

Tension Testing of 8-in. (200-mm) Diameter AWWA C900 DR14 iPVC Pipe

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EXECUTIVE SUMMARY

This report describes the experimental results of the tension testing of 8 inches AWWA C900 DR14 iPVC pipe under axial force. The pipe is corrosive resistant and is known to be capable of tolerating large deformations to improve seismic resiliency. Two types of restraints for connecting the pipes were adopted in the experiments. Tension tests were conducted under a monotonic force applied at the center of the specimens perpendicular to the pipeline direction. It was tested up to severe pipe damage or significant water leakage. Distributed fiber optic sensors were used to capture pipeline behavior, providing insight into deformation and failure mechanisms. The failure modes regarding different restraints are discussed.

Keywords: *iPVC pipe, water pipelines, fiber optic, leakage, sensors.*

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DISCLAIMER

Any opinions, findings, conclusions, or recommendations expressed in this material are those of the author(s) and do not necessarily reflect those of the University of California, Berkeley.

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1 Introduction

This report summarizes the experimental results of two tension tests performed on 8-inch AWWA C900 DR14 iPVC pipes. The pipe is corrosive resistant and is known to be capable of tolerating large deformations which could improve the seismic resiliency of pipeline systems. Two types of gaskets inserted in the fitting (joint) were tested, ReiborLok and TurnerLok Gaskets. The fully assembled fitting and the cross section of the fitting are shown in Figure 1-1. In this report, Specimen 1 refers to the fitting with ReiborLok gasket, whereas Specimen 2 refers to the fitting with TurnerLok gasket.

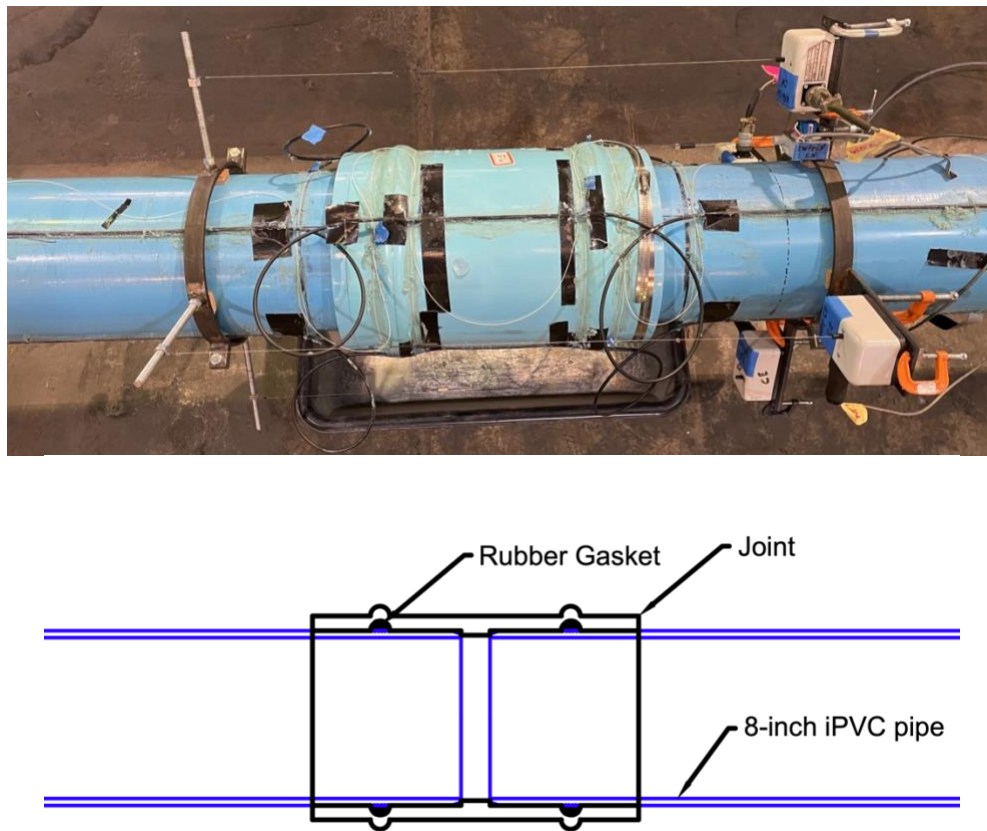


Figure 1-1 Schematic of the fitting of AWWA C900 DR14 iPVC pipe

Two identical pipes were joined together by inserting them into a fitting that passed through a circular rubber gasket with multiple teeth. The purpose of the rubber gasket is to prevent water from leaking, while the teeth are designed to bite into the connected pipe as a locking mechanism, thus restraining the pipes from moving apart. The main difference between the two gaskets is the design of the teeth, as shown in Figure 1-2. ReiborLok gasket equips with more teeth but smaller. On the other hand, the number of the teeth of TurnerLok gasket is fewer but the size of the teeth is larger. It is hypothesized that the design of the teeth could potentially influence the ultimate capacity of the pipeline system under ground movements. Hence, this study aims to understand the capacity and failure mechanism of the pipes equipped with two different gaskets under pure axial force.



Figure 1-2 Gaskets for the specimens (a) for Specimen 1 (b) for Specimen 2

Distributed fiber optic sensors (DFOS) were employed to measure continuous strain development along the longitudinal and circumferential directions. Position transducers tracked specimen movement, while load cells measured applied force, and pressure gauges monitored internal water pressure. Based on experimental data, the subsequent sections provide detailed information about the modes and mechanisms of failure.

2 Experimental Setup

A special experimental setup was designed and constructed to conduct tension and compression tests. Small modifications were introduced into the setup to accommodate changes in the force direction in the tension or compression test. This section describes the setup for the tension test.

Experimental setup. It was designed as a self-reacting system and represents a closed-loop frame. It comprised two 16.5-ft long W14x132 wide flange structural beams and two 7-ft long W10x112 wide flange structural beams. Three holes reinforced with stiffeners were introduced into the short beams. Two outer holes of the short beams were used for assembling the closed-loop frame and bolting all beams together, as presented in the schematic drawing depicted in Figure 2-1. As shown in the drawings, the center hole in the short beam (the red beam in Figure 2-1) was used as an attachment point for the reaction side or loading side of the pipe (the green rods in Figure 2-1).

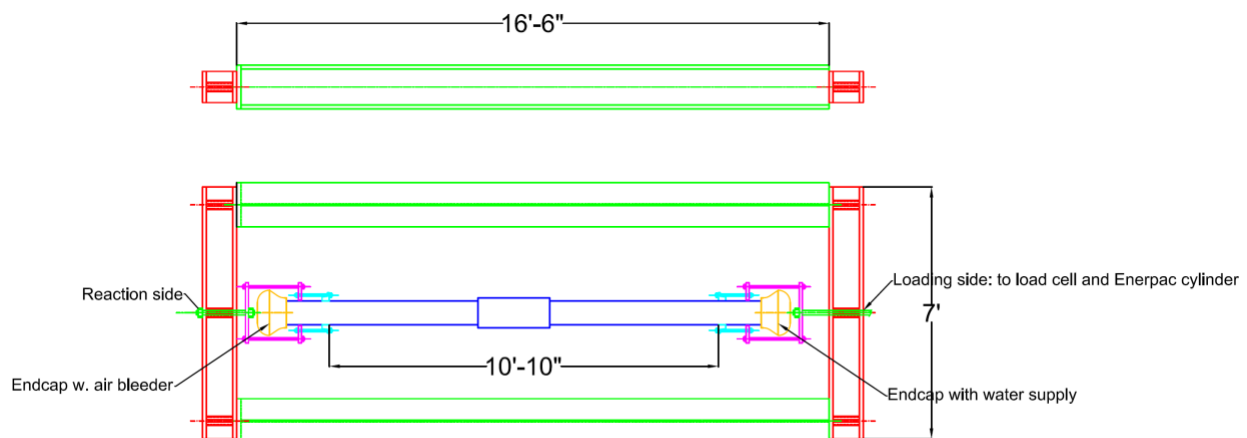


Figure 2-1 Schematic drawing of the experimental setup.

The load was applied by a hydraulic cylinder with an ultimate load capacity of 132-kips. The stroke capacity of the cylinder was greater than 6-in. A hollow hydraulic cylinder was selected for this setup to ensure that the loading rod (the green rod on the right side of Figure 2-1) could be fed through the hole and locked with a nut and a washer plate. A load cell was installed between the cylinder and the short beam, as presented in Figure 2-2.



Figure 2-2 Hydraulic cylinder and load cell on loading side.

To enable force transfer to the pipe on both the reaction and the loading sides, a set of three MegaLug restrainers were installed and connected to the endcap on each side. The rest of the details differed slightly for the reaction and loading sides. On the reaction side, all MegaLug restrainers were engaged together by utilizing four D3/4-in high-strength threaded rods attached to the short I-beam on the reaction side, as presented in Figure 2-3.



