Evaluation of Gate Valve Flanges: Serrated vs Non-Serrated Under External Loading

Submitted to:

Denver Water

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May 2024

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1. Introduction

This report presents test results to investigate the difference between a flange connection machined to a flat surface with a serrated finish in accordance with AWWA C207 and a non-serrated flange connection. The goal was to determine if one type of flange face would leak sooner than the other. A series of tests were performed with nominal 6 in. (150 mm) diameter ductile iron (DI) pipe with Mueller Resilient Wedge Gate Valves. These valves will be referred to as serrated gate valves and non-serrated gate valves from this point on. Figure 1.1 shows the serrated gate valve, and Figure 1.2 shows the non-serrated gate valve. The work was undertaken in the Center for Infrastructure, Energy, and Space Testing which is affiliated with the Civil, Environmental, and Architectural Engineering Department at the University of Colorado Boulder.

The report is organized into three sections. Section 1 provides introductory remarks, including discussion of the test specimens and experimental overview. Section 2 discusses the test results for the serrated face connections and the non-serrated face connections. Lastly, Section 3 provides a comparison of test results.

Figure 1.1. Example of the serrated gate valve

Figure 1.2. Example of the non-serrated gate valve

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1.1. Test Overview

Each specimen tested was a commercially available 6 in. (150 mm) diameter DI pipe conforming to AWWA C600 standards. Table 1.1 provides an overview of the test specimens and experiments performed. Two tests were performed for each joint type. The approximate internal pressure at which the test was conducted is also included.

Table 1.1. Summary of Denver Water tests and specimens

Test Type	Pipe (Company)	Pressure Class (psi)	Joint Type (Company)	Internal Test Pressure, psi (kPa)
4-point Bending w/ Axial Tension	DI (DW)	250	Serrated Mueller Gate Valve	65 (448)
4-point Bending w/ Axial Tension	DI (DW)	250	Non-serrated Mueller Gate Valve	65 (448)

1.2. Test Setup

This section outlines the test setup procedure for loading a given pipe specimen. Figure 1.3 shows an image of the test setup and equipment. The test setup and equipment consisted of a 255.17 Materials Testing System (MTS) actuator, a 220-kip load cell, and a load frame, which were used to apply tensile and transverse bending loads to the test specimen. The test specimens consisted of nominal 6 in. (150 mm) diameter DI pipe, plain end by flanged end connections.

Figure 1.3. Pipe specimen in bi-axial test frame

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1.2.1. Specimen Installation Procedure

The pipe specimen was prepared at a length of approximately 13 ft (3.96 m) for testing (two 72-in. (1524-mm) segments and one 12-in (305mm) connection). The gate valve was installed using the minimum required torque of 150 ft-lb per the Garlock Gasket Tech Manual (Page C-41) for 6 inch nominal pipe sizes. Class 150 flanges were welded at either end to transfer the externally applied axial load and hold pressure. Eight short threaded rods were used to both transfer load to the specimen and hold the endcap in place to maintain live pressure during testing.

1.2.2. Instrumentation

Four string potentiometers (string pots) were attached to the specimen: two to measure axial displacements between the pipe and the connection, and two to measure the vertical displacement during the bending portion of the test. An electronic pressure transducer is installed on the east end to measure internal water pressure during the test.

1.3. Test Procedure

The following section provides details of the test sequence, divided into two parts: pretest and test sequence.

1.3.1. Pretest

Once the specimen is secured in the loading frame and the calibrated instrumentation is installed, the measuring systems are verified. The pipe is filled with water with the air bleed valve in the open position. The air bleed valve is closed once water has flowed from it without any observable air bubbles and the system is pressurized to the laboratory pressure of approximately 65 psi (450 kPa) to check for leaks. Water is introduced into the specimen five hours or more before testing to ensure thermal acclimation to ambient laboratory conditions. Several pressurization sequences are completed to seat and verify readings of strain gauges and check axial force measured by the load cell. In each of the cycles the air bleed valve is opened to release any remaining air. Prior to a pressurization sequence, the nuts between the loading frame and the endcaps are tightened, such that when the pipe is pressurized, the axial force can be measured by the load cell. During the pressurization sequences, the pipe is pressurized to approximately 65 psi (450 kPa) and depressurized several times. The area surrounding the testing frame is cleared of all tools and other objects. Once ready for the test, a pretest meeting is conducted to review installation conditions, walk through instrumentation locations and expectations, and discuss safety equipment and concerns.

1.3.2. Test Sequence

After the pretest meeting is conducted and roles assigned, the test sequence is initiated by starting the data acquisition system and laboratory hydraulic systems. A data sampling rate of 4 Hz is used for all reported tests. The loading nuts at either end of the specimen are tightened to avoid any end movement due to pressurization. An initial 2 kips of load is applied to the specimen to ensure all aspects are engaged prior to removing any supporting fixtures from the pipe. Once supporting fixtures are removed, the axial load is increased to 10 kips and held there for the duration of the test. Vertical displacement is then applied at a rate of 1 in. (25.4 mm) per minute until the first leak is observed at either end of the gate valve. Once noted, vertical displacement continues and pauses for each point of interest outlined in Table 1.2. Once the final point of interest is reached, the vertical displacement is released, the axial load is reduced down to 2 kips, the pressure is released, and the supporting fixtures are put back in place. The torque on the bolts connecting the pipe specimens to the gate valve is then increased to the manufacturer recommended allowable torque of 200 ft-lb., and the sequence outlined above is repeated. Once the test is completed, the data acquisition system is turned off, laboratory hydraulic systems set to low pressure, and data is backed up.

