TEST REPORT

Sensitive Strain Gauge Testing of Large-Diameter Culvert Rehabilitation

Angus W. Stocking, L.S.

In March 2010, an unusually configured culvert passing under Florida State Route 16 was rehabilitated with Permacast® PL-8000, a high strength, fine aggregate composite concrete, formulated by AP/M Permaform.

Florida Department of Transportation (FDOT) has been monitoring the project closely, with the structural integrity of the rehabilitation of particular interest. PL-8000, whether applied with AP/M Permaform's CentriPipe® SpinCaster, or in special cases such as the SR16 project, sprayed onto the internal walls of failing structures, is engineered to provide a structurally sound pipe or culvert, independent of the failing substrate.

The material is a high strength, high build, abrasion resistant and corrosion resistant fine aggregate concrete based on advanced cements and additives. Graded quartz sands are used to enhance particle packing and further improve the fluidity and hardened density. The resultant concrete possesses excellent thin-section toughness, high modulus of elasticity, and self-bonding properties. Fibers are added to aid in the casting process, for increased cohesion, and to enhance the flexural strength of the liner. It is a very strong material, and outstanding for sewer and pipe rehabilitation.

Ed Kampbell, President of Rehabilitation Resource Solutions, has been an AP/M Permaform consultant for several years, developing their design methodology, writing the engineering design guides and technical bulletins, and helping designers make the most of new cementitious materials – particularly PL-8000. Kampbell notes that making the most of this material begins with understanding the details of how culvert rehabilitation differs from burying new pipe. He calls them 'buried bridges' based on their in-place structural performance. The SR 16 culvert was a very good application of this concept.

New cast pipes created with CentriPipe® and PL-8000 can be startlingly thin; in this culvert rehabilitation the total thickness was just a two-inch layer of new concrete, in a failing, 13-foot diameter, corrugated metal pipe. This thickness was designed and certified by engineers for the rehabilitation, and is actually conservative given the strength characteristics of PL-8000. Still, many designers contemplating trenchless sewer rehabilitation have asked for verification of the real world structural performance of PL-8000 and the CentriPipe® system. In 2016, after six and one-half years in place, the evaluation of the SR 16 culvert proved to be an ideal opportunity to answer these remaining performance questions.

In late 2016, visual inspection and sophisticated strain gauge testing of the Florida SR 16 culvert provided solid evidence that PL-8000, is a structurally sound and long lasting rehabilitation technology. After reviewing the report based on strain gauge testing, FDOT District 2 Maintenance Engineer, Robert S. Kosoy, P.E., said, “The strain data show that the movements under heavy truck loading were minor and that this 13-foot diameter corrugated metal pipe, which was lined in 2010, continues to perform well. Thanks for the report.”

2010: Rehabilitation Project

Elements of this structure presented a uniquely difficult rehabilitation project. At 13 feet in diameter, it is quite large. Additionally, it is a bolted multi-plate pipe culvert with very little cover, about a foot at the crown of the roadway and tapering to, literally, just ten inches from top of pavement to culvert at the edge of a paved two lane highway.

