, (5) an interface for data visualization and detection of structural issues. The figure in the next page shows a picture of a practical Resensys SHM system, which can be used for barge collision detection and monitoring of bridge structures.

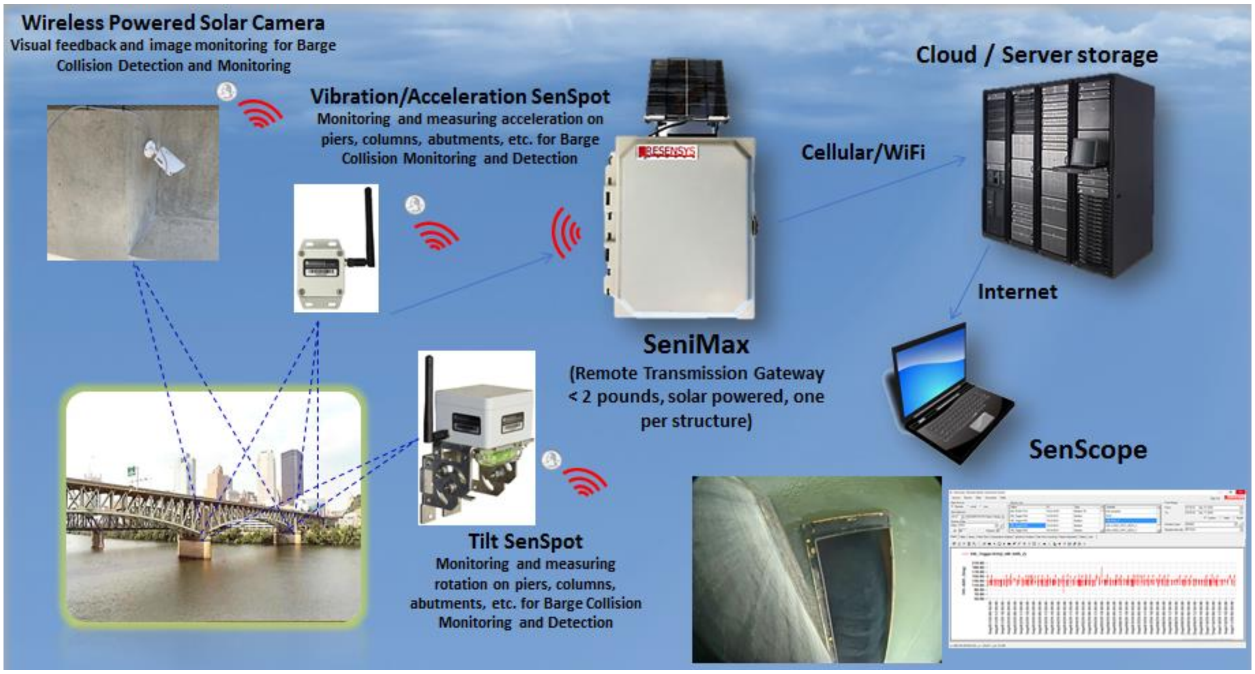
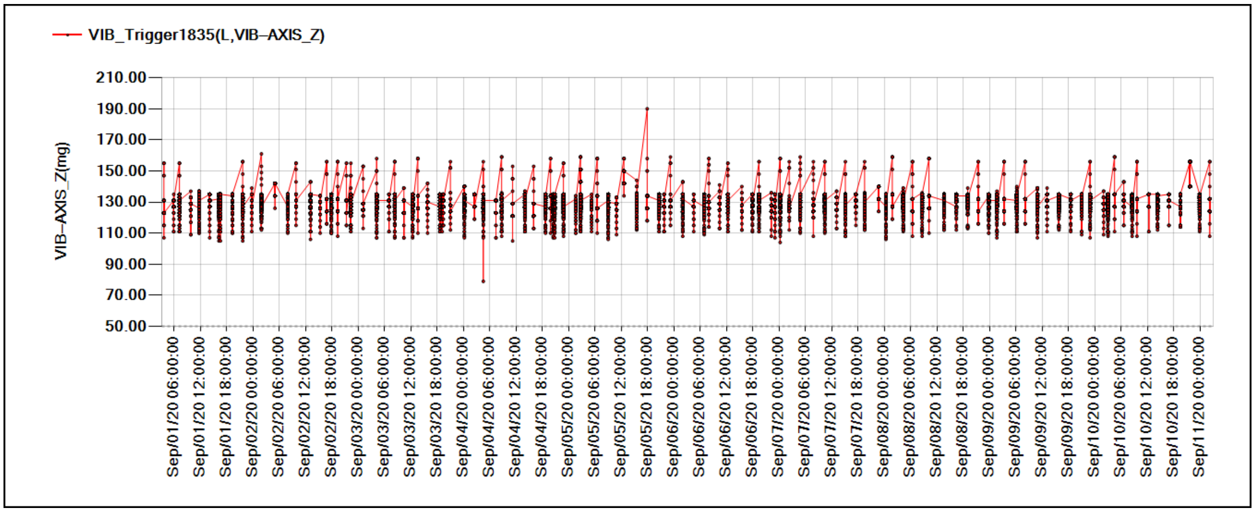
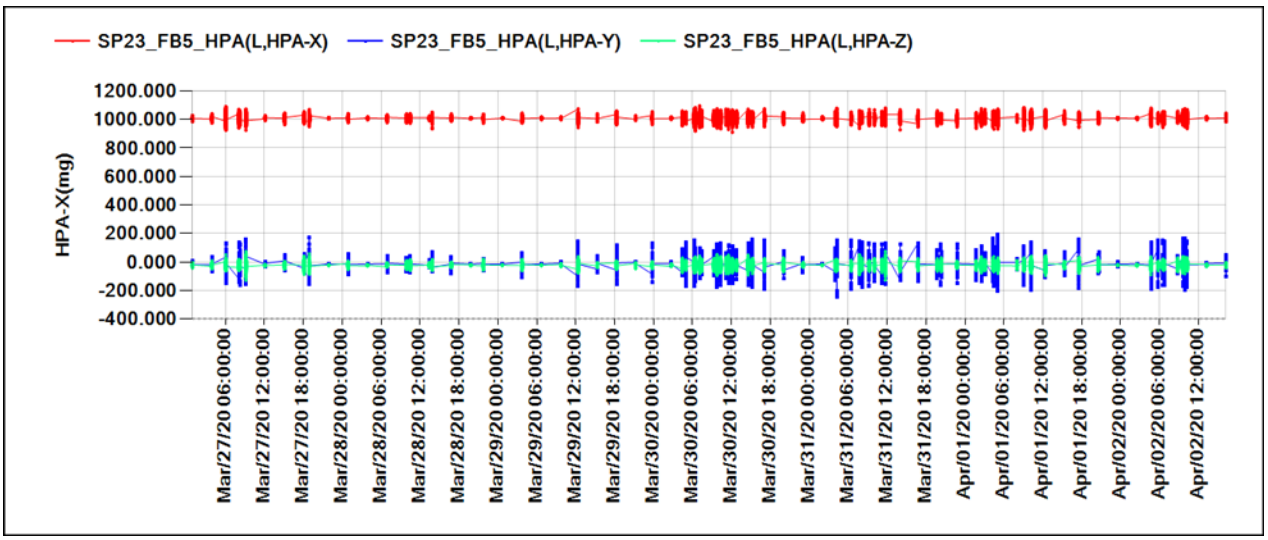