Table 1.2. Points of interest during testing.

ID#	Points of Interest (the test is paused so notes can be taken at each point)
1	First leak is observed at either end of the gate valve (approx. rate of 1 drop/s).
2	First leak is observed on the other end of the gate valve (approx. rate of 1 drop/s).
3	Leak rate on either end of the gate valve is increased to an observable steady steam.
4	Leak rate on the other end of the gate valve is increased to an observable steady stream.
5	A pressure drop of approx. 5psi is observed on the pressure readings.

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2. Test Results

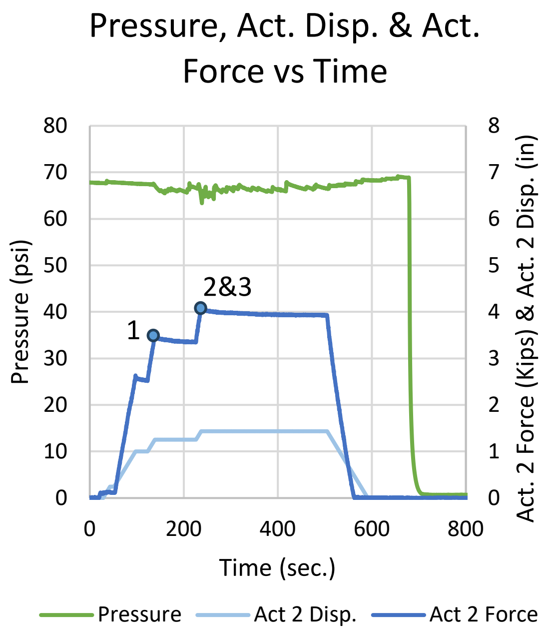
The following section provides results from four 4-point bending tests with applied axial load (tension) on serrated gate valves and non-serrated gate valves. Two tests were performed on DI pipes with flange connections machined to a flat face with a serrated finish with serrated gate valves, and two tests were performed on non-serrated DI pipes with non-serrated gate valves. For all tests, displacement was applied at a rate of 1 in. (25 mm) per minute.

2.1. Serrated Tests

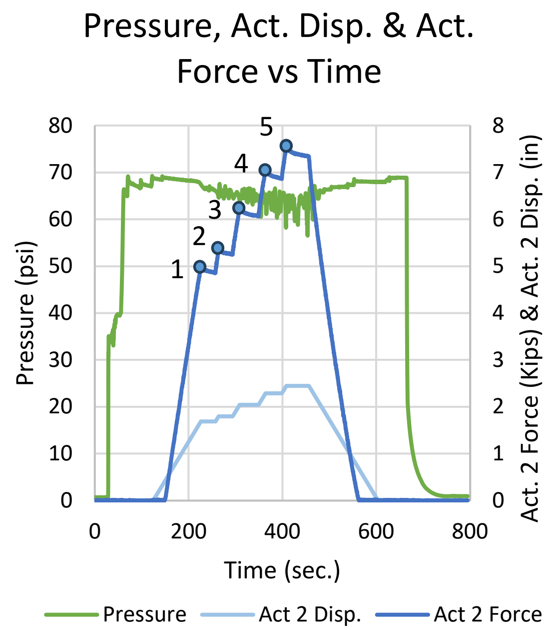
Serrated flange face connections on DI pipes paired with a serrated gate valve were used for the first test. During the test, the specimen was internally pressurized with water to around 65 psi (448 kPa) with minor fluctuations. For the first portion of the test, the bolts connecting the pipes to the valve were torqued to the minimum required spec of 150 ft-lb. The specimen was subjected to 10 kips of axial tension loading, then transverse displacement was applied to the system at the two interior loading saddles. The applied force generated by the transverse loading was captured and recorded by the vertical actuator equipped with a 110-kip load cell. Figure 2.1 (a) presents the progression of internal pressure, applied transverse displacement, and actuator force through the duration of the initial portion of the test. The breaks in transverse displacement indicate points of interest throughout the test, outlined in Table 2.1.

The pipe was then unloaded and the torque on the bolts connecting the pipes to the flange was increased to the maximum allowed torque spec of 200 ft-lb. An axial load of 10 kips was reapplied and transverse displacement was applied again. Figure 2.1 (b) shows the progression of pressure, applied displacement, and actuator force through the duration of the second portion of the test. The breaks in transverse displacement indicate points of interest throughout the test, outlined in

Table 2.2.



(a) Bolts torqued to 150 ft-lb



(b) Bolts torqued to 200 ft-lb

Figure 2.1. Results for pressure, transverse displacement, and actuator force vs. time for serrated test 1

Table 2.1. Points of interest for serrated test 1 (torqued to 150 ft-lb)

ID#	Location	Observation	Act. Disp. (in)	Act. Force (Kips)
1	West	First leak was observed (approx. rate of 1 drop/s).	1.7	4.9
2	East	Second leak was observed (approx. rate of 1 drop/s).	1.8	5.2
3	West	The first leak rate was increased to an observable steady stream.	2.0	6.0
4	East	The second leak rate was increased to an observable steady stream.	2.2	6.9
5	NA	Substantial leak observed on both ends of the valve and pressure decreased by ~5 psi.	2.4	7.4