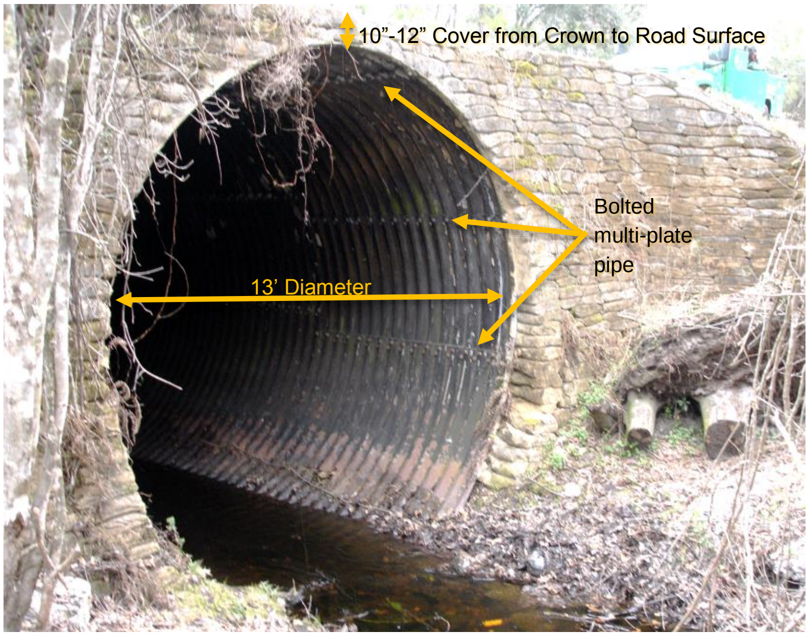

Figure 1: Florida State Route 16 Culvert Attributes

Tropical Storm Faye blew through this region in 2008, and heavy storm flows created a large void on one side of the culvert, which was also visibly rusting and failing. At the time, a regional maintenance manager named Spencer Townsend commented that a couple of minivans could have fit into the hole. Given the relative thinness of cover, and the void, it was clear that any rehabilitation technique used had to have outstanding structural strength. This ruled out sliplining and cured-in-place-pipe (CIPP), which would also have been prohibitively expensive at this diameter. To make matters even more challenging, FDOT and the affected Florida counties (Clay and Nassau) really wanted to keep SR 16 open during rehabilitation, as it is an economically important truck route connection between I-95 and US 301 in the center of the state.

In response to these challenging circumstances, FDOT and Transfield Services (contracted regional maintenance managers) decided on PL-8000 – the high strength material used in the CentriPipe® process. The project was a pilot project in Florida. The material had previously been used for years in smaller diameters, but this was one of the first times on such a big pipe. However, PL-8000 is very high strength, and it includes an additive that makes the material very sticky, and is very well suited for spraying onto a pipe.


Figure 2: Fully structural, smooth, watertight rehabilitated culvert

Following installation, the rehabilitation was judged to be a complete success. A conservative two-inch layer of PL-8000 was applied onto the bolted metal substrate, partly to ensure a minimum cover of one-half inch over the culvert's protruding bolts. Traffic never stopped, the rehabilitation supported the roadway, and the new concrete culvert had little effect on flow volume, due to its thinness and its smoothness compared to the rough corrugated substrate.

But spraying cementitious material in a large diameter pipe, with very little soil cover between the crown of the pipe and the road, meant FDOT and others were very interested in the solution's long-term performance. In 2016 they were able to put that performance to the test.

2016: Evaluation and Testing

In January 2016, an initial walkthrough was conducted. Visually, the rehabilitated culvert still looked brand new with no visible wear, voids, or fractures.

Figure 3: Six-year visual inspection - No visible wear, voids, or fractures

While the concrete lining is not thick, particularly compared to competing solutions, the strength of the material provides long-term structural integrity. And in smaller pipe projects where culvert flow volumes are critical, the relatively thin layers of material do not significantly impact diameter or flow volumes.

The like-new appearance of the repaired culvert was good evidence in itself—the total absence of fractures from heavy live loads proved that the PL-8000 lining was holding up to traffic loads.

To fully measure and quantify the structural integrity of the process and the rehabilitated structure, AP/M Permaform commissioned independent testing to be performed by Resensys LLC, a company that devises sensors and testing protocols to detect strains and stresses in existing infrastructure like bridges and roadways. The size of this structure, the minimal cover between crown and roadway, and the unusual amount of force transferred to the new lining, made it an ideal project to collect performance data useful to any agencies and engineers planning their own rehabilitation projects for load-bearing structures.

On November 21, 2016, a Resensys team installed four highly sensitive SenSpot sensors evenly spaced along the 96-foot long culvert crown (top inner surface), plus a data logger to record data from the sensors.

