# Part II: Summary of Pipe Spring™ Full Scale Testing

Introduction

Pipe Spring LLC is pleased to announce the successful test and evaluation of the Pipe Spring™ system completed by ADV Integrity in May 2019. The technical staff of ADV Integrity are highly experienced regarding the development, testing, and performance evaluation of non-metallic repairs. They have completed several hundred tests with similar configurations. The full report is available upon request via email at info@pipespring.net or by contacting a Pipe Spring LLC representative.

Part I of this summary focused on burst test results and performance considerations for metal loss defects which display typical yielding and bulging behavior. Pipe Spring LLC believes that the technology, while not a "true metallic repair," as defined in ASME PCC-2 Article 4, has demonstrated the intent of this article to restore metal loss defects to the original capacity of the pipe. We further believe that Pipe Spring technology is fully compliant ASME PCC-2 Article 3, as a mechanically applied non-welded steel sleeve, to be considered as a variation of a "type A" sleeve for regulatory and code compliance purposes.

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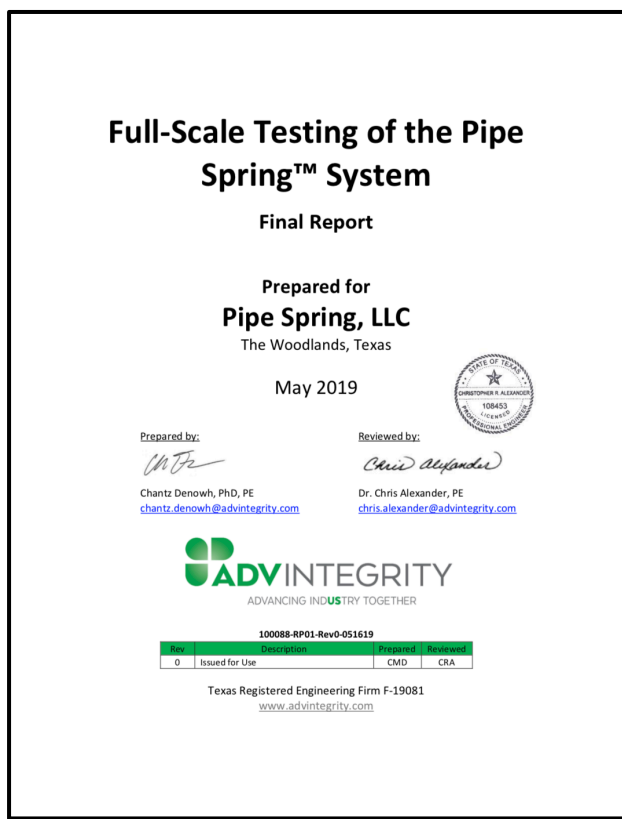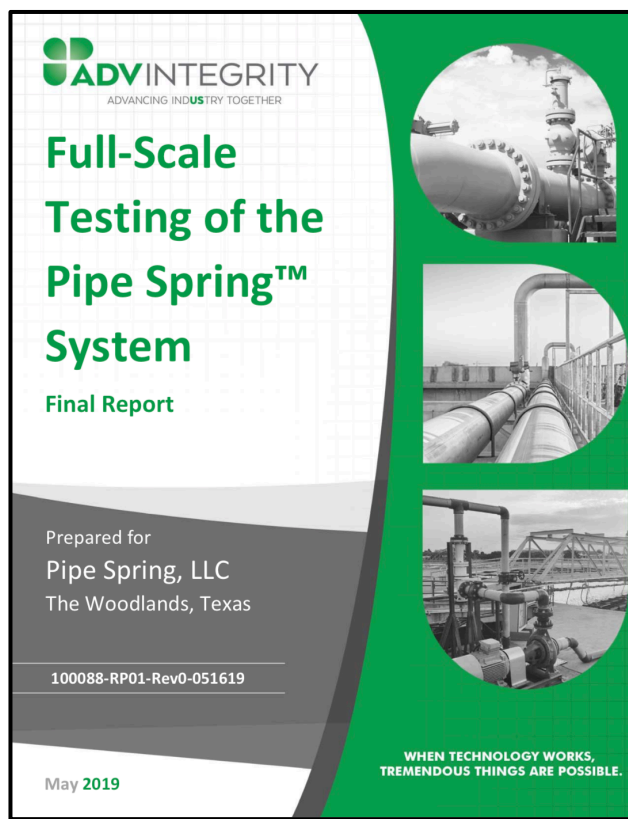
Part II

