Interim Results of the PetroSleeve (Steel Compression Reinforcement Sleeve; Repair F) from the JIP Evaluation of Repair Technologies for Circumferential Cracks on Pipelines

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Abstract

A joint industry project including both industry and government, organized by C-FER, has been undertaken to determine if a non-welded repair technology can be used to repair circumferential defects.

With the development of advanced internal inspection tools, industry is now capable of locating circumferential cracking. Obviously, having developed the ability to locate cracking, industry is required to return the integrity of the defect joint back to its' original level.

Repair methods currently available include removing the affected pipe section (cut out) or installing a welded steel sleeve around the defect (Type B sleeve). The first case is extremely costly, and the second case introduces additional concerns considering the in-service weld.

Consequently, this JIP was instigated to determine whether a non-intrusive repair such as a wet lay-up, composite fabric, preformed composite coil, steel sleeve, or bolt-on repair sleeve/collar could, when installed, prevent the circumferential crack from extending.

This project, broken into 4 phases, consists of the evaluation of current non welded to the pipe technologies and testing those technologies that have promise to repair circumferential cracking.

Phase 1 consisted of Non-destructive tensile testing. This consisted of, after having researched repair types, inviting potential proponents (6) to install their repair technology on three sections of 24" pipe pressurized to 785 psi (5400 kPa). In each case, each proponent separately installed their repair type. There was no information exchanged between the proponents.

Following repair installation, the three vessels were pressure cycled and then put under tension to yield of the pipe parent material.

Phase 2 considered the effect of installation pressure. This consisted of having three participants install their repair technology on seven vessels that were pressurized at 30%, 50%, and 70% of SMYS. The vessels were pressurized to various levels, put under tension, and then, at 72% SMYS, put under tension until failure.

Phase 3 consisted of destructive tensile testing with circumferential flaws. In this phase, the repair types were Vendor 1, Vendor 2, and a type B sleeve. In all cases, the repairs were installed at 50% SMYS, initially exposed to pressure variances, and then setup for the tensile test. At 72% SMYS (1482 psi; 10,200 kPa) the vessels were put under tension until failure occurred.

Phase 4 will consist of a long-term performance of repairs test. In this test the test vessels will be put under tension and load, to simulate field conditions. This test commenced last quarter, 2024.

One of the technologies that was selected for testing was the PetroSleeve (Repair F). This paper

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describes the JIP, as it pertains to the Steel Compression technology.

Introduction

With the continued development of internal inspection tools, the industry now can locate circumferential cracking. Having located the cracking, the challenge then is to determine if there is a non-intrusive repair method that can arrest circumferential crack growth.

Repair methods currently available include removing the affected pipe section (cut out) or installing a welded steel sleeve around the defect (Type B sleeve). The first case is extremely costly, and the second case introduces additional concerns considering the in-service weld.

With industry collaboration, a JIP was formed to investigate the possibility of a non-intrusive repair (non-welding to the pipe). C-FER was engaged to conduct the JIP.

Phase 1

The first phase concerned the evaluation of the various non-intrusive repair methods that had promise to repair circumferential cracking. Following a technology review of all the industrial non-intrusive repair options1, six promising technologies were selected, of which one was the PetroSleeve (Repair F).

To evaluate the six technologies, each was evaluated by comparing the axial stiffness after they had been installed on 24-inch X52 vessels.

Each repair system participant was invited, at separate times, to install their repair type on the three of 24-inch X52 vessels. During installation, the vessels were pressurized to 785 psi (5400 kPa) to simulate pipeline operations. Following the installations, various testing situations were performed by C-FER.

At the completion of the testing, each participant received only the testing record of their repair technology (completed).

Phase 2

The second Phase was used to determine the effect of pipe pressure during repair installation (completed).

Phase 3

The third Phase involved destructive testing with circumferential flaws (completed).

Phase 4

The fourth Phase is a long-term performance test. The test commenced fall, 2024, with the testing of the first vessel completed December 2024. It is expected that the testing of remaining 2 vessels will be completed spring 2025.