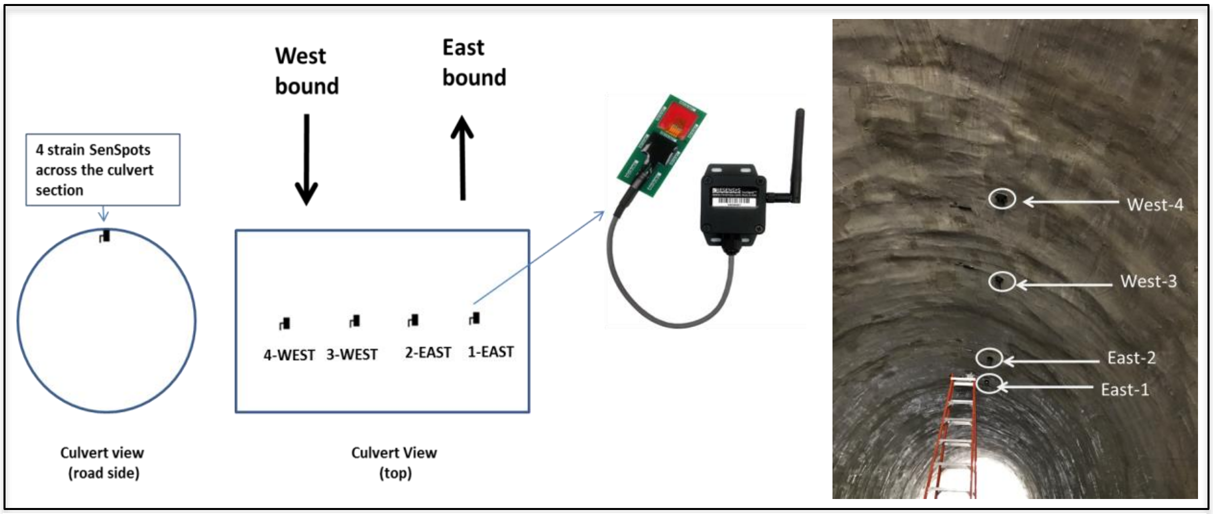

Figure 4: Placement of strain gauges within pipe

The strain gauges used in wireless SenSpot sensors are "foil strain gauge, SGD-30/120-LY40" provided by Omega Engineering where a half-bridge method (two perpendicular gauges) for strain measurement is used. The readings from the gauges are amplified by a zero drift amplifier with a gain=125, and then using a 14-bit analog to digital converter the strain readings are reported by SenSpot sensor with a resolution of 2 microstrains. In layman's terms, the SenSpots are highly sensitive strain gauge sensors, able to measure very subtle deformations in infrastructure when under stress.

On November 22, 2016, the culvert was deliberately subjected to extreme load testing. A loaded 18-wheeler, with verified weight of 83,620 pounds, was contracted to drive over the culvert in both directions, stopping each way with cab axles, and then trailer axles, directly over the crown of the culvert. Axle alignment was verified visually, with an alignment tool, and by monitoring the strain gauges during truck movement—basically,

Figure 5: Strain testing with loaded 83,620 pound 18-wheeler

redundant methods were used to ensure truck weight was placed to have maximum impact.

The resulting sensor data showed that the loading effects of the truck weight on the rehabilitated SR 16 culvert were negligible. According to the Resensys report, “During truck tests of November 22, 2016, very little strain change was observed and as a result, it is logical to assume that the structure can carry load up to (and possibly even larger than) the weight of the truck used when the tests were conducted.”