Figure 2-3 Attachment details on the reaction side.

An additional transitional 2-inch thick steel plate was introduced on the loading side. In this case, the threaded rods were attached to this plate which had a hole in the middle. This hole was used for the high-strength 1-1/4-inch Williams rod, via which the tension force was applied. The attachment details on the loading side are presented in Figure 2-4.



Figure 2-4 Attachment details on the loading side.

As shown in Figure 2-4, an air-bleeder and a pressure gage were installed on the loading side of the pipe. The pipe was pressurized from a hose connected on the reaction side, as shown in Figure 2-3. Two identical pieces of iPVC pipes were assembled together by having a sleeve joint at the connection point. Since the specimens were set in a symmetric way, the centerline of the fitting is define as the center of the specimens. A photo of the final setup is given in Figure 2-5.



Figure 2-5 Photo of the completely assembled test setup.

Test specimens. Two pipe assemblies were tested to examine the tension capacity of the sleeve with two different gaskets. The gaskets from two different manufacturers were used, as summarized in Table 2-1.

Table 2-1 Summary of test specimens

No	Specimen name	Gasket	Date
1	CSI-2023-PPI-T01	ReiberLok	10/17/2023
2	CSI-2023-PPI-T02	TurnerLok	10/20/2023

3 Instrumentation

The instrumentation consisted of conventional sensors (position transducer, load cell, pressure gage) and distributed fiber optic sensors. The instrumentation plan is discussed in the following sections.

3.1 Conventional Instruments

The experimental setup and the specimen were extensively instrumented. The instrumentation consisted of a load cell, position transducers measuring the displacement of the pipes across the joint, and a position transducer monitoring the displacement of the sleeve on the loading side, as summarized in Table 3-1. In addition, fiber optic sensing was utilized, which is discussed in detail in the respective section of the report.

Table 3-1 Summary of conventional instrumentation

Column No in data file	Channel name	Description	Measurement, units
3	Pacific - 1 (0:0:0) loadcell	Load cell	Applied force, lbs
4	Pacific - 2 (0:0:1) waterpress	Pressure gage	Water pressure, psi
5	Pacific - 74 (0:9:1) smwp1	Position transducer	Displacement of sleeve (loading side), in
6	Pacific - 75 (0:9:2) novo1	Position transducer	Displacement of MegaLug (reaction side), in
7	Pacific - 76 (0:9:3) novo2	Position transducer	Displacement of MegaLug (loading side), in
8	Pacific - 77 (0:9:4) wp1	Position transducer	Displacement across the joint, in
9	Pacific - 78 (0:9:5) wp2	Position transducer	Displacement across the joint, in
10	Pacific - 79 (0:9:6) wp3	Position transducer	Displacement across the joint, in
11	Pacific - 80 (0:9:7) wp4	Position transducer	Displacement across the joint, in

Figure 3-1 shows position transducers used for measuring displacement across the joint and displacement of the sleeve with respect to the pipe on the loading side. A schematic drawing of the instrumentation locations is presented in Figure 3-2.



Figure 3-1 Position transducers for displacement monitoring of the joint.

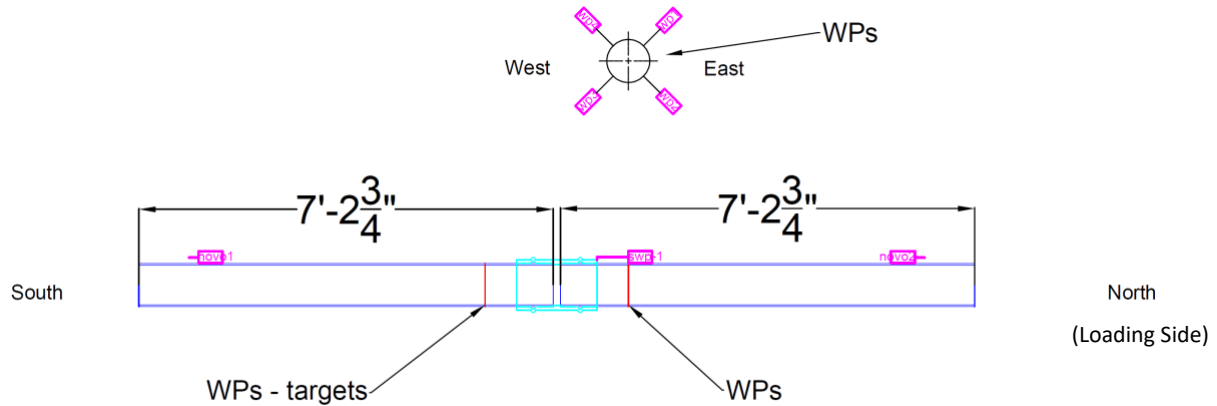


Figure 3-2 Position transducers for displacement monitoring of the joint.

A typical installation of the position transducer monitoring MegaLug's displacement is presented in Figure 3-3.

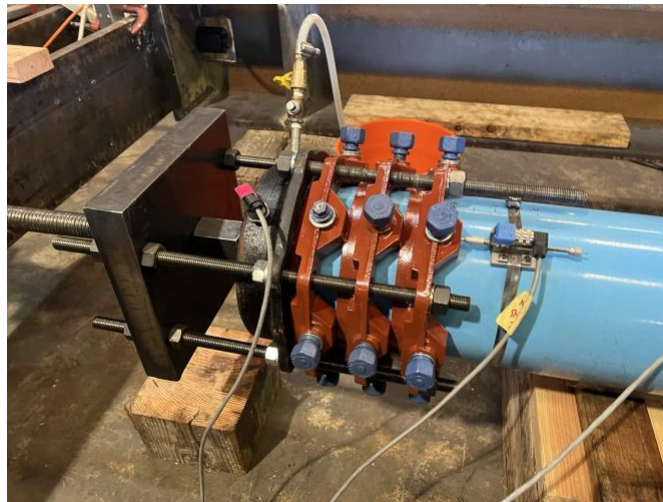


Figure 3-3 Position transducer for monitoring displacement of MegaLug (pipe loading side).

3.2 Fiber Optic Sensors

Two types of fiber optic cables manufactured by NanZee Sensing Technology Co. were used; (a) 5 mm diameter armored cable (NanZee 5mm) and (b) 0.9 mm diameter cable (NanZee 0.9mm). 3M SCOTCH-WELD DP8010 epoxy was used to attach the cables to the pipes. Figure 3-4 and show the layout and locations of the sensors. NanZee 5mm cables (blue lines) were used in the longitudinal direction to mimic the use on construction sites. They were attached on both pipes, 90 degrees apart, numbered F9-F16. On the other hand, to better understand the deformation mechanism of the pipes, NanZee 0.9mm (red lines) was used for measuring circumferential strains, numbered F1-F8. Two circumferential sensors with about 18-inch spacing were installed on both pipes. In addition, two circumferential sensors were placed on both sides of each of the gaskets. Since there are two gaskets in the fitting to lock the two pipes, there are in total four circumferential sensors on the fitting. The local names of DFOS are listed in Table 3-2.

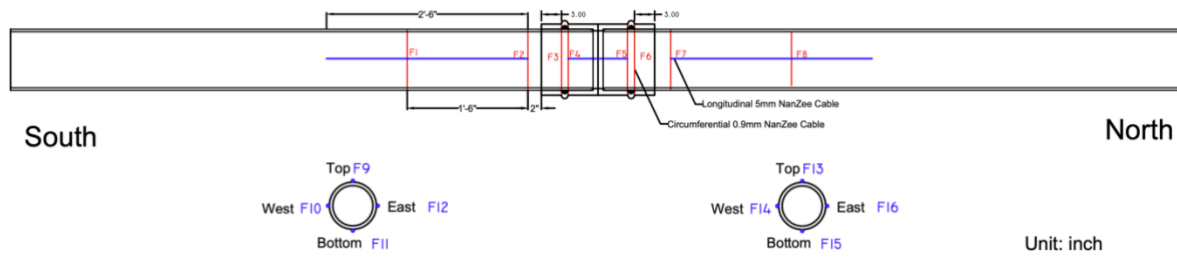


Figure 3-4 Instrumentation plan of fiber optic sensors of the specimens

Table 3-2 Summary of fiber optic sensors

Instrument	Location	Local Instrument Name
DFOS	4.375 inch south of center, Circumferential	F1
	5.375 inch south of center, Circumferential	F2
	10.375 inch south of center, Circumferential	F3
	28.375 inch south of center, Circumferential	F4
	4.375 inch north of center, Circumferential	F5
	5.375 inch north of center, Circumferential	F6
	10.375 inch north of center, Circumferential	F7
	28.375 inch north of center, Circumferential	F8
	South pipe, Top, Longitudinal	F9
	South pipe, West, Longitudinal	F10
	South pipe, Bottom, Longitudinal	F11
	South pipe, East, Longitudinal	F12
	North pipe, Top, Longitudinal	F13
	North pipe, West, Longitudinal	F14
	North pipe, Bottom, Longitudinal	F15
	North pipe, East, Longitudinal	F16

A Rayleigh-based optical frequency domain reflectometry (OFDR), Luna ODiSI 6100 series, was used in the experiments for data acquisition. The analyzer is capable of measuring up to 100 meters long fiber optic cable with an accuracy of less than ± 1 micro strain when taking a measurement every 0.65mm. Appendix A provides more information about the cables and the analyzer.