Table 2.2. Points of interest for serrated test 1 (torqued to 200 ft-lb)

ID#	Location	Observation	Act. Disp. (in)	Act. Force (Kips)
1	West	First leak was observed (approx. rate of 1 drop/s).	1.2	3.4
2/3	West	The leak rate was increased to an observable steady steam. (A slow leak of approx. 1 drop/s was also observed on the east side of the valve at this point.	1.4	4.0

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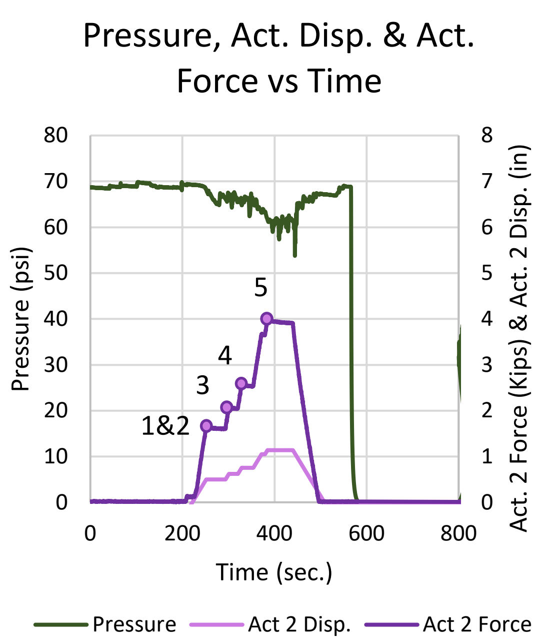
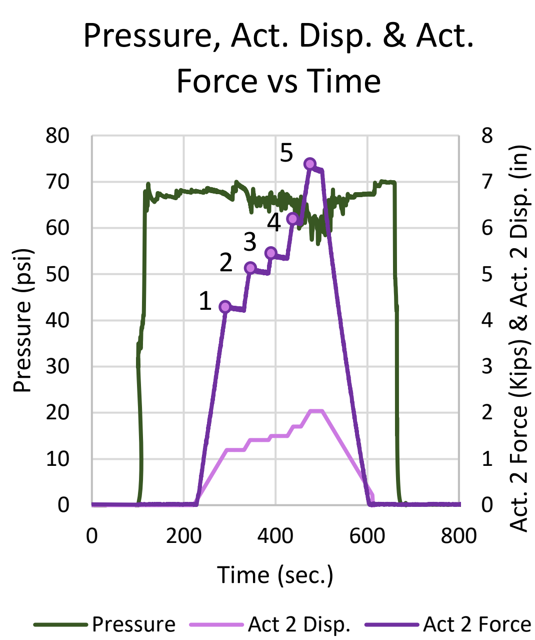
The second test was completed using the same serrated ductile iron pipes used during the first test, and a new serrated gate valve. The same procedures and criteria were used for the duration of the second test. Figure 2.2 shows the relationship between pressure, applied transverse displacement, and actuator load relative to time for (a) the portion of the test performed at a torque spec of 150 ft-lb and (b) the portion of the test performed at a torque spec of 200 ft-lb. Table 2.3 outlines the points of interest noted during the first portion of the test, and Table 2.4 outlines the points of interest noted during the second portion of the test.



(a) Bolts torqued to 150 ft-lb



(b) Bolts torqued to 200 ft-lb

Figure 2.2. Results for pressure, transverse displacement, and actuator force vs. time for serrated test 2

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Table 2.3. Points of interest for serrated test 2 (torqued to 150 ft-lb)

ID#	Location	Observation	Act. Disp. (in)	Act. Force (Kips)
1/2	East/West	First leak was observed on both ends of the valve at close to the same time. (approx. rate of 1 drop/s). The leak on the west side was slightly faster	0.5	1.7
3	West	The first leak rate was increased to an observable steady stream.	0.6	2.1
4	East	The second leak rate was increased to an observable steady stream.	0.7	2.6
5	NA	Substantial leak observed on both ends of the valve and pressure decreased by ~5 psi.	1.1	4.0

Table 2.4. Points of interest for serrated test 2 (torqued to 200 ft-lb)