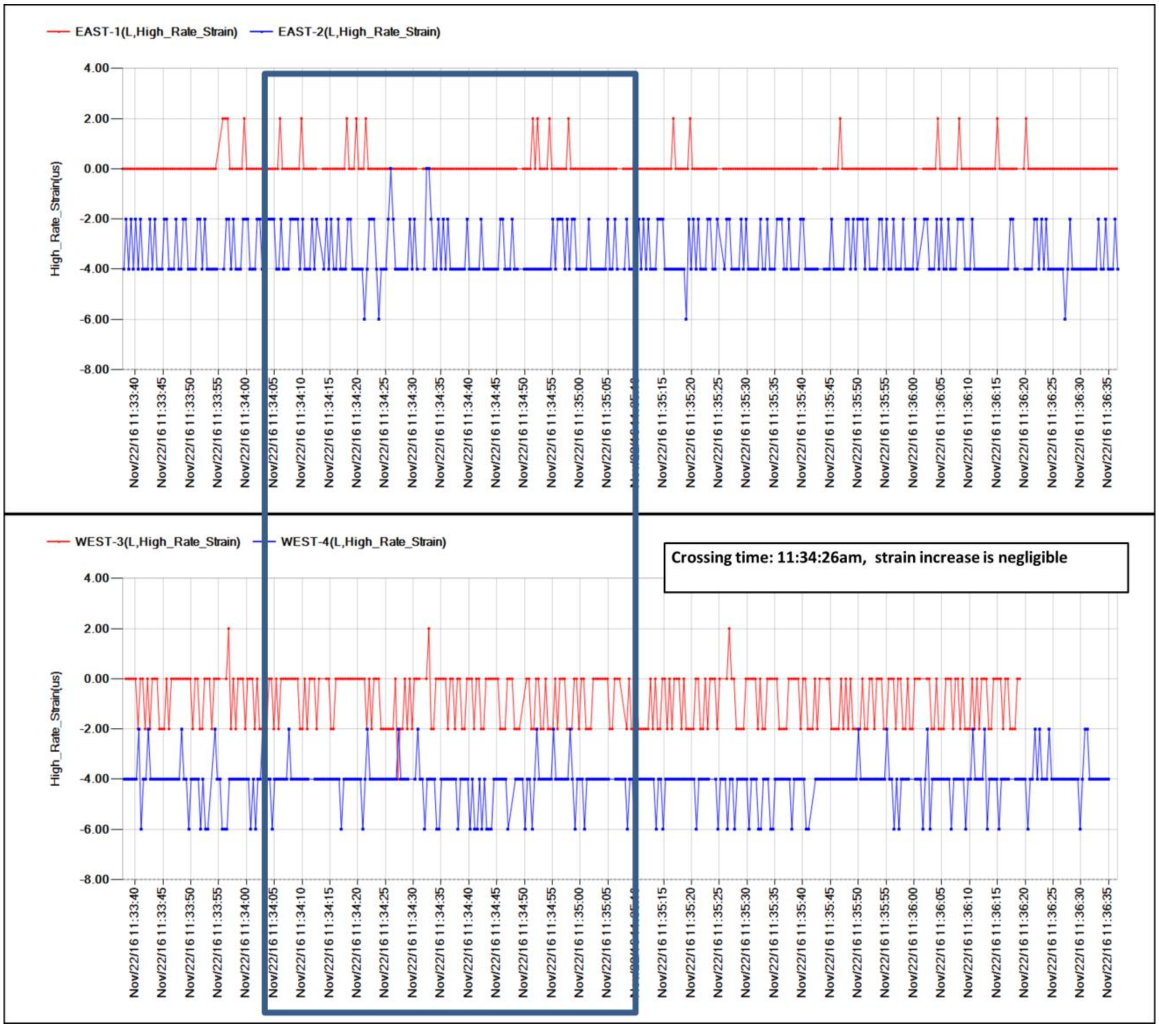

Figure 6: Load Rating Test 1 - Truck moved east-bound with speed of 3 MPH. No significant strain was observed.

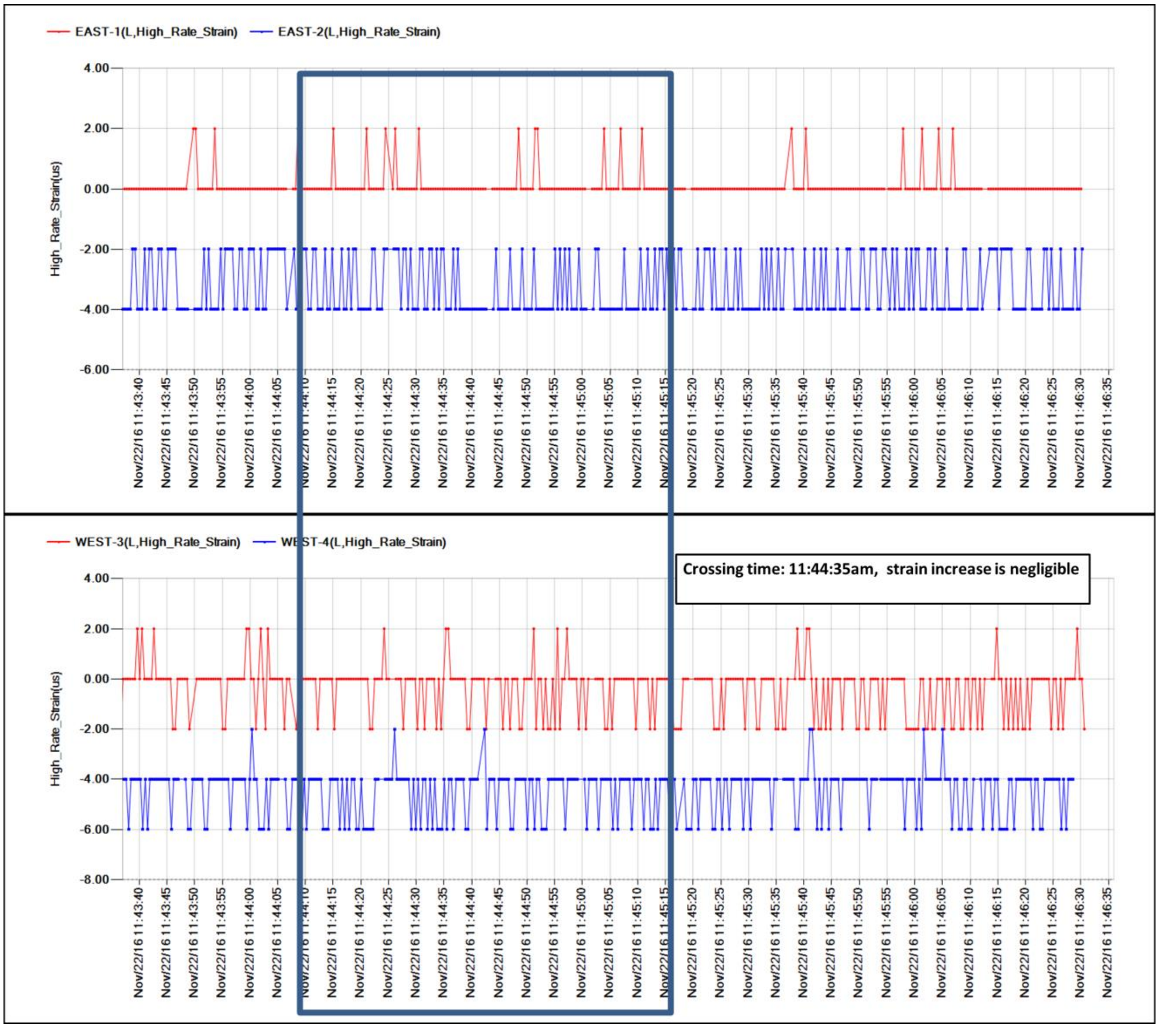

Figure 7: Load Rating Test 2 - Truck moved west-bound with speed of 3 MPH. No significant strain was observed.