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Description of Repair F

The steel compression sleeve consists of two steel halves that have been assembled around the pipe and attached by welding sidebars. No welding directly to the carrier pipe is required.

With a sleeve install, the pipe is put into compression, the sleeve in tension. Disbondment at zero pressure is prevented.

Prior to installing a sleeve, the engineering installation parameters must be obtained which consists of the internal pressure at the repair site, the pipe wall thickness, product type, flow rate and pipe temperature. This information, in conjunction with the sleeve properties, is used to calculate a design installation temperature.

Proprietary engineering software incorporating the physical and field conditions is used to determine both the installation parameters and the resulting stress state of the repair. Installation parameters are calculated for each sleeve installation due to changing operating conditions.

Phase 1 Non-Destructive Tensile Testing (completed) (2)

For this Phase, 3 sections of 24” x 0.374” X52 pipe were provided for repairs identified as A to F. The vessels were pressurized to 785 psi (5400 kPa; 48% SMYS). One repair of each type was installed on each vessel, at different locations. The different locations were selected so that all participant repairs would be exposed to similar conditions.

Below is a photograph of the Repair F on pipe specimens.

Figure 1. Repair F

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Following the installation of Repair F, the other participants were invited to install, separately, their repair systems. When a participant was installing their repair, the other repairs were covered to prevent identification.

The testing procedure for the 3 vessels consisted of:

- Pressure the vessels to 785 psi (5400 kPa; 48% SMYS)
- Install the various repair systems.
- De-pressure
- Place each vessel on the large frame hydraulic tension apparatus.
- Pressure to 785 psi; apply 915 kips tension and release.
- Pressure cycle 9x; pressure 0 to 1170 psi (8060 kPa; 72% SMYS)
- Pressure to 1170 psi (8060 kPa); apply tension to failure.

Each repair was instrumented such that the relative stretching of the pipe under the repair with respect to the stretching of the repair was measured.

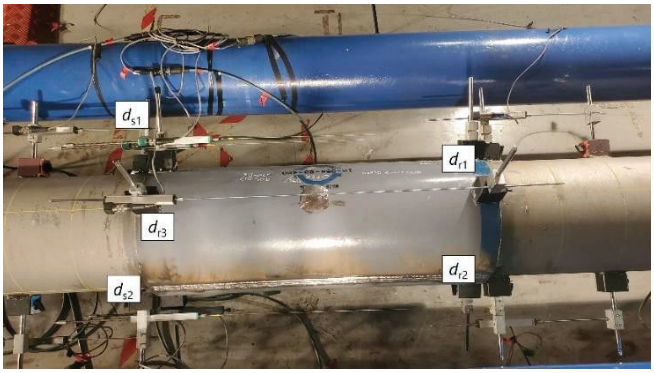


Figure 2. Typical Instrumentation Arrangement

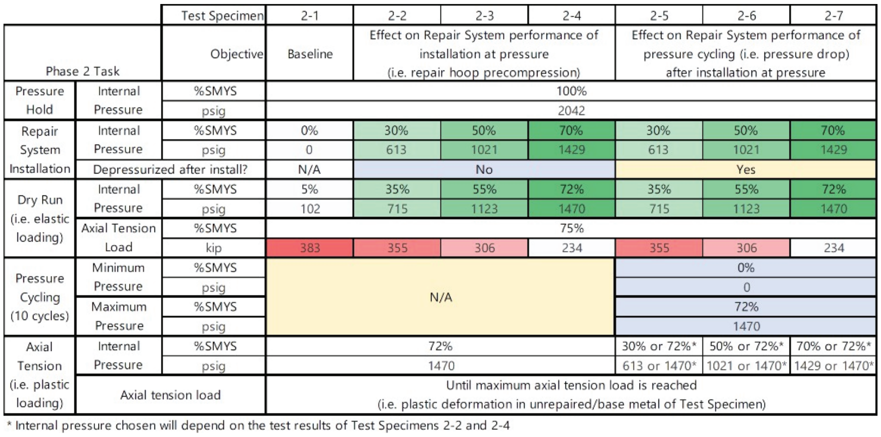
As mentioned above, for the last test, each pipe specimen was pressurized to 1170 psi (8060 kPa) and axial tension was applied until a section of the control pipe reached plastic collapse (approximately 1263 kip on average).