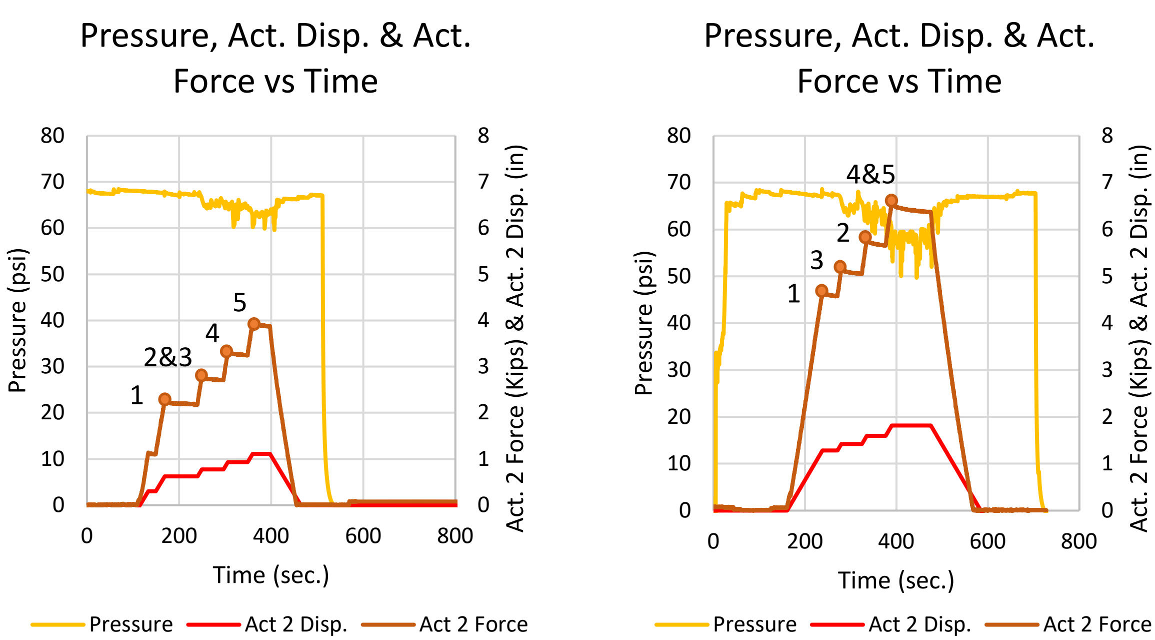
ID#	Location	Observation	Act. Disp. (in)	Act. Force (Kips)
1	West	First leak was observed (approx. rate of 1 drop/s).	1.2	4.2
2	East	Second leak was observed (approx. rate of 1 drop/s).	1.5	5.0
3	West	The first leak rate was increased to an observable steady stream.	1.6	5.4
4	East	The second leak rate was increased to an observable steady stream.	1.8	6.1
5	NA	Substantial leak observed on both ends of the valve and pressure decreased by ~5 psi.	2.0	7.3

2.2. Non-serrated Tests

Non-serrated flange face connections on DI pipes paired with a non-serrated gate valve were used for this test. During the test, the specimen was pressurized to around 65 psi (448 kPa) with minor fluctuations. For the first portion of the test, the bolts connecting the pipes to the valve were torqued to the minimum required spec of 150 ft-lb. The specimen was subjected to 10 kips of axial tension loading, then transverse displacement was then applied to the system at the two interior loading saddles. The applied force generated by the transverse loading was captured and recorded by the vertical actuator equipped with a 110-kip load cell. Figure 2.3 (a) presents the progression of pressure, applied transverse displacement, and actuator force through the duration of the initial portion of the test. The breaks in transverse displacement indicate points of interest throughout the test, outlined in Table 2.5.

The pipe was then unloaded and the torque on the bolts connecting the pipes to the flange was increased to the maximum allowed torque spec of 200 ft-lb. An axial load of 10 kips was reapplied and transverse displacement was applied again. Figure 2.3 (b) shows the progression of pressure, applied displacement, and actuator force through the duration of the second portion of the test. The breaks in transverse displacement indicate points of interest throughout the test, outlined in

Table 2.6.



(a) Bolts torqued to 150 ft-lb

(b) Bolts torqued to 200 ft-lb

Figure 2.3. Results for pressure, transverse disp., and actuator force vs. time for non-serrated test 1

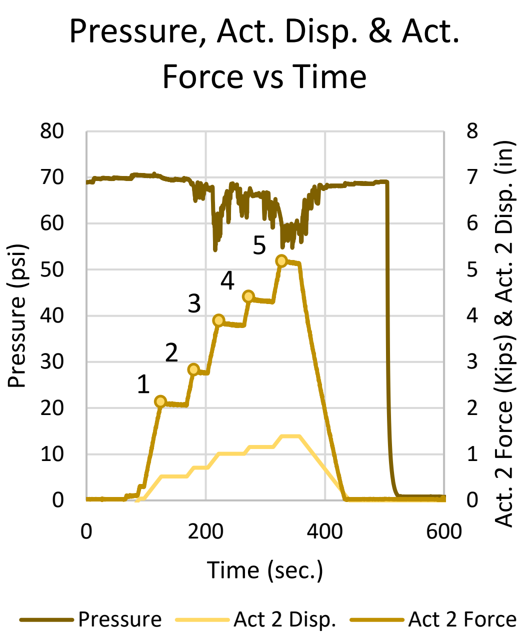
Table 2.5. Points of interest for non-serrated test 1 (torqued to 150 ft-lb)

ID#	Location	Observation	Act. Disp. (in)	Act. Force (Kips)
1	West	First leak was observed (approx. rate of 1 drop/s). Inconsistent drops were observed on the east side.	0.7	2.2
2/3	West	The first leak rate was increased to an observable steady steam. (Leak on the east end reached a rate of approx. 1 drop/s)	0.8	2.7
4	East	The second leak rate was increased to an observable steady stream.	1.0	3.3
5	NA	Substantial leak observed on both ends of the valve and pressure decreased by ~5-8 psi.	1.1	3.9