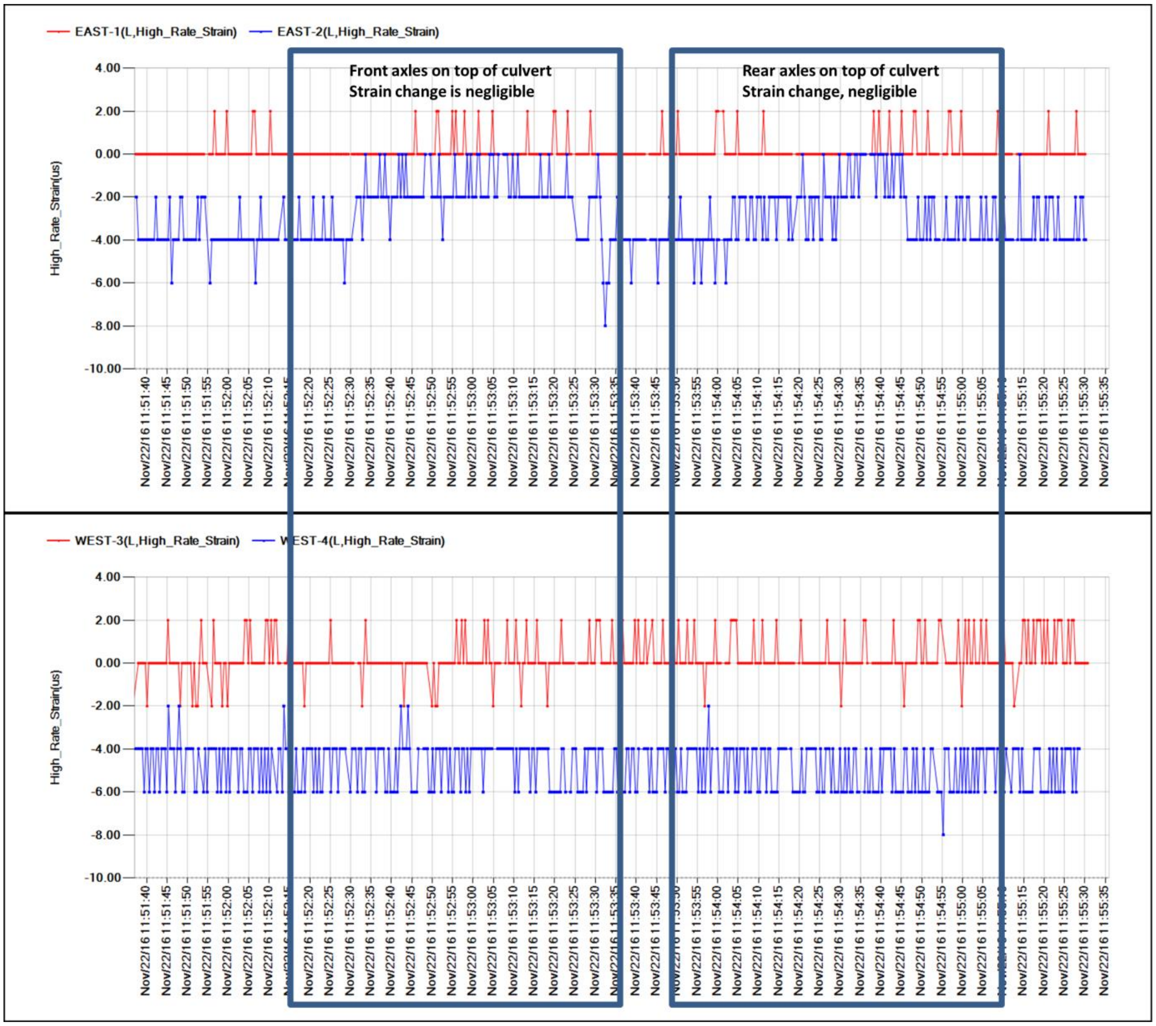

Figure 8: Load Rating Test 3 - Truck moved east-bound, stopping at 11:52 a.m. EST with front axles on top of culvert, and at 11:54 a.m. EST with rear axles on top of culvert. East-2 strain SenSpot sensor shows 2-4 microstrain increase in strain and for other three strain SenSpot sensors, no significant change in strain was observed.