The design goal of the pipe spring technology had two major thrusts:

1) Demonstrate acceptable for metal loss defects, including an Engineering Critical Assessment (ECA) and reliable engineering data and analysis
2) Utilize the steel's isotropic material properties, high modulus of elasticity, conformity of thin layers, and installation method to immediately share load to address various strain-based concerns.

The ADV Integrity full-scale program involved a dedicated installation of a Pipe Spring™ unit for the express purpose of evaluating the efforts to minimize the delay in load sharing, as well as to determine an "effective modulus" of the system when installed on pipe. This effort recognized that a traditional material property tensile test of modulus would likely produce a reliable and repeatable value. However, this value would likely exceed an experimentally determined "effective modulus."

The *Project Background* section in ADV's report describes the effort to empirically derive an effective modulus. In addition to the Pipe Spring™ unit installed over a machined corrosion feature, a second Pipe Spring™ was installed on the base pipe. The purpose of this reinforcement was to empirically derive an effective modulus for the Pipe Spring™ system using Equation 1 below.

In Equation 1, all the values are known except the pipe hoop stress and effective elastic modulus of the reinforcing material, Er. The pipe hoop stress was calculated using the strain gages beneath the system.

$$\sigma_S = \frac{P \cdot R}{t_S \left[1 + \frac{E_r t_r}{E_S t_S}\right]}$$

Where:

σ_s Hoop stress in pipe steel (psi)

P Internal pipe pressure (psig)

R Radius of pipe steel (inches)

t_s Thickness of pipe steel; not reduced in this case (inches) E_s Elastic modulus of pipe steel (psi)

t_r Thickness of reinforcing material (inches)

E_r Elastic modulus of reinforcing material (psi)

Equation 1 was derived assuming strain compatibility at the steel/Pipe Spring™ interface and that the load from the internal pressure is shared by the pipe steel and Pipe Spring™ system.

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The hoop stress in the pipe steel is calculated from the hoop strain measurements only and is only accurate for the linear-elastic strain response. The effective modulus is a direct measure of the Pipe Spring™ modulus in the hoop direction from experimental results. The Pipe Spring™ modulus could be determined using standard tensile test specimens removed from flat plates, but creating flat plates is not the same as installation on a pipe and will yield different results. Deriving the effective modulus using Equation 1 and experimental results is more representative of the actual modulus for the Pipe Spring™ or any other type of reinforcement.