Illustration of Resensys SHM based on [SenSpot™](#) sensors and Wireless Solar Powered Camera for barge collision detection and monitoring of bridge piers

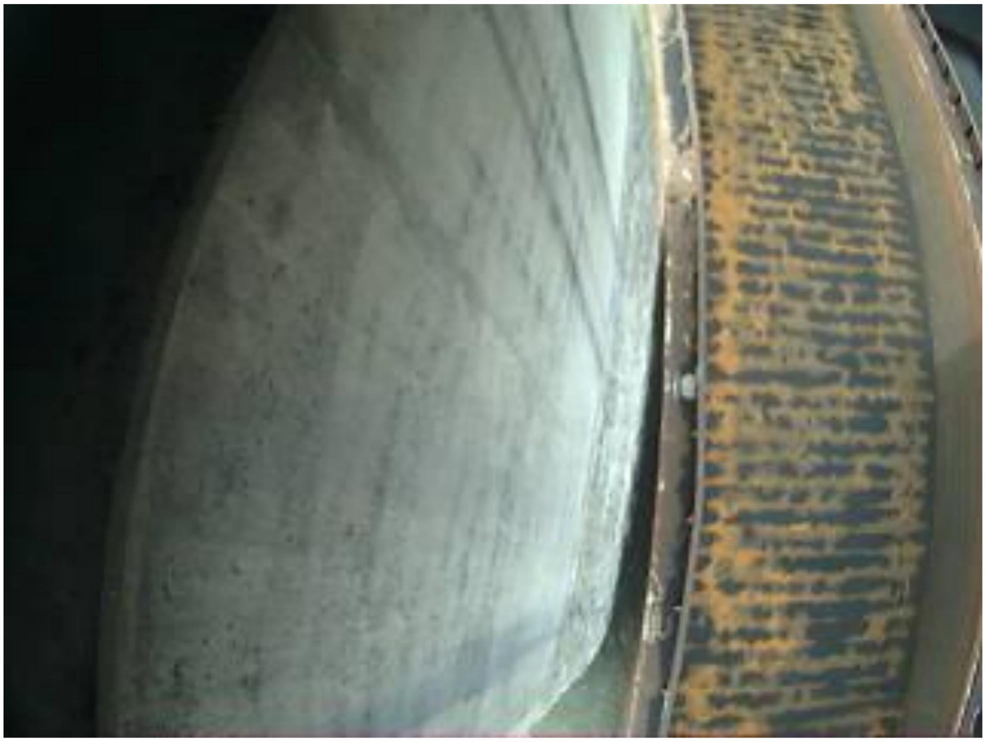


Vibration (Acceleration-X) measurements of an installed [Wireless Vibration/Acceleration SenSpot™ sensor]() on the pier of a bridge for barge collision detection
(Resensys [SenScope™]() software has the capability of data analysis and visualization).



Accelerometer measurements (X, Y and Z) of an installed [Wireless Vibration/Acceleration SenSpot™ sensor]() on the pier of a bridge for barge collision detection.
(The device can take up to 400 samples of tri-axial acceleration per second. Barge collisions are reliably detected using the 3-dimesional acceleration data).
(Resensys [SenScope™]() software has the capability of data analysis and visualization).


A typical picture taken by Resensys Wireless Solar Powered Camera indicating the field of view when there is a barge floating in close proximity of the pier.
(This kind of picture can be time-stamped).


A typical picture taken by Resensys Wireless Solar Powered Camera that shows a barge at very small clearance of the bridge pier is passing (at the time of the detected impacts)
(This kind of picture can be time-stamped)

Technical Specifications:

	Wireless Tilt SenSpot™ sensor	Wireless Vibration/Acceleration SenSpot™ sensor
Size (Dimension)	-Transmitter Dimension: 79.6mm(3.13”)x74.6mm(2.94″) x 52mm(2.05”) -AssemblyDimension:120.8mm (4.76”) x 96.6mm (3.8”)x149.9mm (5.9”)	50mm (1.96”) x 50mm (1.96”) x 34mm (1.34”)
Weight	180 g (6.3 oz.)	About 120grams (4.2 oz.)
Mounting	Flange-mount or adhesive tape	- Self-adhesive, no drilling is required (e.g. steel) -Flange-mount, drilling is required (e.g. concrete)
Accuracy (Resolution)	-Narrow Range HRT: ≤0.0003º(5.2μrad) -Regular tilt : 0.1º	4 ug (“g” is the acceleration of gravity)
Frequency of Sampling	Producing sub-arc second accuracy tilt measurements and data	(Taking up to 400 samples of tri-axial acceleration per second)
Measurement Range	-Operating range: • Narrow Range High Resolution Tilt : ± 0.5º(with respect to vertical position) • Regular tilt: all directions -Linear range: • Narrow Range HRT: ±1º • Mid-Range HRT: ±10º -Repeatability: • Narrow Range HRT: ≤0.001º (17.5μrad) • Regular Tilt:1º -Time constant: ≤1sec(High resolution tilt)	±2g (“g” is the acceleration of gravity)
Alert Threshold	Fixed and Adaptive Threshold alerts	Fixed and Adaptive Threshold alerts
Operating temperature	-40°C to +65°C(-40°Fto +150°F)	-40°C to +65°C (-40 °F to +150°F)
Lifetime	battery life of 10 years (Ultra-low-power)	battery life of 10 years (Ultra-low-power)
Installation Time	1-2 minutes	1-2 minutes
Complementary sensing	temperature, battery voltage, etc.	temperature, battery voltage, etc.
Communication range	1.0km(0.62mile)free space	1.0km(0.62mile)free space
Power source	Replaceable lithium ion battery	Replaceable lithium ion battery
Wireless communication	no wiring is required for data collection- IEEE 802.15.4	no wiring needed for deploying the system- IEEE 802.15.4