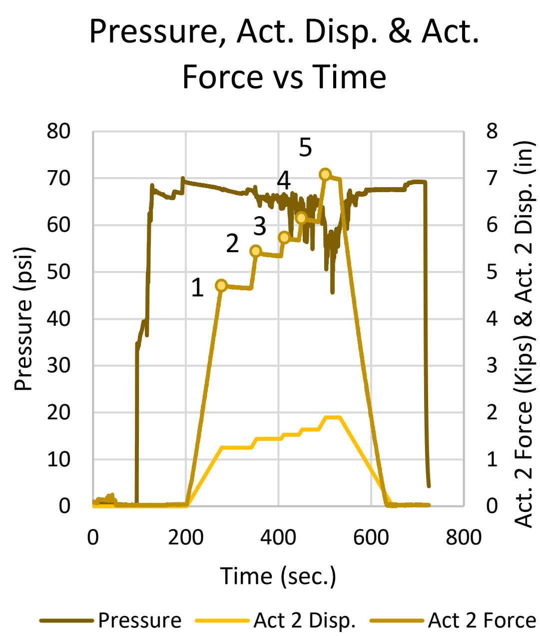
Table 2.6. Points of interest for non-serrated test 1 (torqued to 200 ft-lb)

ID#	Location	Observation	Act. Disp. (in)	Act. Force (Kips)
1	West	First leak was observed (approx. rate of 1 drop/s).	1.3	4.7
3	West	The first leak rate was increased to an observable steady stream. (Still no leak on east side)	1.4	5.1
2	East	Second leak was observed (approx. rate of 1 drop/s).	1.6	5.8
4/5	East	The second leak rate was increased to an observable steady stream. (The pressure had decreased by ~8-10 psi at this point.)	2.2	6.5

The second test was completed using the same non-serrated flange connection DI pipes used during the first test, and a new non-serrated gate valve. The same procedures and criteria were used for the duration of the second test. Figure 2.4 shows the relationship between pressure, applied transverse displacement, and actuator load relative to time for (a) the portion of the test performed at a torque spec of 150 ft-lb and (b) the portion of the test performed at a torque spec of 200 ft-lb., respectively. Table 2.7 outlines the points of interest noted during the first portion of the test, and Table 2.8 outlines the points of interest noted during the second portion of the test.



(a) Bolts torqued to 150 ft-lb



(b) Bolts torqued to 200 ft-lb

Figure 2.4. Results for pressure, transverse disp., and actuator force vs. time for non-serrated test 2

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Table 2.7. Points of interest for non-serrated test 2 (torqued to 150 ft-lb)

ID#	Location	Observation	Act. Disp. (in)	Act. Force (Kips)
1	East	First leak was observed (approx. rate of 1 drop/s).	0.5	2.1
3	East	The first leak rate was increased to an observable steady stream.	0.7	2.8
2	West	Second leak was observed (approx. rate of 1 drop/s). The rate of the first leak increased to a heavy stream.	1.0	3.8
4	West	The second leak rate was increased to an observable steady stream. The rate of the leak on the east was much heavier.	1.1	4.3
5	NA	Substantial leak observed on both ends of the valve and pressure decreased by ~5-8 psi.	1.3	5.2

Table 2.8. Points of interest for non-serrated test 2 (torqued to 200 ft-lb)

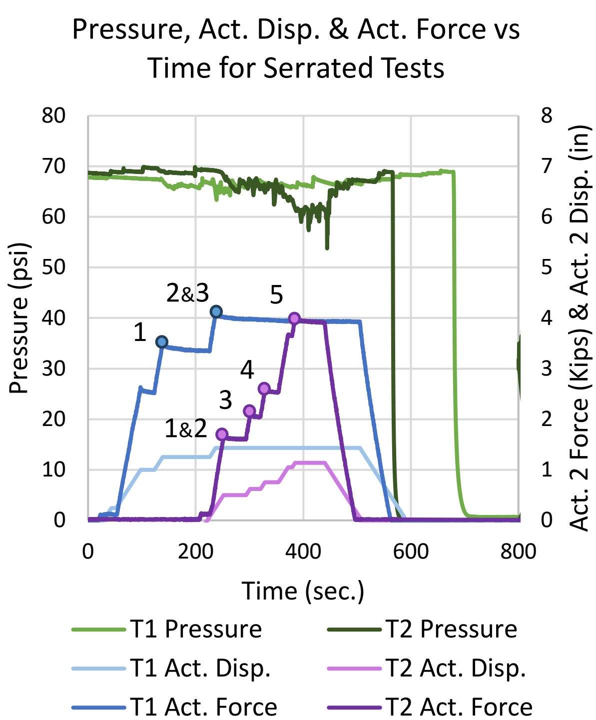
ID#	Location	Observation	Act. Disp. (in)	Act. Force (Kips)
1	East	First leak was observed (approx. rate of 1 drop/s).	1.3	4.8
2	West	Second leak was observed (approx. rate of 1 drop/s). The rate of leaking on the east was a choppy stream.	1.5	5.5
3	East	The first leak rate was increased to an observable steady stream. The rate of leaking on the west was a choppy stream.	1.6	5.8
4	West	The second leak rate was increased to an observable steady stream.	1.7	6.2
5	NA	Substantial leak observed on both ends of the valve and pressure decreased by ~5-10 psi.	1.9	7.1