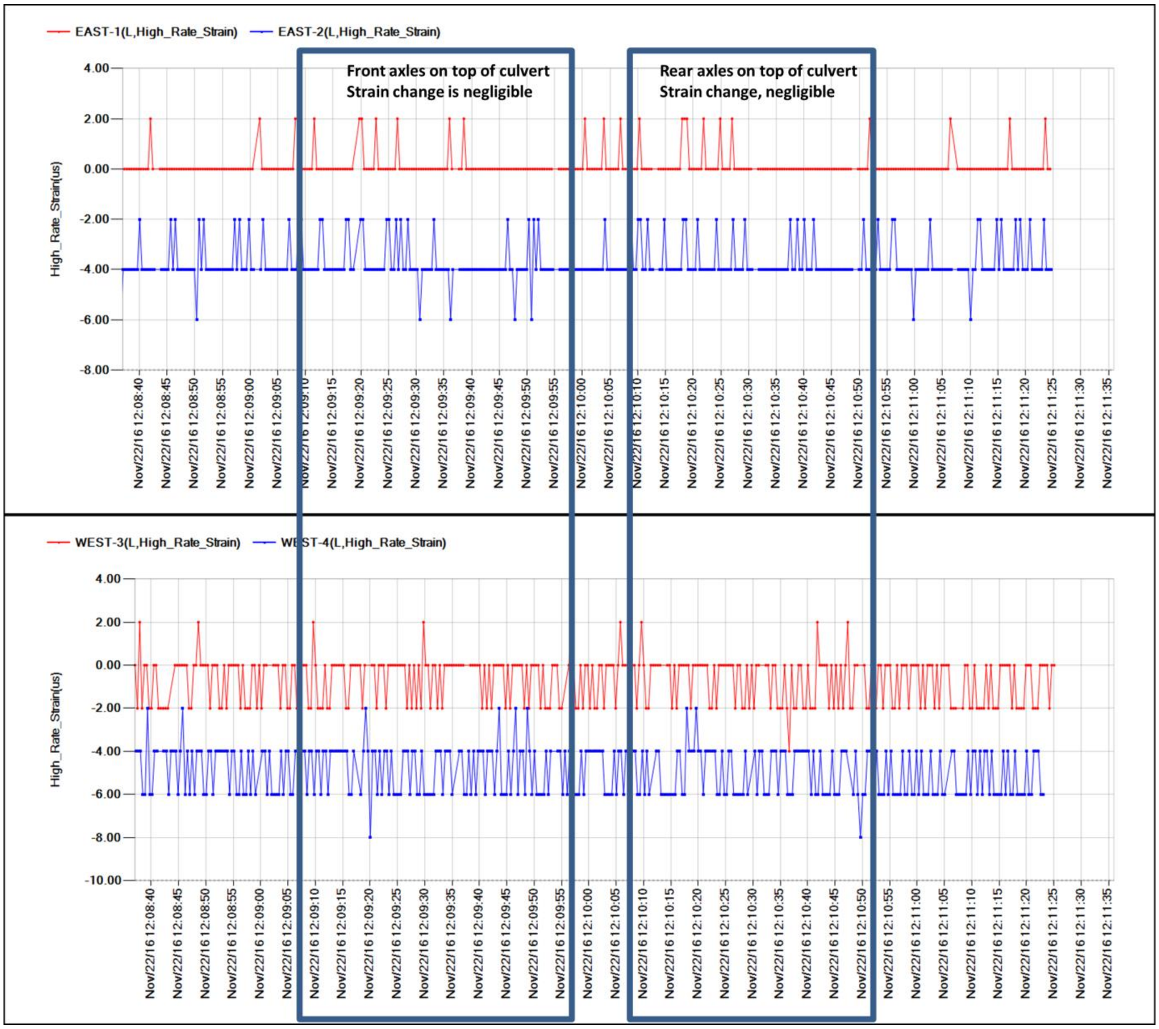

Figure 9: Load Rating Test 4 - Truck moved west-bound, stopping with front axles on top of culvert at 12:09 p.m. EST, and rear axles on top of culvert at 12:10 p.m. EST. No significant change in strain was observed.

Live load testing was also conducted, with the sensors left in place and data continuously recorded from November 22 to December 9. These results further confirmed the structural qualities of the repair. Again, from the Resensys report:

“Monitoring strain at four locations across the section of the culvert from November 22, 2016 until December 9, 2016 shows that no strain change has been caused by traffic (live load). Generally, live load (e.g., passing of heavy trucks) can result in transient (spike-like) strain change events. However, inspection of the strain graphs during the reporting period does not show any transient strain change. This implies the safe load carrying capacity of the structure under the existing traffic conditions. In addition, this observation is consistent with the truck test loads conducted on November 22,0 2016.”

