



NEW TEST METHOD FOR REINFORCED CONCRETE PIPE JOINT HYDROSTATIC INFILTRATION

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Abstract: The hydrostatic performance of reinforced concrete pipe (RCP) depends on the gasket design and its materials properties, the joint design and its quality, the joint dimensional tolerance during pipe manufacturing, and more importantly, the quality of the concrete pipe installation. Existing specifications pertinent to testing RCP joint performance are limited to evaluating the exfiltration of the joint. It ignores the fact that, for a non-pressure gravity sewer, the true requirement for hydrostatic performance is to resist groundwater infiltration. Existing testing standard is only available in the field which is costly and difficult to perform. The test is limited by the groundwater condition. The repair cost is high in the case of failure. There is need to develop a simple yet effective method for gaging the infiltration capacity of the RCP joint at the manufacturing facilities. In the present study, a new testing method is developed to address this need. The proposed method was applied to conventional RCP diameters ranging from 600 to 1200 mm. The test results show that the proposed method provides a scientific and unbiased evaluation of both the joint capacity hydrostatic infiltration and the working external pressure of the joint. Recommendations for future development of a related standard test method are provided.

Keywords: Reinforced; Concrete; Pipe; Hydrostatic; Test; Joint; Infiltration.

1 INTRODUCTION

1.1 Background

For over a century, concrete pipe has been the primary solution for storm water management networks and wastewater collection systems. In such gravity flow, concrete pipe design has essentially focussed on the rigid pipe structure, soil-pipe interaction and joint structural integrity. The true hydrostatic performance of the reinforced concrete pipe (RCP) joint was not emphasized. Even though there are several specifications that require the manufacturer to conduct hydrostatic pressure testing of the pipe, such tests do not ensure confidence in the joint performance after in-situ installation.

Common hydrostatic tests performed by pipe manufacturers generally use internal pressure to detect exfiltration. However, actual hydrostatic conditions experienced in service by the pipe include not only internal pressure, but also external pressure when a pressure head from groundwater above the pipe level is present (ACPA 2009). The resistance to groundwater infiltration is one of the design criteria of RCP (MTO 2007). Most joint leakage issues reported in construction sites or via closed-circuit television (CCTV) inspections are a result of groundwater infiltration. Deep RCP installation with high groundwater table

usually escalates the risk of leaky joints. Concerns of such infiltration have been reported as early as the 1970s (APWA 1971, Gottstein 1973). It was recognised that the problem of infiltration and inflow (I&I) would cause the sewer to have premature capacity issues and associated high water treatment costs. Such concerns continued to prevail in recent years (Pipeline 1999, Kesik, 2015, Hey et.al. 2016). Uncontrolled I&I in sanitary sewers causes detrimental financial and environmental effects to municipalities (FCM/NRC 2003). For instance, in a storm network, infiltration can carry fines from the embedment soil around the pipe into the sewer, causing settlement and misalignment problems (INDOT 2014, NYSDOT 2013).

The performance of the pipe joint is predominantly influenced by the joint quality, installation quality and external conditions. While, external conditions cannot be easily controlled, they need to be considered in design. The quality of the joint and installation can be evaluated, examined and inspected. Without an effective and simple qualifying test method for joint infiltration, designers resort to using more expensive pressure pipes in gravity flow applications to mitigate the I&I risks.

In recent decades, emerging alternative pipe materials such as PVC, high density polyethylene, polypropylene, fiber glass and other flexible pipe materials tend to promote better joint performance than that of concrete pipe, along with other advantages, such as chemical resistance, lightweight, longer lay length and ease of handling and installation. Hence, the concrete pipe industry is pursuing technological advancements to enhance the RCP sustainability, resilience and overall life-cycle value. Chief among the barriers that need to be overcome by modern RCP is mitigating challenges related to the hydrostatic joint performance.

1.2 Existing Standards

Twelve standard practices related to the joint hydrostatic performance were reviewed (Table 1). They can be categorized into three groups: joint quality, in-field quality, and pressure rating evaluations.

Internal hydrostatic tests are by far the most commonly used by RCP manufacturers to validate the joint quality. Single or multiple pipe sections can be pressurized internally to a certain pressure level and duration in either a horizontal or vertical orientation. However, these tests usually take place over a short period (typically 10 minutes or less) and conclude by visual inspection for exfiltration leakage. Standard practices such as CSA A257.2, ASTM C443, ASTM C1628 and BS EN 1916 require horizontal pipe sections to be tested not only in a straight alignment, but also in a deflected alignment. CSA A257.2 and BS EN 1916 require the joint performance under offset condition. While the intent of such tests is a proof of design, the results may not correlate to real field performance.