4 Test Results

All test results are discussed in this section. In addition, a summary of the failure mode and performance of the 8 inches AWWA C900 DR14 iPVC pipe is included.

4.1 Axial Force and Joint Opening

The pipes were filled with water and pressurized to about 70 psi. A monotonic force was applied on the longitudinal axis of the pipeline. Four wire pots were attached around the circumference of the north pipe 90 degrees apart from each, and were fixed on the south pipe. The average joint opening is the mean of the four wire pot readings. The axial force and average joint

opening results are shown in Figure 4-1. The maximum axial force with corresponding average joint opening of each specimen are 1) 34,884 lbs force with 0.76 inch displacements, and 2) 11,884 lbs force with 0.28 inch displacements. Water pressure drops were observed at the time reaching the maximum axial force for both specimens. The force and displacement relationships prior to failure are very similar between the two specimen, suggesting the initial setups of the experiments were similar. Specimen 2 failed at an earlier stage, compared to Specimen 1. This might be because of the different designs of the gaskets. The TurnerLok gasket has larger but fewer teeth which might potentially introduced a local concentrated stress, resulting in earlier localized failure. Also, as discussed later on, the specimens behaved differently as the loading increased, which may have contributed to the difference in the failure load. This issue will be investigated in the FE analysis of the experiments planned in the future. The test results are summarized in Table 4-1.

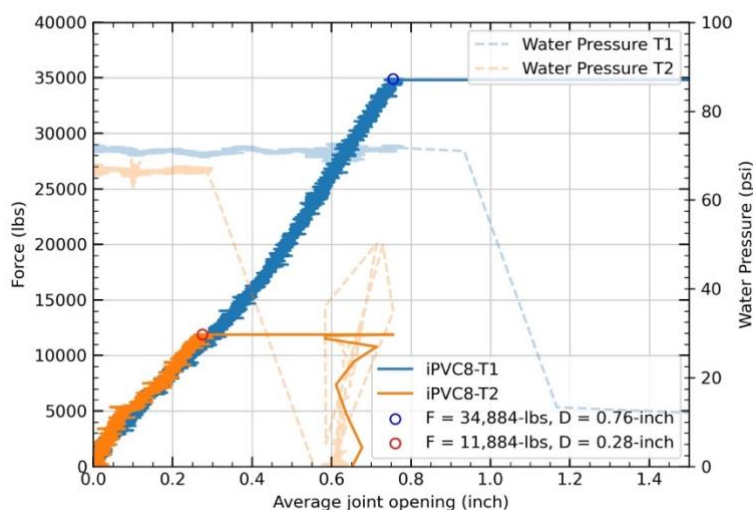


Figure 4-1 Axial force, average joint opening, and water pressure results of Specimen 1 and 2

Table 4-1 Summary of the tests

	Max. Axial Force (lbs)	Max. Avg. Joint Opening (inch)	Gasket
Specimen 1	34,884	0.76	ReiberLok
Specimen 2	11,884	0.28	TurnerLok

4.2 Failure Modes

On both of the specimens, the failure occurred in the joint segment close to the point where the teeth bit on the pipe. This indicates that the interaction between the teeth and the jointed segment caused the failure. The failures of both specimens are shown in Figure 4-2. Although shear/tensile stresses at the gasket locations likely governed both failures, the failure patterns were different. In Specimen 1 (ReiberLok gasket), the failure occurred around the circumference of the fitting. On the other hand, in Specimen 2 (TurnerLok gasket), the failure was observed only on the top side of the joint. The difference might be due to the design of the gasket. The ReiberLok gasket has numerous smaller teeth, which potentially distribute the applied load more evenly. With more teeth, the forces per tooth are smaller, reducing stress concentration around individual teeth. TurnerLok gasket has fewer but larger teeth, which concentrate greater stress at their boundaries.

This might be why Specimen 2 failed at an earlier stage. A detailed evaluation of the pipe failure mechanism will be carried out with the finite element model planned in the future.

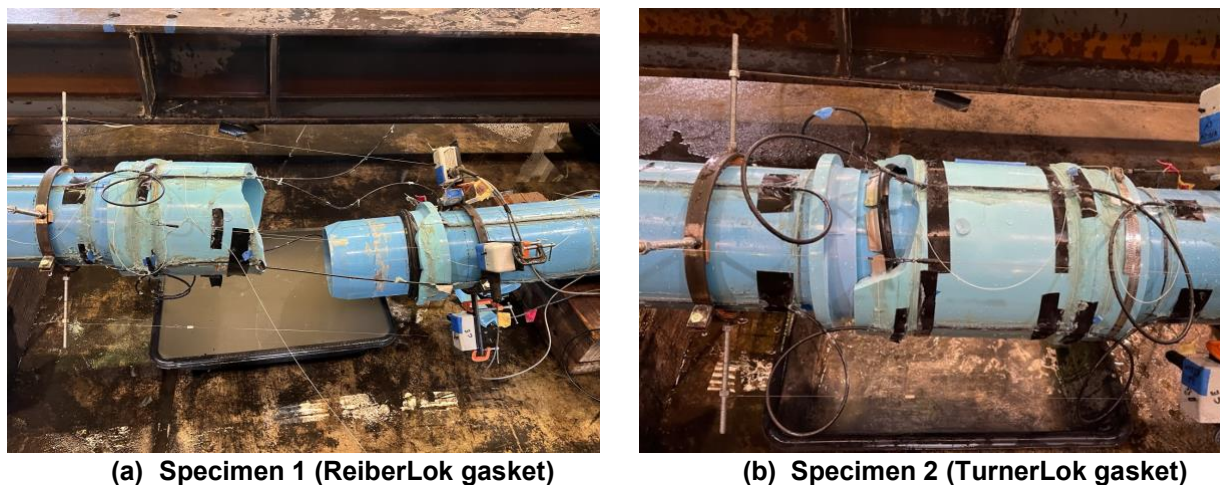


Figure 4-2 Failure of Specimen 1 and 2

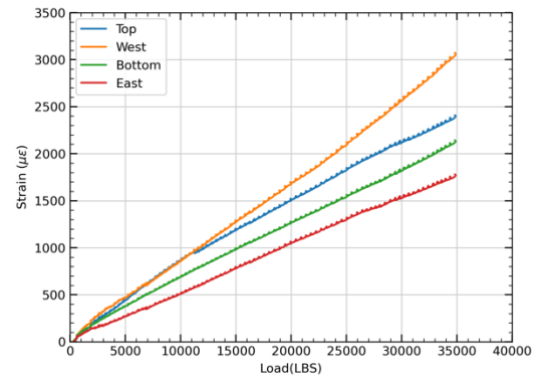
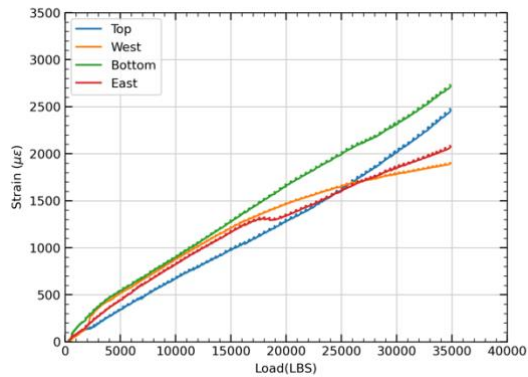
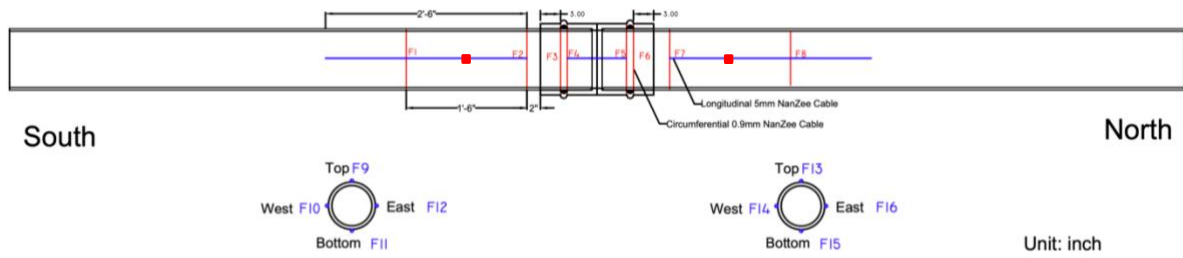
4.3 Axial Strains

The axial strain results of Specimens 1 and 2 from the distributed fiber optic strain (DFOS) sensors are shown in Figure 4-3 to Figure 4-6. Figure 4-3 shows the relationship between the axial strain and axial loads at the midpoints of F1 and F2 (south pipe), and the midpoints of F7 and F8 (north pipe), measured by the longitudinal sensors. The results from both specimens show that all the pipes were experiencing tensile stresses. However, difference on magnitude of the strains at different locations are observed on both specimens.