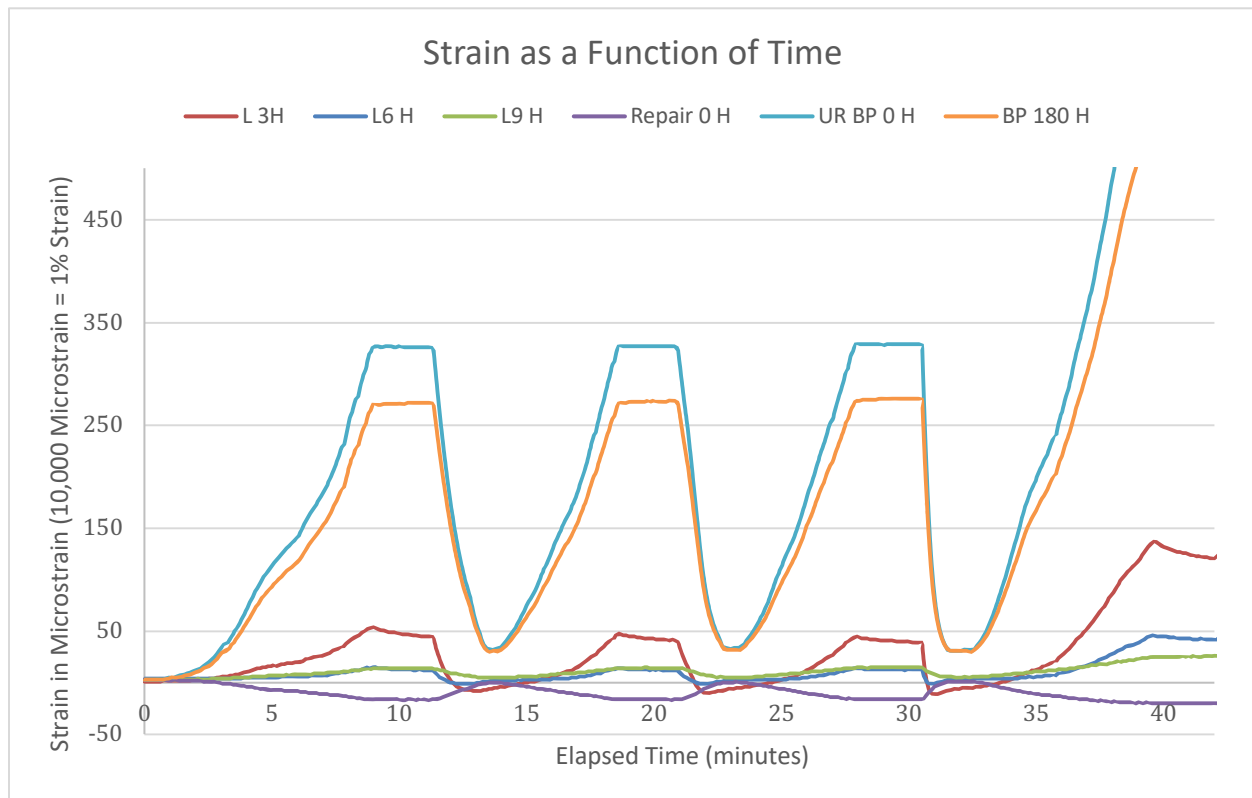The following plots have been developed based on the ADV test data:
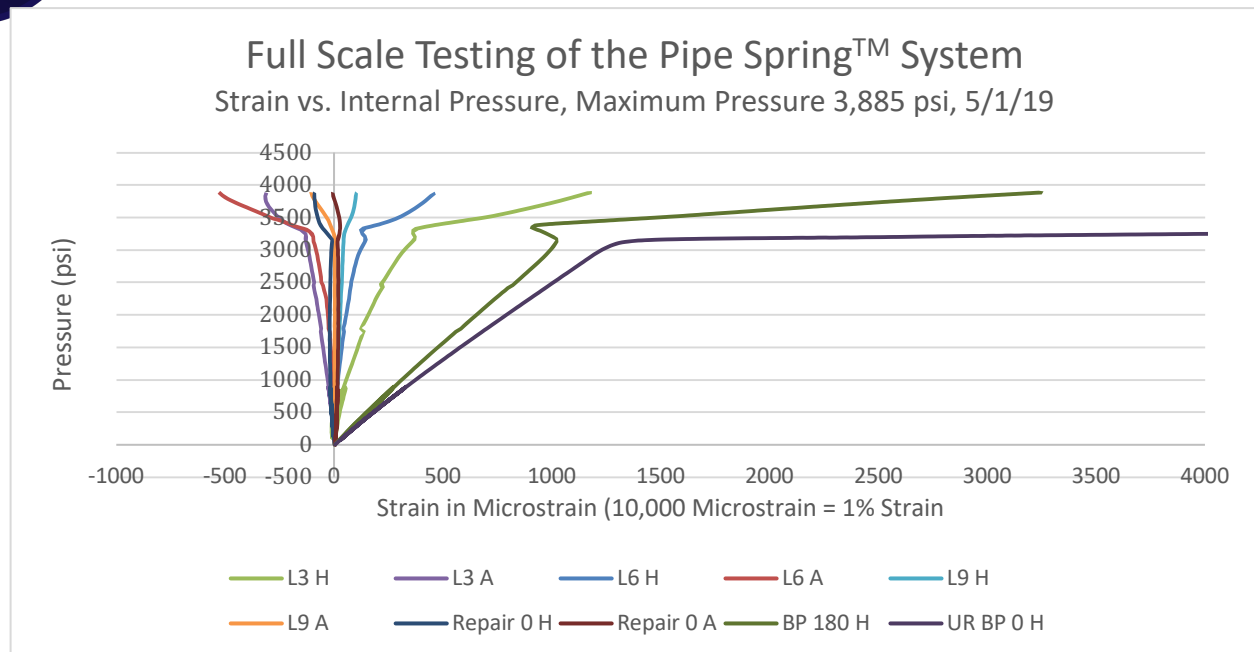