3. Comparisons

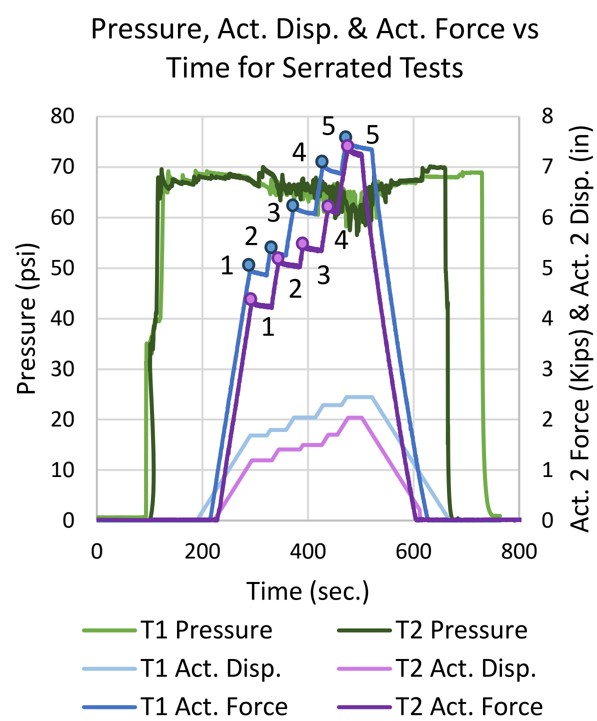
The following section will compare test results that were previously presented in Section 2 of this report.

3.1. Serrated Test Comparison

Figure 3.1 shows the results from the first and second test performed on serrated DI pipes joined with a serrated gate valve. Table 3.1 shows the results for actuator displacement and actuator force for each test when the gate valve was torqued to 150 ft-lb. During this initial portion of the test, the second test leaked at a lower actuator force and displacement compared to the first test. Test 1 was also paused and unloaded prior to achieving the last two points of interest outlined in previous sections. Table 3.2 shows the results for actuator displacement and actuator force for each test when the gate valve was torqued to 200 ft-lb. For the first leak observed during testing (1), the average actuator displacement and actuator force is 1.45 in and 4.55 kips, respectively. For the first steady stream leak observed (3), the average actuator displacement and actuator force is 1.8 in and 5.7 kips, respectively.



(a) Bolts torqued to 150 ft-lb



(b) Bolts torqued to 200 ft-lb

Figure 3.1. Comparison of pressure, transverse displacement, and actuator force vs time between serrated test 1 and serrated test 2

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Table 3.1. Comparison of serrated test 1 and serrated test 2 at points of interest (torqued to 150 ft-lb)

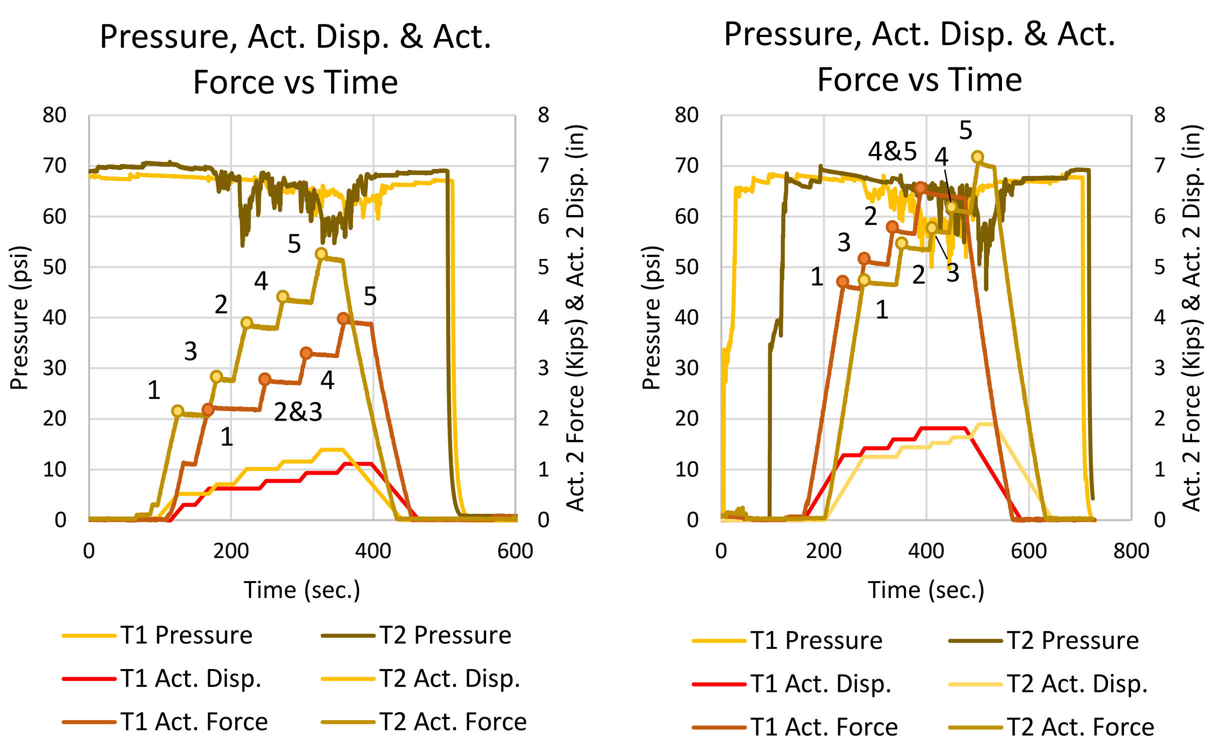
ID#	Points of Interest	T1 Act. Disp. (in)	T2 Act. Disp. (in)	T1 Act. Force (Kips)	T2 Act. Force (Kips)
1	First leak is observed at either end of the gate valve (approx. rate of 1 drop/s).	1.2	0.5	3.4	1.7
2	First leak is observed on the other end of the gate valve (approx. rate of 1 drop/s).	1.4	0.5	4.0	2.1
3	Leak rate on either end of the gate valve is increased to an observable steady steam.	1.4	0.6	4.0	2.1
4	Leak rate on the other end of the gate valve is increased to an observable steady stream.	NA	0.7	NA	2.6
5	A pressure drop of approx. 5psi is observed on the pressure readings.	NA	1.1	NA	4.0