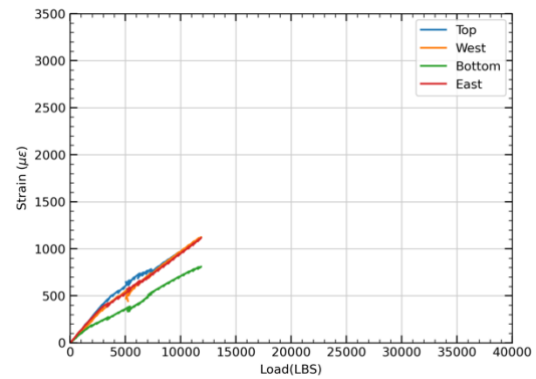
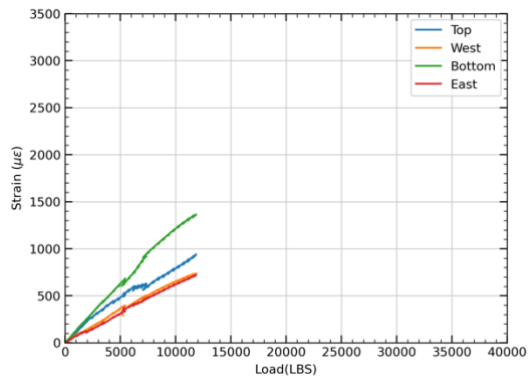
The strain data on the south pipe of Specimen 1 show a slight variation between the top and bottom. This could be due to the pipe being slightly bent towards the top. The strain developments on the east and west sides are similar at the beginning of the loading. However, when the load reached approximately 16,000 lbs, the strains started to develop at a slower pace. This indicates that there was less stress on the two sides compared to the top and bottom. It is possible that the pipe started to elongate during this loading stage. Consequently, the locking gasket had less contact to the pipe at the east and west sides in comparison to the top and bottom. This resulted in less axial force being transferred through the two sides compared to the top and bottom. This phenomenon is illustrated in Figure 4-4.

The strain data on the north pipe of Specimen 1 show that there are significant differences in strain development compared to the south pipe. When comparing the strains on the top and bottom, it is observed that the pipe was slightly bent towards the downside. Similarly, when comparing the strains on the west and east sides, it is noticed that the pipe was bending towards the east side. One possible explanation for this phenomenon could be attributed to the initial relative movement between the locking gaskets and the pipes. Due to this initial adjustment, there is a possibility that the locking gasket was not engaged with the pipe on a perfect vertical plane, causing some bending force when axial force was applied.

The fitting broke at the north pipe connection, potentially because of the larger spatial variation in strains on the north side connection compared to the south side connection.



(a) Specimen 1 (ReiberLok gasket)



(b) Specimen 2 (TurnerLok gasket)

Figure 4-3 Axial strain vs load. (Left) South pipe. (Right) North Pipe.

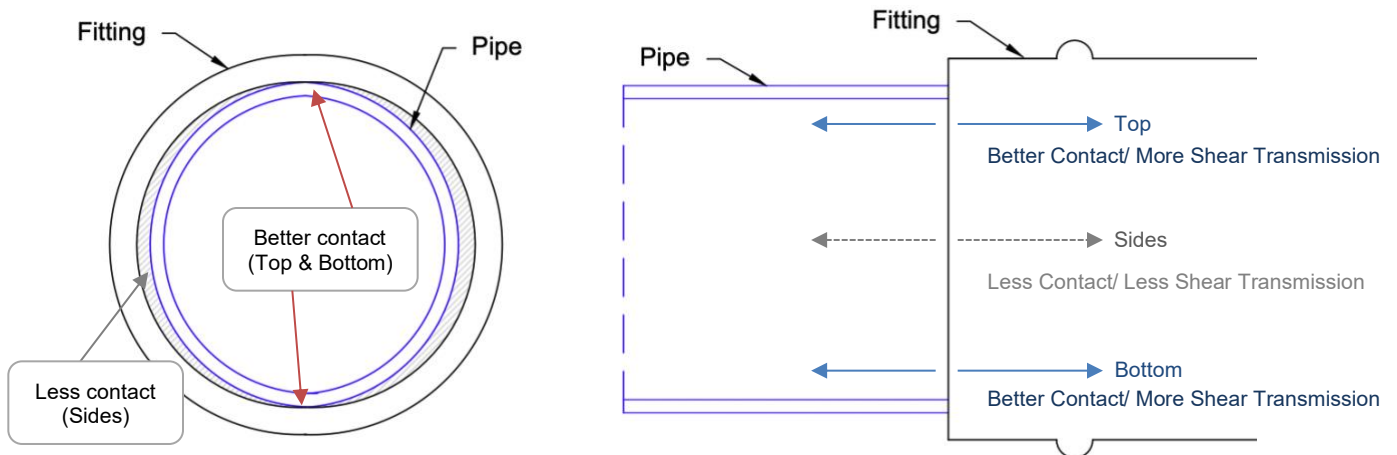
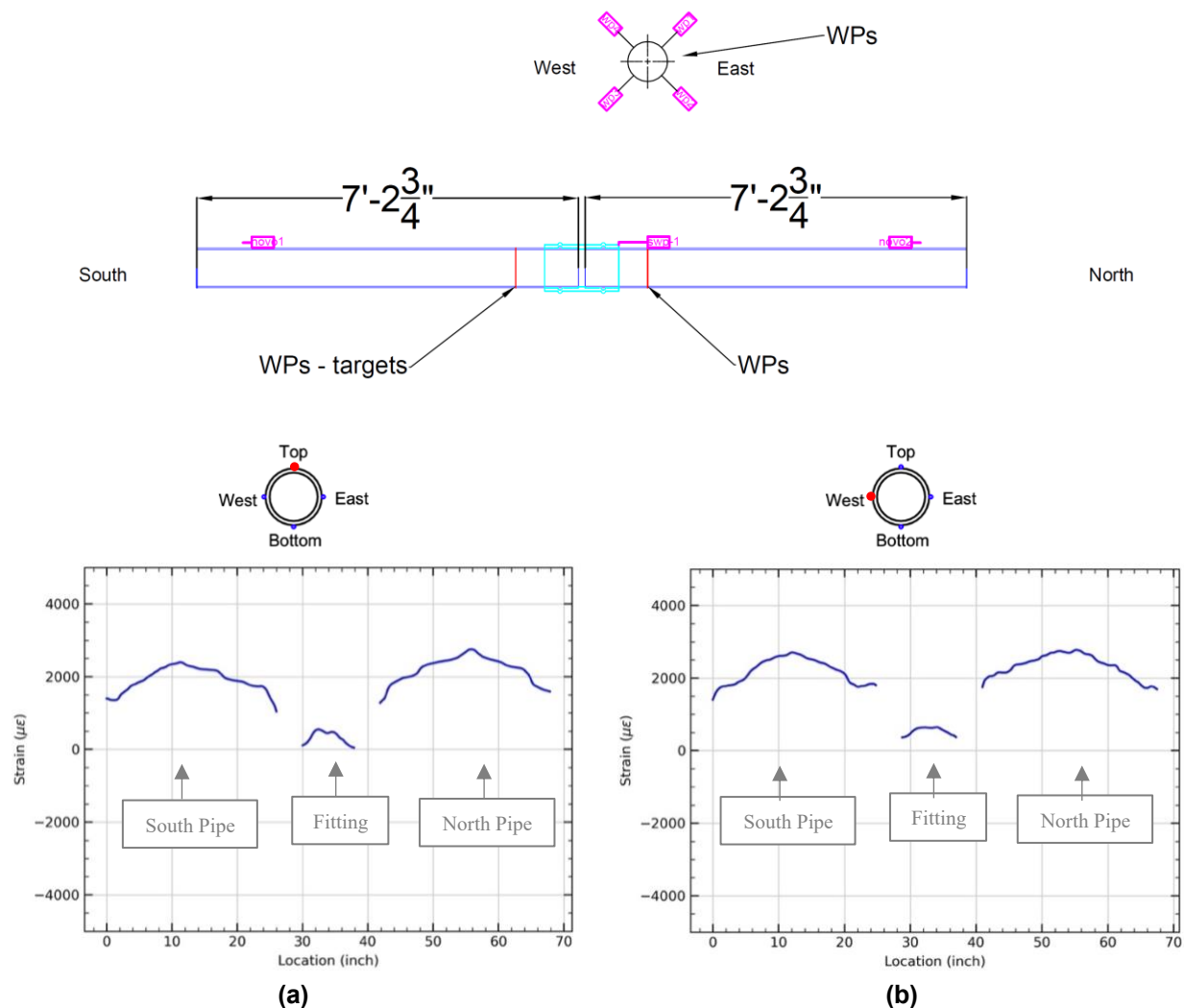