At the conclusion and detailed analysis of Phase 1, the results illustrated that Repair F was considered as being acceptable for further testing.

Phase 2 Effect of Installation Pressure (completed) (3)

For this phase the test specimens consisted of 7 of 12” x 0.25” X52 vessels. For the installation of the repair types, each vessel was pressurized to a level depending on the testing objectives. One of the situations was specifically selected to simulate Phase 1, that utilized 24” pipe.

The selected repair types were identified as Repair A, B, and F.

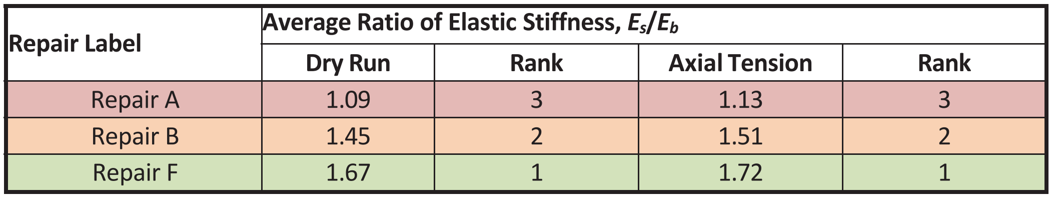


		Test Specimen	2-1	2-2	2-3	2-4	2-5	2-6	2-7
Phase 2 Task		Objective	Baseline	Effect on Repair System performance of installation at pressure (i.e. repair hoop precompression)			Effect on Repair System performance of pressure cycling (i.e. pressure drop) after installation at pressure		
Pressure Hold	Internal Pressure	%SMYS	100%						
		psig	2042						
Repair System Installation	Internal Pressure	%SMYS	0%	30%	50%	70%	30%	50%	70%
		psig	0	613	1021	1429	613	1021	1429
	Depressurized after install?		N/A	No			Yes		
Dry Run (i.e. elastic loading)	Internal Pressure	%SMYS	5%	35%	55%	72%	35%	55%	72%
		psig	102	715	1123	1470	715	1123	1470
	Axial Tension Load	%SMYS	75%						
		kip	383	355	306	234	355	306	234
Pressure Cycling (10 cycles)	Minimum Pressure	%SMYS	N/A				0%		
		psig					0		
	Maximum Pressure	%SMYS					72%		
		psig					1470		
Axial Tension (i.e. plastic loading)	Internal Pressure	%SMYS	72%				30% or 72%*	50% or 72%*	70% or 72%*
		psig	1470				613 or 1470*	1021 or 1470*	1429 or 1470*
	Axial tension load		Until maximum axial tension load is reached (i.e. plastic deformation in unrepaired/base metal of Test Specimen)						

* Internal pressure chosen will depend on the test results of Test Specimens 2-2 and 2-4

Figure 3. Testing Matrix

As noted in Phase 1, Repairs A, B, & F again were instrumented such that the relative stretching of the pipe under the repair with respect to the stretching of the repair was measured. Two ratios were determined; the elastic stiffness of the steel under the repair (s) with respect to the elastic stiffness of the base pipe (b), and the stretch of the steel under the repair (s) with respect to the stretch of the base pipe (b).