Table 3.2. Comparison of serrated test 1 and serrated test 2 at points of interest (torqued to 200 ft-lb)

ID#	Points of Interest	T1 Act. Disp. (in)	T2 Act. Disp. (in)	T1 Act. Force (Kips)	T2 Act. Force (Kips)
1	First leak is observed at either end of the gate valve (approx. rate of 1 drop/s).	1.7	1.2	4.9	4.2
2	First leak is observed on the other end of the gate valve (approx. rate of 1 drop/s).	1.8	1.5	5.2	5.0
3	Leak rate on either end of the gate valve is increased to an observable steady steam.	2.0	1.6	6.0	5.4
4	Leak rate on the other end of the gate valve is increased to an observable steady stream.	2.2	1.8	6.9	6.1
5	A pressure drop of approx. 5psi is observed on the pressure readings.	2.4	2.0	7.4	7.3

3.2. Non-serrated Test Comparison

Figure 3.2 shows the results from the first and second test performed on non-serrated flange connection DI pipes joined with a non-serrated gate valve. Table 3.3 shows the results for actuator displacement and actuator force for each test when the gate valve was torqued to 150 ft-lb. During this initial portion of the test, each test first leaked at a very similar actuator force and displacement. However, as the second test progressed, a few of the points of interest occurred in a different order than the first test, as well as both of the serrated tests. Test 2 also achieved higher actuator loads and displacements for the later points of interest compared to the first test. Table 3.4 shows the results for actuator displacement and actuator force for each test when the gate valve was torqued to 200 ft-lb. For the first leak observed during testing (1), the average actuator displacement and actuator force is 1.3 in and 4.75 kips, respectively. For the first steady stream leak observed (3), the average actuator displacement and actuator force is 1.5 in and 5.45 kips, respectively.



(a) Bolts torqued to 150 ft-lb

(b) Bolts torqued to 200 ft-lb

Figure 3.2. Comparison of pressure, transverse displacement, and actuator force vs time between non-serrated test 1 and non-serrated test 2

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Table 3.3. Comparison of non-serrated test 1 and non-serrated test 2 at points of interest (torqued to 150 ft-lb)

ID#	Points of Interest	T1 Act. Disp. (in)	T2 Act. Disp. (in)	T1 Act. Force (Kips)	T2 Act. Force (Kips)
1	First leak is observed at either end of the gate valve (approx. rate of 1 drop/s).	0.7	0.5	2.2	2.1
2	First leak is observed on the other end of the gate valve (approx. rate of 1 drop/s).	0.8	1.0	2.7	3.8
3	Leak rate on either end of the gate valve is increased to an observable steady steam.	0.8	0.7	2.7	2.8
4	Leak rate on the other end of the gate valve is increased to an observable steady stream.	1.0	1.1	3.3	4.3
5	A pressure drop of approx. 5psi is observed on the pressure readings.	1.1	1.3	3.9	5.2

Table 3.4. Comparison of non-serrated test 1 and non-serrated test 2 at points of interest (torqued to 200 ft-lb)

ID#	Points of Interest	T1 Act. Disp. (in)	T2 Act. Disp. (in)	T1 Act. Force (Kips)	T2 Act. Force (Kips)
1	First leak is observed at either end of the gate valve (approx. rate of 1 drop/s).	1.3	1.3	4.7	4.8
2	First leak is observed on the other end of the gate valve (approx. rate of 1 drop/s).	1.6	1.5	5.8	5.5
3	Leak rate on either end of the gate valve is increased to an observable steady steam.	1.4	1.6	5.1	5.8
4	Leak rate on the other end of the gate valve is increased to an observable steady stream.	2.2	1.7	6.5	6.2
5	A pressure drop of approx. 5psi is observed on the pressure readings.	2.2	1.9	6.5	7.1

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3.3. Serrated vs Non-serrated Test Comparison

Figure 3.3 shows the pressure, transverse displacement, and actuator force for each test performed with the joining bolts tightened to the maximum torque of 200 ft-lb. The third point of interest, which was the first observed steady stream leak, is used for comparing the differences in displacement capacity and force capacity between the serrated and non-serrated tests. This point is used because it was one of the clearer stopping points during the tests and is considered the most likely point of "failure" when deciding which type of joint face leaks sooner. Table 3.5 shows the actuator displacements for both serrated tests and both non-serrated tests. The average displacement for the serrated and non-serrated test are 1.8 in. and 1.5 in., respectively. The non-serrated test shows a decrease in transverse displacement capacity of about 17%. Table 3.6 shows the actuator force for both serrated tests and both non-serrated tests. The average displacement for the serrated and non-serrated test are 5.7 kips and 5.45 kips, respectively. The non-serrated test shows a decrease in transverse force capacity of about 5%. Though the averages for the serrated tests are higher than the averages for the non-serrated tests, each individual test did not follow this trend. The second non-serrated test performed had the same actuator displacement and a high actuator force at this point of interest. Since the differences between the average actuator displacement and force are both relatively small, and each individual test performed does not follow this trend consistently, the CIEST team cannot confirm that serrated faces perform better than non-serrated faces when looking at their ability to hold internal water pressure.