Figure 4-4 Sketch of pipe-fitting deformation mechanism

Regarding the south pipe of Specimen 2 the strain developments on the east and west sides are similar, but the magnitudes are considerably smaller compared to those measured at the top and bottom. This difference may be attributed to the uneven installation of the locking gaskets. The results suggest that the teeth on the top and bottom engaged better, resulting in better stress transfer than on the east and west sides. The TurnerLok gasket is less stiff than the ReiberLok gasket, making it more challenging to maintain a perfect circle while installing it. The TurnerLok gasket tends to distort, increasing the difficulty of installation. Due to this imperfect gasket-pipe interaction, the development of tensile stress/strains varied at different locations of the pipe from the beginning of loading.

The strains developed on the north pipe of Specimen 2 are similar, except for those on the bottom. The strain developed on the bottom is much smaller compared to other locations. This may be due to imperfect installation of the locking gasket. The results suggest that the bottom side of the teeth of the locking gasket was not fully engaged with the pipe, which reduced the force transferred through this region.

The fitting broke at the south pipe connection, potentially because of the larger spatial variation in strains on the south side connection compared to the north side connection.



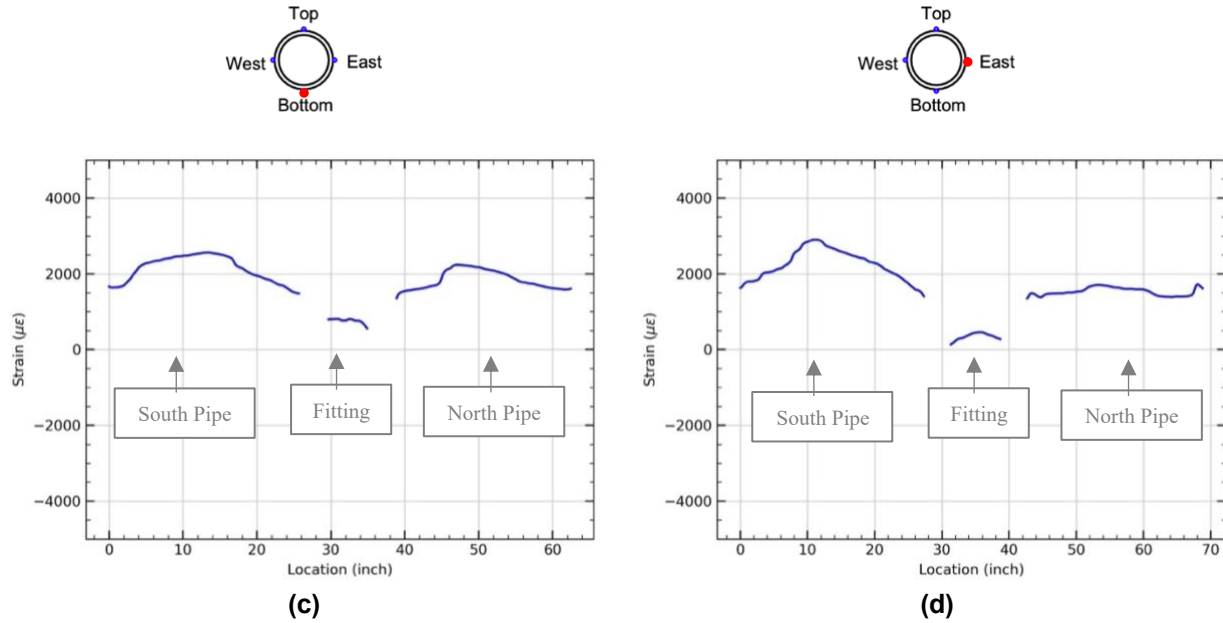


Figure 4-5 Axial strain development of west pipe of Specimen 1 under 32,000-LBS axial loading condition. (a) Top, (b) West side, (c) Bottom, (d) East side

Figure 4-5 shows the axial strain distribution of Specimen 1 under 32,000 lbs loading condition, close to failure. The figures are plotted from the south to the north, and the two gaps on the plots are the locations of the boundaries between the fitting and the pipes where no DFOS was attached. Tensile strains are observed at all locations when forces are applied in the axial direction. The strain profiles on the south and north pipes are similar, while the magnitudes of strain on the fitting are smaller than those measured on the pipes. This is due to the difference in thickness between the fitting and the pipes. The thicker wall of the fitting makes it much stiffer than the pipes, resulting in smaller strains developed on the fitting compared to the pipes.

Figure 4-6 illustrates strain measurements from Specimen 2 under an 11,500 lbs axial loading condition. Since the maximum load was smaller, the strain magnitudes are also smaller compared to those from Specimen 1. However, a similar pattern of strain distribution is noted with larger strains observed on the pipes as opposed to the fittings. This is because the pipes have a smaller wall thickness than the fittings.



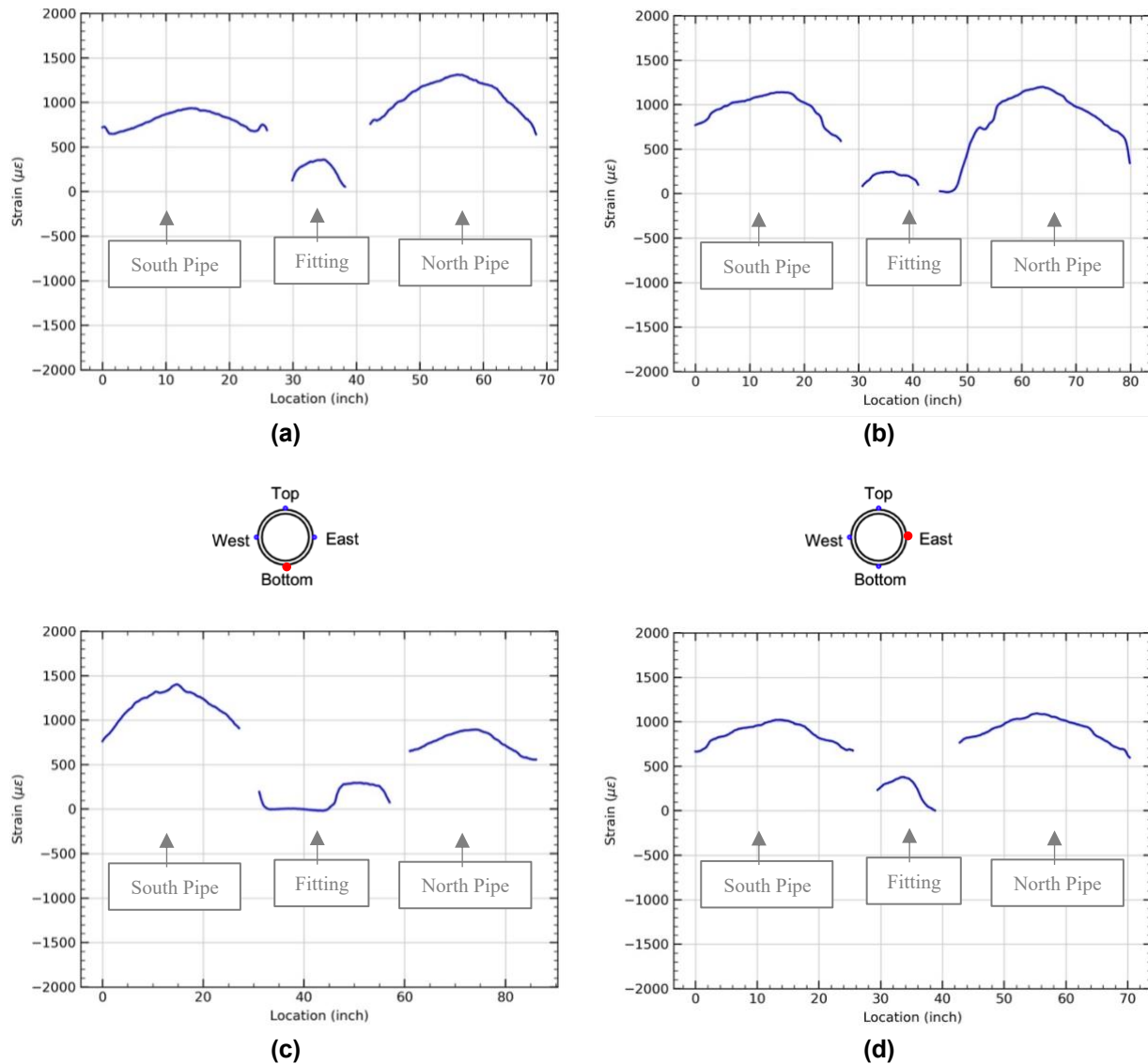


Figure 4-6 Axial strain development of west pipe of Specimen 2 under 11,500-LBS axial loading condition. (a) Top, (b) West side, (c) Bottom, (d) East side