Repair Label	Average Ratio of Elastic Stiffness, E_s/E_b			
	Dry Run	Rank	Axial Tension	Rank
Repair A	1.09	3	1.13	3
Repair B	1.45	2	1.51	2
Repair F	1.67	1	1.72	1

Figure 4. Relative Performance of Repairs During Elastic Loading (Higher Ratio = More Stiffness)

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Repair Label	Average $\Delta\bar{d}_s/\Delta\bar{d}_b$		Minimum $\Delta\bar{d}_s/\Delta\bar{d}_b$		Rank
	Dry Run	Axial Tension	Dry Run	Axial Tension	
Repair A	0.91	0.84	0.83	0.67	3
Repair B	0.70	0.71	0.62	0.56	2
Repair F	0.61	0.53	0.51	0.33	1

Figure 5. Relative Performance of Repairs into Plastic Loading (Lower Ratio = More Stiffness)

Phase 3 Destructive Tensile Testing with Circumferential Flaws (completed)

Phase 3 was the first test that included a simulated circumferential crack. For this phase, the test specimens consisted of 3 of 12" x 0.25" X52 vessels. The test specimens had a single 40%, 60%, or 80% simulated circumferential crack placed at the 12:00 position.

The repair technologies being tested were Vendor 1, Vendor 2 (Repair F) and a Type B sleeve.

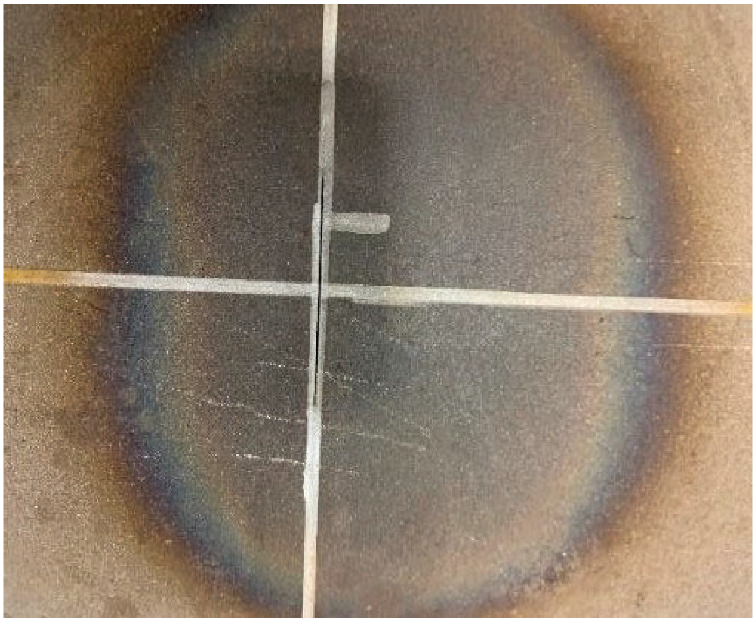

Figure 6. Photo illustrating the 80% simulated crack

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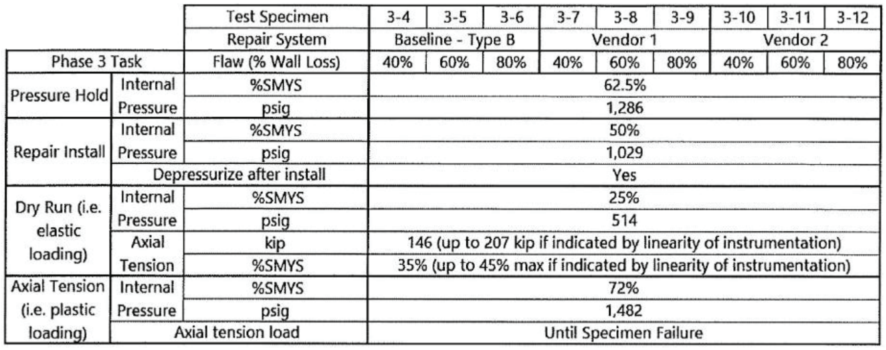

		Test Specimen	3-4	3-5	3-6	3-7	3-8	3-9	3-10	3-11	3-12
		Repair System	Baseline - Type B			Vendor 1			Vendor 2		
Phase 3 Task		Flaw (% Wall Loss)	40%	60%	80%	40%	60%	80%	40%	60%	80%
Pressure Hold	Internal Pressure	%SMYS	62.5%								
		psig	1,286								
Repair Install	Internal Pressure	%SMYS	50%								
		psig	1,029								
	Depressurize after install		Yes								
Dry Run (i.e. elastic loading)	Internal Pressure	%SMYS	25%								
		psig	514								
	Axial Tension	kip	146 (up to 207 kip if indicated by linearity of instrumentation)								
		%SMYS	35% (up to 45% max if indicated by linearity of instrumentation)								
Axial Tension (i.e. plastic loading)	Internal Pressure	%SMYS	72%								
		psig	1,482								
	Axial tension load		Until Specimen Failure								