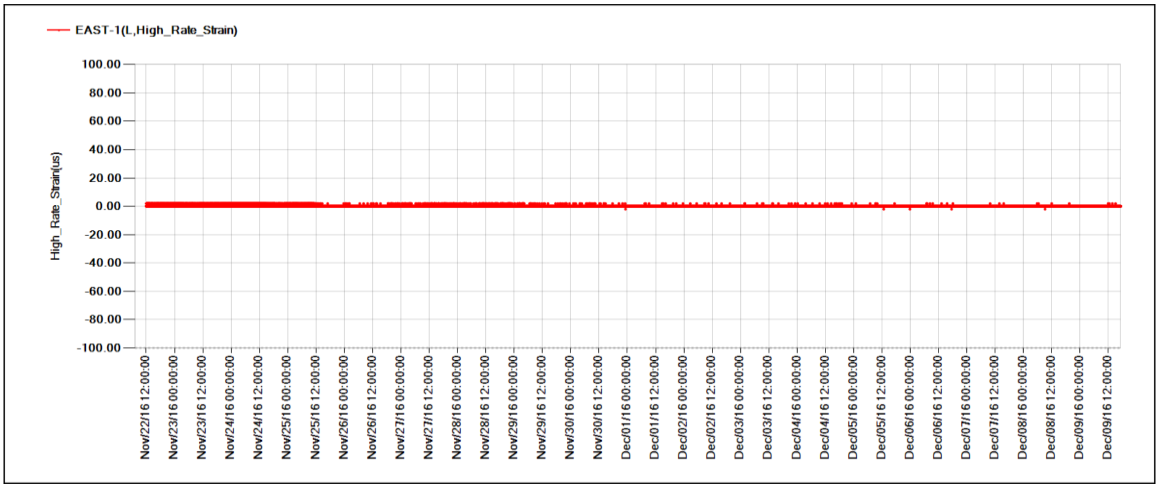

Figure 10: Continuous Strain Monitoring - Readings of South SenSpot installed on East Bound of the culvert (East-1)

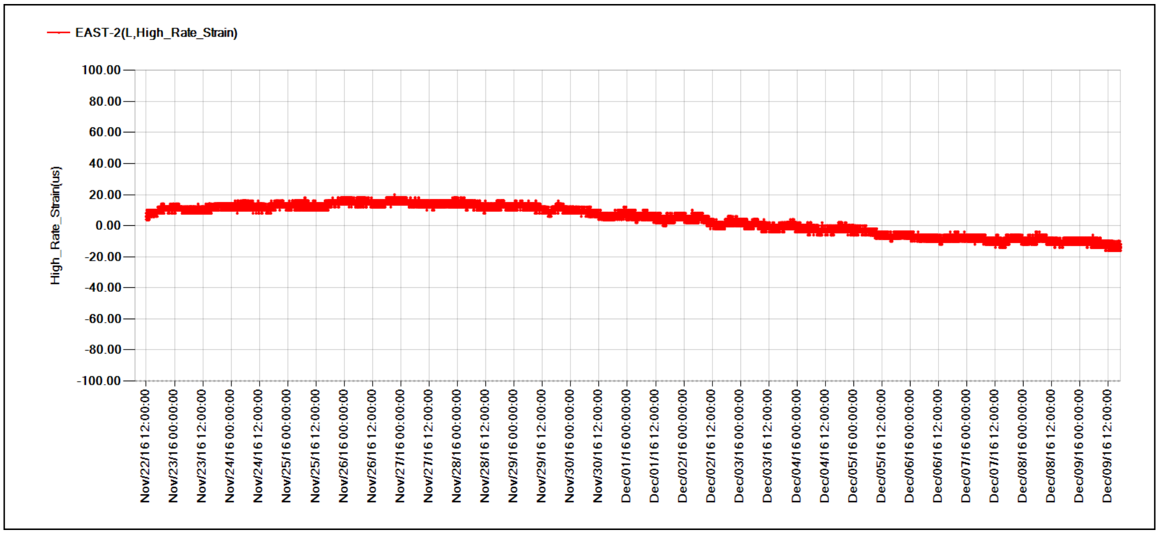

Figure 11: Continuous Strain Monitoring - Readings of North SenSpot installed on East Bound of the culvert (East-2)