4.4 Hoop Strains

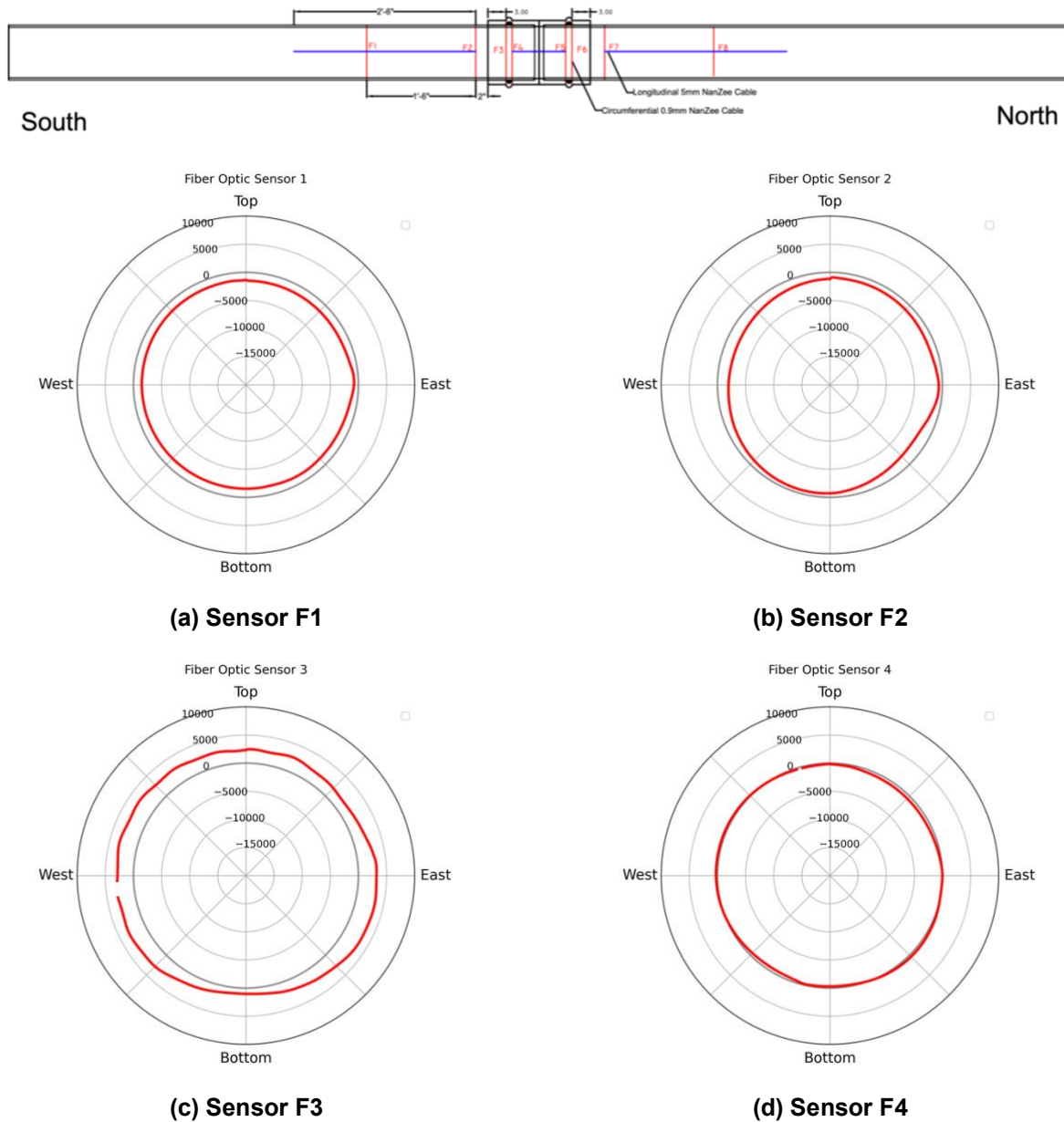
The hoop strain results measured from Specimen 1 are plotted in Figure 4-7. The figure illustrates the results obtained by the sensors positioned on the fitting (F3 and F4) and the sensors nearest to the fitting on both pipes (F2 and F7).

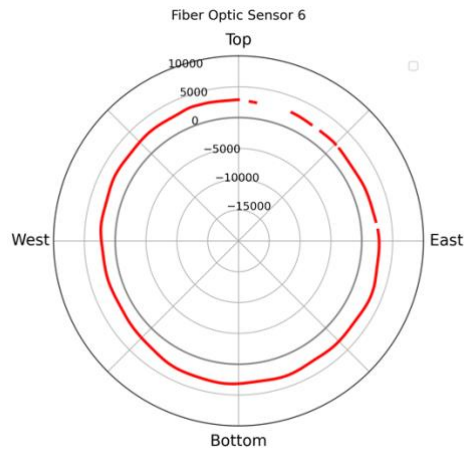
The results obtained from F2 and F7 on the pipes show compressive strains, indicating that the pipes are contracting radially while being pulled out. This phenomenon occurs due to Poisson's effect, where strains in the circumferential direction oppose those in the longitudinal direction with a smaller magnitude.

Sensor F3 was positioned north of the gasket location, while Sensor F4 was located south of it. As the pipe was pulled out, the wedged side of the teeth on the gasket pressed against the fitting, causing the outer side of the fitting from the gasket location to expand by the gasket-fitting

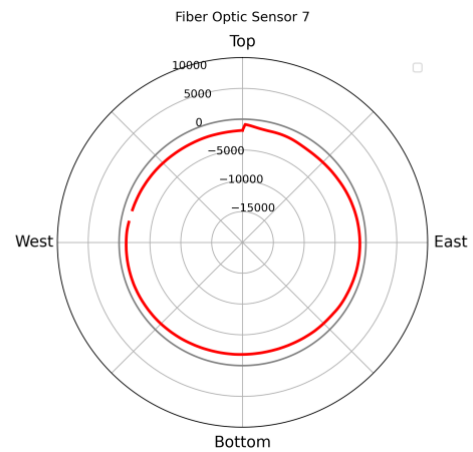
interaction, as shown in Figure 4-8. This phenomenon is clearly observable in the results measured by Sensor F3, where the fitting exhibited tension all around its circumference. A similar pattern is evident in the results from Sensor F6.

Compressive strains are observed on the inner side of the fitting from the gasket location, as indicated by Sensor F4 measurements. As demonstrated in earlier sections, the longitudinal strains in this section are smaller, leading to reduced hoop strains due to Poisson's effect. Although similar behavior would be expected at the location of Sensor F5, its results are not reported in this study due to sensor damage during testing. The fitting degormation mechanism is visualized in Figure 4-8.

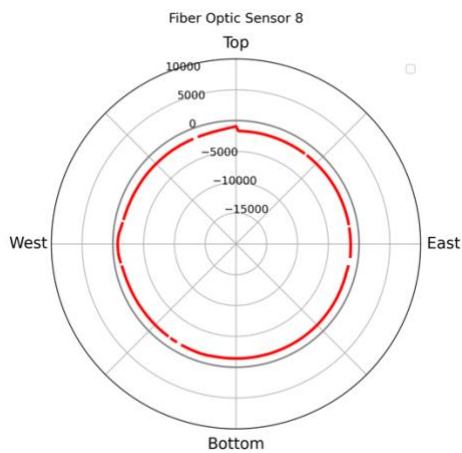




(e) Sensor F6



(f) Sensor F7



(g) Sensor F8

Figure 4-7 Strain distribution in the circumferential direction of Specimen 1 under 32,000-LBS loading condition.