Figure 7. Testing Matrix

Figure 8. Installing Repair F

Per the Figure 7 Testing Matrix, each vessel was pressurized to 1286 psi (62.5% SMYS) to confirm that the crack would not rupture during repair installations. The vessels then were pressurized to 1029 psi (50% SMYS) for repair installations.

The final testing procedure involved applying axial tension until failure.

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Figure 9. During Phase 3 Tensioning

Figure 9 illustrates the test setup. The vessel was pressurized to 25% SMYS, (514 psi, 3,541 kPa). At that point, depending on readings, the internal pressure was increased to 72% SMYS (1482 psi (10,210 Kpa) and tension applied to failure. This involved increasing tension until the base pipe entered the plastic range and the crack opened.

The crack opened when the tension was 560 Kip (560,000 lb-force). At that tension level, the parent pipe was in the elastic range.

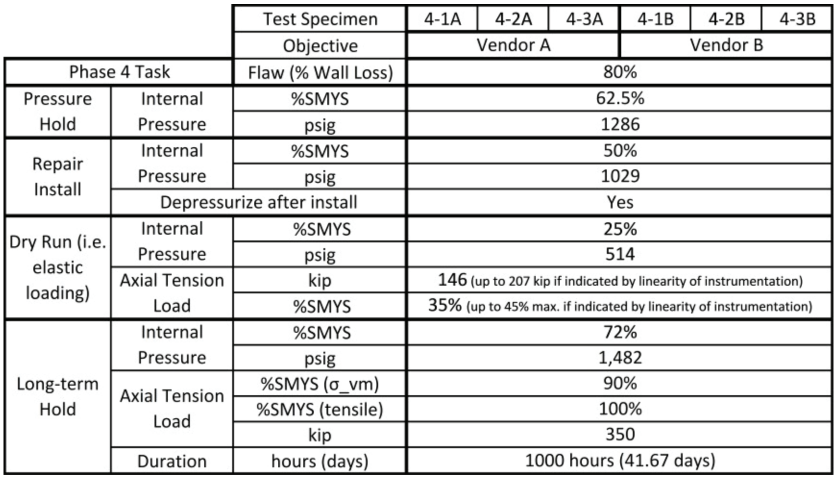
As an example of the stretching that the pipe experienced, the 18-foot vessel was stretched 5.44”, representing 2.8%

longitudinal stretch. The 3-foot section of pipe under the sleeve stretched 0.375”, representing 1.6% stretch, a ratio of 0.57.

Figure 10. At the failure point where crack opened

Phase 4 Long-term Performance of Repairs (In progress)

Phase 4 commenced October 2024. The repair technologies being tested were Vendor A (Repair F), Vendor B. The test matrix is:



		Test Specimen	4-1A	4-2A	4-3A	4-1B	4-2B	4-3B
		Objective	Vendor A			Vendor B		
Phase 4 Task		Flaw (% Wall Loss)	80%					
Pressure Hold	Internal Pressure	%SMYS	62.5%					
		psig	1286					
Repair Install	Internal Pressure	%SMYS	50%					
		psig	1029					
	Depressurize after install		Yes					
Dry Run (i.e. elastic loading)	Internal Pressure	%SMYS	25%					
		psig	514					
	Axial Tension Load	kip	146 (up to 207 kip if indicated by linearity of instrumentation)					
		%SMYS	35% (up to 45% max. if indicated by linearity of instrumentation)					
Long-term Hold	Internal Pressure	%SMYS	72%					
		psig	1,482					
	Axial Tension Load	%SMYS (σ_vm)	90%					
		%SMYS (tensile)	100%					
		kip	350					
	Duration	hours (days)	1000 hours (41.67 days)					

Figure 11. Testing Matrix

Three test specimens having an 80% simulated circumferential crack were repaired using Repair F. The first specimen was put on test, with the 1000 on-test hours completed December 4, 2024. The other two specimens will be tested following the completion of test Specimen 1.