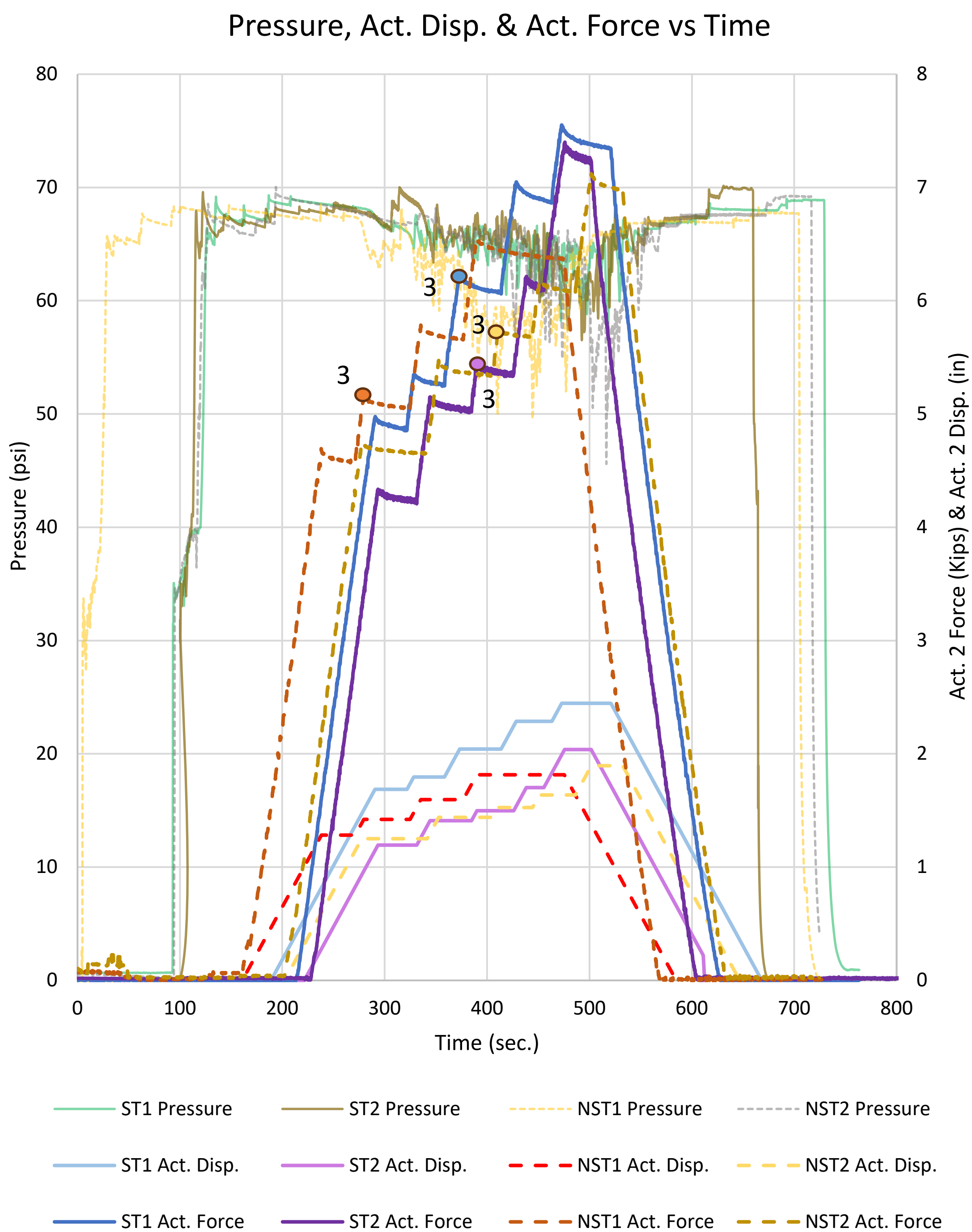

Figure 3.3 Comparison of pressure, transverse displacement, and actuator force vs time between each test at 200 ft-lb

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Table 3.5. Comparison between the actuator displacement of each test at interest point 3 (torqued to 200 ft-lb)

ID#	Points of Interest	ST1 Act. Disp. (in)	ST2 Act. Disp. (in)	NST1 Act. Disp. (in)	NST2 Act. Disp. (in)
3	Leak rate on either end of the gate valve is increased to an observable steady steam.	2.0	1.6	1.4	1.6

Table 3.6. Comparison of serrated test 1 and non-serrated test 2 at points of interest (torqued to 200 ft-lb)

ID#	Points of Interest	ST1 Act. Force (Kips)	ST2 Act. Force (Kips)	NST1 Act. Force (Kips)	NST2 Act. Force (Kips)
3	Leak rate on either end of the gate valve is increased to an observable steady steam.	6.0	5.4	5.1	5.8

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Acknowledgements

The authors wish to recognize the excellent effort of University of Colorado students and staff that made these experiments successful. Namely, the contributions of graduate students Jessica Ramos, and undergraduates Coen Hines, Benjamin Hewitt, and Alyssa McCarthy are gratefully acknowledged. Great thanks are extended to CIEST staff members Kent Polkinghorne, John Hindman, and Davis Holt for their constant support and expertise.

Appreciation is extended to Denver Water for technical and financial support for this study. The authors also thank the Mueller representatives for providing gate valves.

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