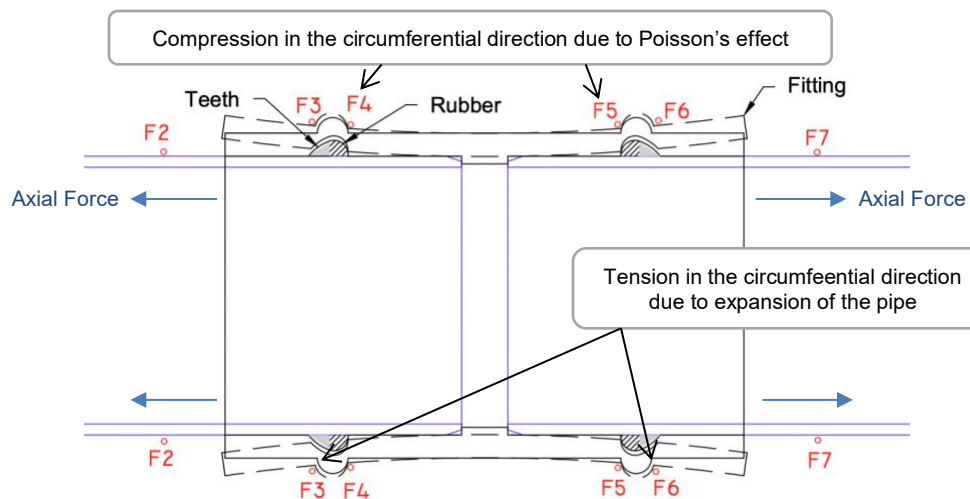
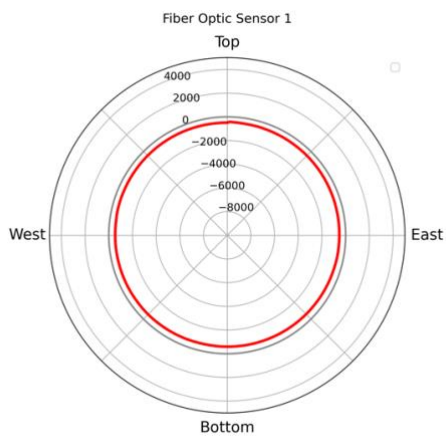
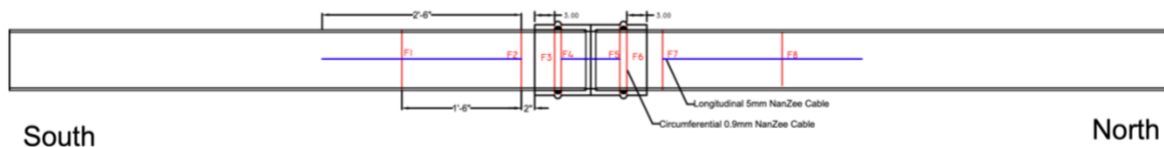
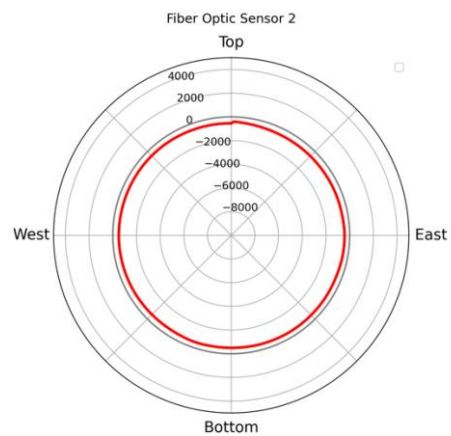


Figure 4-8 Sketch of the fitting deformation under axial force

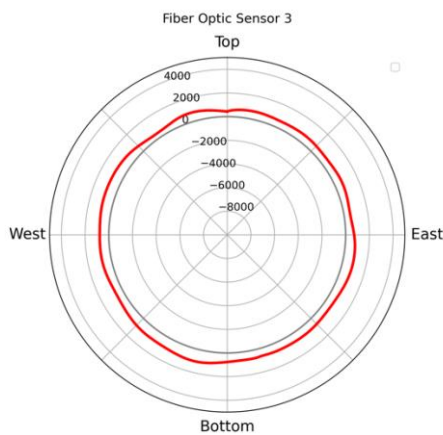
Figure 4-9 shows the hoop strain results in Specimen 2. The sensor's locations are the same as that of Specimen 1. Similar to the observations in Specimen 1, both north and south pipes exhibited circumferential compression due to Poisson's effect. Circumferential tension was observed on the outer parts of the fitting (i.e., F3 and F6), while compressive strains were detected at the middle section of the fitting (F4 and F5). The observed mechanism in Specimen 2 is the same as that in Specimen 1.



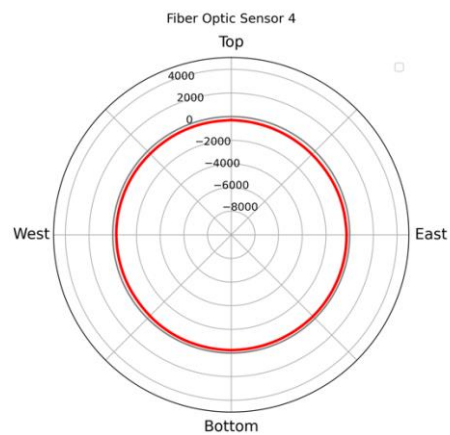
(a) Sensor F1



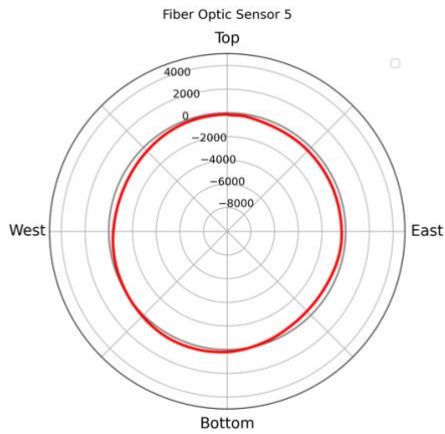
(b) Sensor F2



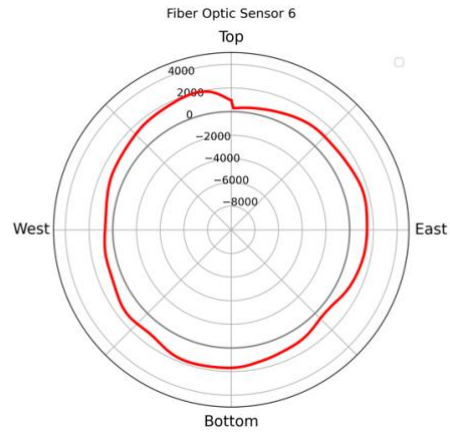
(c) Sensor F3



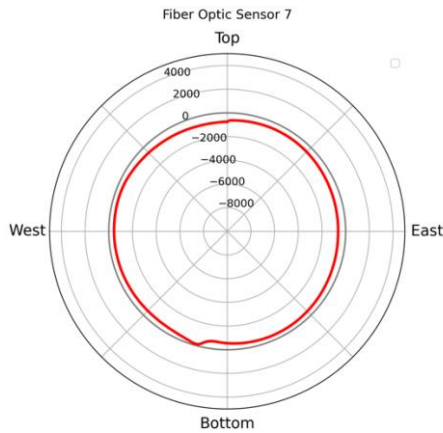
(d) Sensor F4



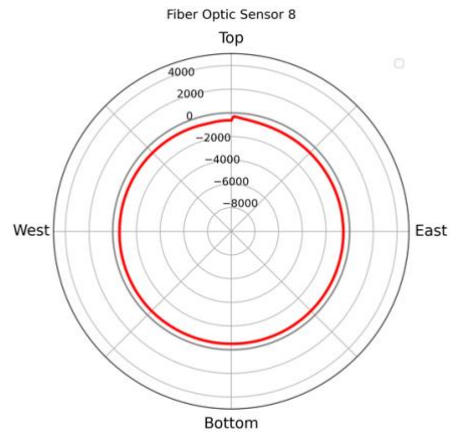
(e) Sensor F5



(f) Sensor F6



(g) Sensor F7



(h) Sensor F8

Figure 4-9 Strain distribution in the circumferential direction of Specimen 2 under 11,500-LBS loading condition.

5 Conclusions

This report outlines the findings of the tension loading experiments conducted on 8-inch AWWA C900 DR14 iPVC pipes fitted with two different types of rubber gaskets (ReiberLok and TurnerLok) under tensile force. The objective was to test the pipes until severe damage or water leakage occurred.