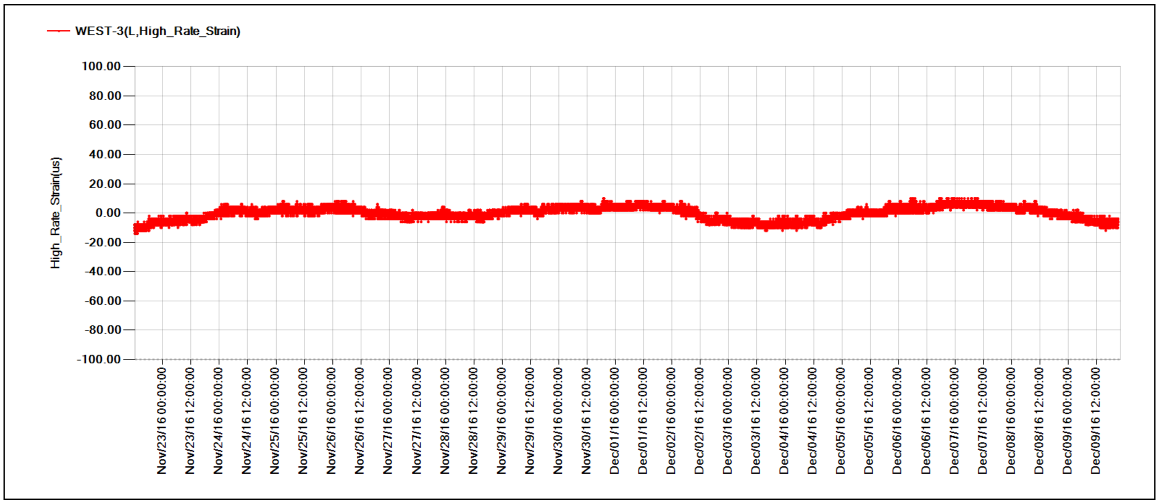

Figure 12: Continuous Strain Monitoring - Strain readings of South SenSpot installed on West Bound of the culvert (West-3)

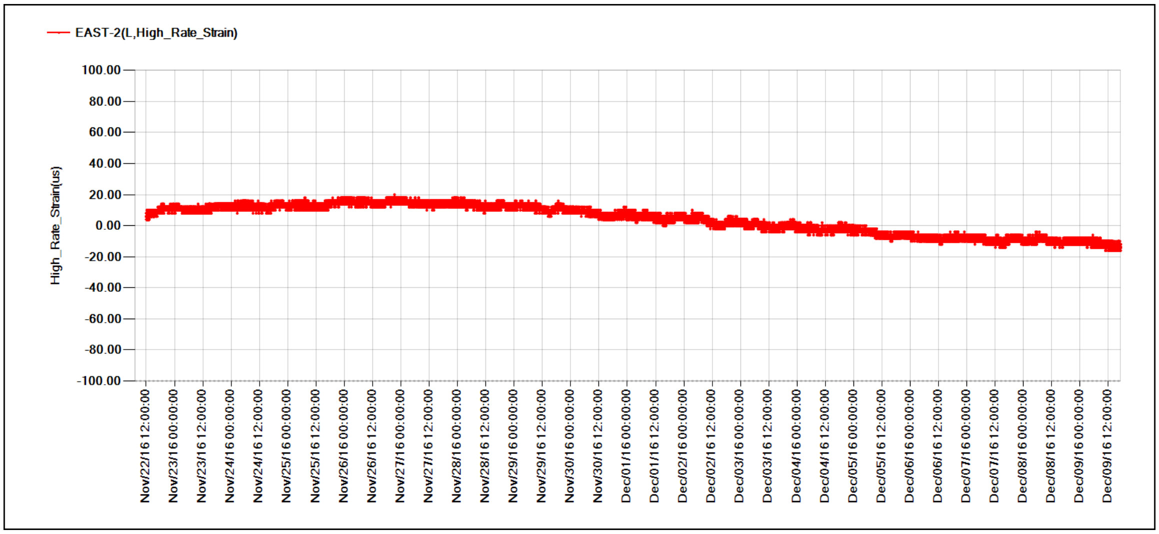

Figure 13: Continuous Strain Monitoring - Strain readings of North SenSpot installed on West Bound of the culvert (West-4)

“This data validates the use of PL-8000 here, and also validates the design methodology used,” says Kampbell. “Most engineers would have predicted a lot of give, or bending, would have occurred but that wasn't observed in this real world look at the CentriPipe® in place. As applied, the material instead went into an arch-like load behavior response mode (i.e. compression or thrust dominant throughout the 2.0-inch wall thickness), showing that even shallow cover provided a significant amount of support for this type of buried bridge. These are very useful results for engineers working on culvert rehabilitations as they demonstrate the minimal need for adding additional reinforcement meshes to carry any ‘assumed’ large flexural stresses in these arch-like structures.”

For sewer network operators and infrastructure agencies, the test data helps alleviate any concerns regarding the structural integrity, project designs, and long-term, real-world performance of this material and solution.

Figure 14: November 2016 - Photo of structurally sound rehabilitated pipe, taken during strain gauge testing.

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Angus W. Stocking, L.S. is a licensed land surveyor who has been writing about infrastructure since 2002.