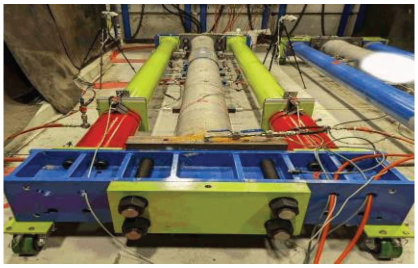


Figure 12. Illustrating Specimen 4-1A on Test

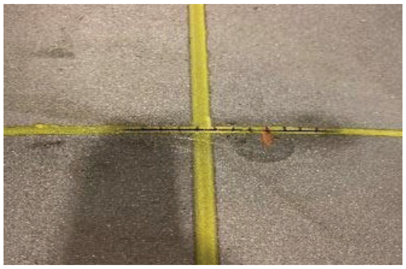


Figure 13. Illustrating Specimen 4-1A 80% Crack

Observations

Phases 1, 2 & 3 have been completed, with Vendor A (Repair F) participating in Phase 4. Figure 14 illustrates strain vs. loading during a Phase 3 test.

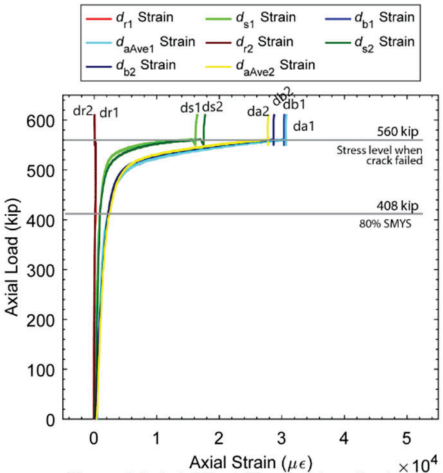


Figure 4.5 Axial Test (Tension Loading)
Axial Load vs. Axial Strain

Figure 14 (4)

Phase 3 exposed the repaired vessel to increasing tension until failure occurred (crack opening and internal pressure dropping to zero). At that point, the vessel steel was in the plastic region.

As can be seen in Figure 10, the steel under the sleeve had entered the plastic region. This extension of the steel under the sleeve was illustrated by noticing that the epoxy, that had extruded from beneath the sleeve during installation, had moved away from the sleeve edge. At the time when the crack opened, water was seen dripping out from between the sleeve and pipe. The pressure had dropped to zero. The pipe had stretched 2.8% while the steel under the sleeve had stretched 1.6%. In referring to Figure 14, when the crack opened, the tension was at 560 kip. This tension level was sufficient to put the pipe into the plastic range.

At the point where the steel had reached 80% SMYS, at the 408 Kip level, (Figure 14), the crack had not opened.

For Phase 4, testing of Specimen 4-1A was completed December 4, 2024, with no leakage. Specimens 4-2A & 4-3A will be put on test.

Conclusions

The testing at this point has illustrated that Repair F (PetroSleeve) has the possibility of being able to repair circumferential cracking.

In analyzing Repair F, Phase 3, it is obvious that just before crack opening, the steel under the sleeve had entered the plastic region. It is summarized that as the steel at the edge of the sleeve yielded, it also reduced in circumference. This reduction resulted in breaking the compressive bond between the pipe and sleeve. As the reduction progressed, the result was that the crack became exposed to the tensile force, steel stretched, and the crack opened.

On a practical sense, the crack did not rupture until the vessel steel was in the plastic range. For this situation to occur on an operating pipeline, a serious occurrence, such as a hill land slide or earthquake would be required. For a circumferential cracking occurring on pipe located in level terrain, stretching of the pipe cannot occur.

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