Figure A

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Full Scale Testing of the Pipe Spring™ System
Strain vs. Internal Pressure, Maximum Pressure 3,885 psi, 5/1/19

Figure B

Full-Scale Testing of the Pipe Spring™ System
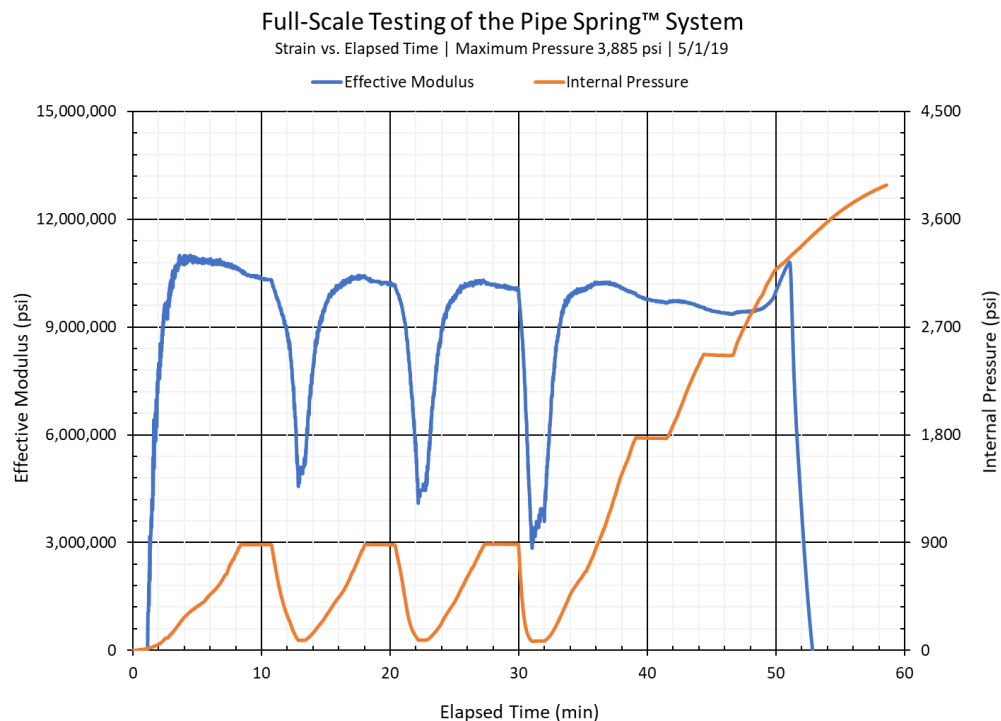Strain vs. Elapsed Time | Maximum Pressure 3,885 psi | 5/1/19

Figure C

Conclusions:

ADV Integrity calculated an empirically derived modulus of elasticity of the Pipe Spring™ system of approximately 10 million PSI. They also noted that the strain gauge wires intruded on the experimental data. The .185-inch of diameter added to the thickness of the repair due to the

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strain gauge wire intrusion. Elimination of the extra thickness produced an effective modulus of elasticity of approximately 14 million PSI. In addition to this direct calculation adjustment, the presence of the wires and strain gauges intruding on the reinforcement would be deleterious to the reinforcement.

The Pipe Spring™ system also displayed a rather immediate dynamic response, with strain seen within the layers of the reinforcement when the unrepaired base pipe was only at 50 micro strain (Figure A). The modulus plot (Figure C) confirms the initial dynamic response as being essentially immediate. The three early pressure cycles from near zero to 36% of SMYS, clearly show the modulus contribution near zero pressure.

Pipe Spring LLC believes it is appropriately conservative to utilize a 14 million PSI value for the effective modulus of elasticity of the system, for the purposes of considering strain-based concerns.

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