The two tested specimens had similar initial responses in terms of force-strain developments, but their ultimate capacities were different. Specimen 1, which was equipped with a ReiberLok gasket, reached a maximum force of 34,884 lbs and had 0.76 inches of displacement. On the other hand, Specimen 2, which used a TurnerLok gasket, achieved a lower maximum axial force of 11,884 lbs and had 0.28 inches of displacement. Both specimens experienced water pressure drops upon reaching the maximum axial force. The difference in performance can be attributed to the different designs of the gasket teeth. The smaller teeth on the ReiberLok gasket

appeared to distribute the load more evenly, thus reducing local stress concentration. The larger but fewer teeth on the TurnerLok gasket may have led to greater stress concentrations at tooth boundaries, resulting in earlier localized failure.

Fiber optic sensors were utilized to monitor the development of axial and circumferential strains in a fitting. The inner section of the fitting underwent radial contraction due to the axial tension caused by Poisson's effect. On the other hand, a radial expansion mechanism was observed at the outer parts of the fitting where the gaskets bore against it while pulling out the pipes. The fitting experienced significant shearing at the gasket locations, which ultimately led to its failure at these locations.

The strain developments on the pipes could have been influenced by the quality of the engagement between the locking gaskets and the connected pipes. During the testing of Specimen 1, the south pipe showed that, after reaching a load of around 16,000-lbs, the strains on the west and east sides began developing slower compared to the top and bottom. This could be because the pipe and the fitting were elongating, resulting in a looser contact between the pipe and the locking gasket on these two sides. For the north pipe, there was a noticeable differences in strain magnitude among the four locations. This might have been due to bending that occurred from the beginning of the test. The initial movement between the fitting and the pipe might have caused the locking gasket to move, resulting in their teeth not engaging perfectly in a vertical plane, leading to bending throughout the test.

It was observed that the engagement between the locking gasket and the connected pipes had an impact on the strain patterns of Specimen 2. In the south pipe, the strains developed on the top and bottom were consistently higher than those on the other two sides. This suggests that the force was transferred more effectively on the top and bottom, but not as effectively on the west and east sides. The north pipe showed that, except for the strain on the bottom, the strain patterns were aligned well. This could be because the teeth on the bottom were not engaging well with the pipe, leading to less effective force transfer at that location

6 References

PPI Pipe (n.d.). iPVC Water Pipe. <https://ipvcpipe.com/eng/sub/ipvc01.php>

Wu, J., Jiang, H., Su, J., Shi, B., Jiang, Y., & Gu, K. (2015). Application of distributed fiber optic sensing technique in land subsidence monitoring. *Journal of Civil Structural Health Monitoring*, 5(5), 587-597.

Appendix A: Distributed Fiber Optic Sensing

Using the physical properties of light, fiber-optic sensing can detect changes in temperature, strain, and other parameters when light travels along a fiber, which uses fiber-optic cables as sensors and can measure over long distances at 100 to 1000s of points on a single cable or multiplexed cables depending on the analyzer used. Compared to the other sensing technologies, fiber-optic sensing has distinct advantages such as small size, light weight, and strong resistance to corrosion and water. Distributed fiber optic sensing consists of two main components, an analyzer, and fiber-optic cables. LUNA ODiSI 6000 series interrogator was used as the analyzer, and NanZee Sensing Technology Co manufactured the fiber-optic cables in the experiments.

LUNA Interrogator



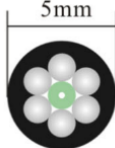
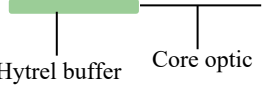
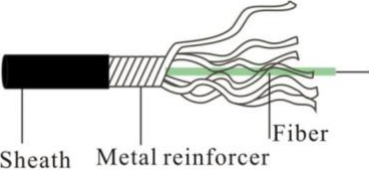
Figure A-1. LUNA ODiSI 6000 Series optical distributed sensor interrogator (LUNA, 2022)

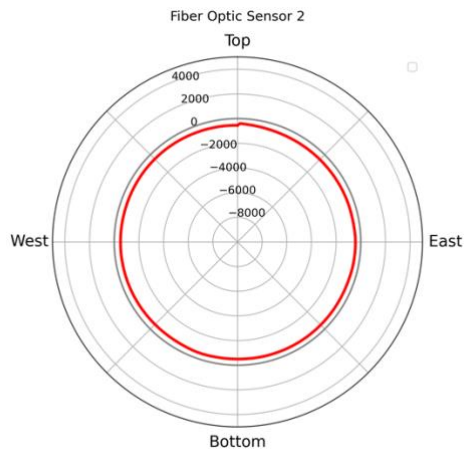
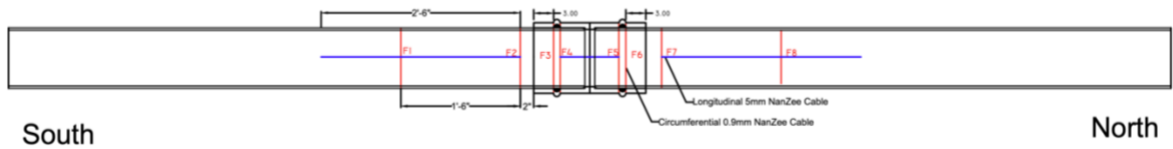
LUNA ODiSI 6104 is an optical distributed sensor interrogator that can provide thousands of strain or temperature measurements per meter of a single high-definition fiber sensor. High-Definition H.D.D) Sensors - Strain & Temperature (HD-SC) temperature sensors utilize an advanced interrogation mode of the ODiSI to increase the accuracy of measurements when the sensors are subjected to strain, such as in embedded and surface-mount installations. It can achieve a sensor gauge pitch (the distance between two measurement points) as small as 0.65 mm, a sensor length of up to 100 m, and a measurement rate of up to 250 Hz with an accuracy of less than ± 1 microstrain.

Fiber-optic Cable

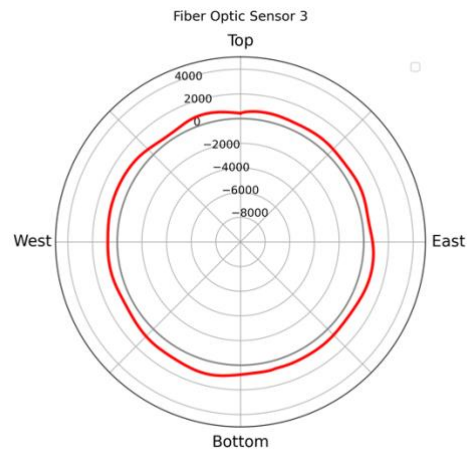
Two types of fiber optic cables manufactured by NanZee Sensing Technology Co. were used; (a) 5 mm diameter armored cable (NanZee 5mm) and (b) 0.9 mm diameter cable (NanZee 0.9mm). Table A-1 lists the information on the cables. The difference between the two cables is the thickness and material of the coating. NanZee, a 5mm cable, provides a sheath layer and steel reinforcement, resulting in better protection to the optical core; hence, it can be used for the actual field application. The coating of NanZee 0.9mm cable is thinner than NanZee 5mm cable. NanZee 0.9mm cable has less protection, but a more sensitive strain response is achieved.

Table A-1 Schematic illustration of the selected strain sensor cable (Wu et al., 2015)

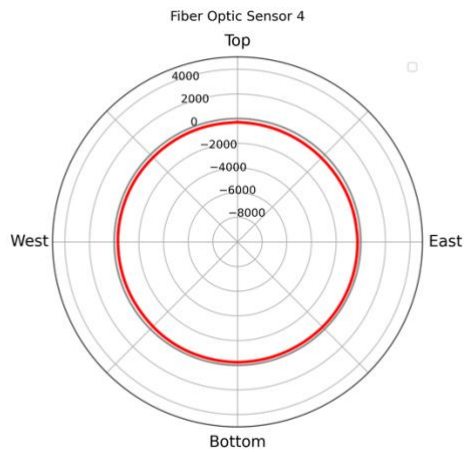
Brand	NanZee Sensing Technology Co.	
Model	NZS-DSS-C07	NZS-DSS-C02
Cross section		
Side view		



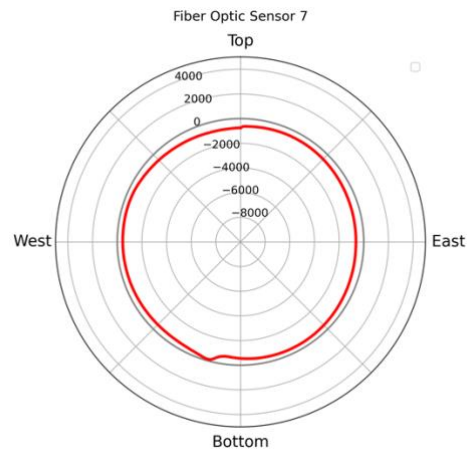
(a) Sensor F2



(b) Sensor F3



(c) Sensor F4



(d) Sensor F7

Figure 0-1 Strain distribution in the circumferential direction of Specimen 1 under 32,000-LBS loading condition.