In-field tests allow the contractor to measure the amount of leakage using air or water after the installation of the pipeline. Some of these tests can have safety concerns, are difficult to perform, and time consuming. For an infiltration test such as the ASTM C1103, a certain level of groundwater is needed for the test. Such conditions may not be available at the time of the test. Other standard tests such as ASTM C969 and ASTM C1214 allow pressure reduction over a long section of pipe. If the total leakage exceeds the limit, it is hard to identify which joints are the source of the problem. In addition, these tests are usually difficult to execute during construction and only examine the pressure resistance over a short time period.

The last type of tests including AS/NZS 4058, AWWA C302 and ASTM C361 provides a pressure rating. Among these standards, AWWA C302 and ASTM C361 technically pertain to pressure pipe. The test method requires at least an additional 20% pressure beyond the required class to be met. These standards are more stringent and are commonly being specified in gravity sewer applications that only require an elevated joint performance. ASTM C361 requires the evaluation of the pressure rating under both aligned and offset positions. These tests only examine the internal pressure rating and do not reflect clear correlation to field performance.

1.3 Scope

The pipe joint performance expectation by municipalities is clearly a watertight joint. The pipeline needs to be designed to withstand hydrostatic pressure from the average groundwater level. Watertight joint is defined as a joint that provides zero leakage of water infiltration and exfiltration for a specific head or

pressure application (AASHTO 2009). Existing tests conducted by pipe manufacturers evaluate exfiltration and do not address infiltration. Thus, it is very costly to discover performance issues during or after construction and the repair cost is far more expensive than the initial material and construction costs (Romer 2004). Many situations cause legal litigation between the contractor and the manufacturer. It is apparent that there is a misconception of the end user's expectation. Existing standards related to RCP joint performance do not provide sufficient consideration to certain field conditions, such as deep installation with a high groundwater condition. Current tests validate the resistance to exfiltration and assume that the joint performance to resist infiltration is interchangeable. In fact, the joint and the gasket are not symmetrical in nature, thus this assumption seems to be scientifically incorrect. There is no standard test method to validate the joint performance and capacity for infiltration. Leaky pipe joint is usually caused by the installation quality. However, it is challenging to quantify and validate quality during installation. End users generally demand RCP joints that can withstand infiltration.

Because of these gaps, it is important to develop an industry standard test method to validate RCP joints' hydrostatic performance, capacity and behaviour against infiltration. In order to simulate the sustaining hydrostatic pressure from ground water acting on the pipe joint, the method to pressurize the exterior of the joint is developed. The scope of the present research is to:

1. Provide a standard testing method that can be easily and safely conducted by any pipe manufacturer.
2. Recommend a standard testing procedure that can effectively qualify the RCP joint under a certain pressure rating.
3. Explore the factors influencing the joint hydrostatic capacity.
4. Establish a bench mark so that further study on joint quality or joint conditions, such as deflected and offset alignments, can be conducted.

Table 1 Summary of Joint Performance Standards

Standard	Ori.*	#. of Pipe	#. of Jt.	Med.**	Dir.***	Pressure Limit (kPa)#	Test Duration	Acceptance Criteria	Leak Exam.
Joint Quality									
CSA A257	H	3	2	W	I	105 (A), 90 (D), 35 (O)	10 min	No leak	Visual
ASTM C433	X	2	1	W	I	90 (A), 70 (D)	10 min	No leak	Visual
ASTM C990	V	2	1	W	I	90 (A)	10 min	No leak	Visual
ASTM C1628	X	2	1	W	I	90 (A), 70 (D)	10 min	No leak	Visual
AS/NZS 4058	H	4	3	W	I	90 (A)	60 min	Limit leakage	Measure
	V / H	1	0	W	I	90, +20% of Opr.	90sec/10mm wall	Limit leakage	Measure Visual
BS EN 1916	H	2	1	W	I	50 (A), 50 (D), 50 (O)	15 min		Visual
GB/T 16752	V / H	1	0	W	I	60 CL1, 100 CL2,3	10 min	No leak	Visual
Pressure Rated									
AWWA C302	H	2 Min.	1+	W	I	Operating	48 hours	No leak	Visual
					I	120 % of	20 min	No leak	Visual

ASTM C361	X	2	1	W	I	operating 120% of spec 75- 300 375 (A), 375 (O)	Not specified	No leak	Visual
In-field Quality									
ASTM C1214	H	Var	V	A	E	Initiate at 23.7	0.3 - 6 min/100ft based on size	Limit Leakage	Gauge
ASTM C969	H	<700ft	V	W	I / E	Min. 6 (2ft head)		Limit Leakage	Gauge
ASTM C1103	H	2	1	A / W	E	24 > GWT	5 sec	Limit Leakage	Gauge

*Ori.: H – Horizontal, V – Vertical, X – Not specified, **Media: W – Water, A- Air, ***I – Internal pressure, E – External Pressure, #A – Aligned, D – Deflected, O - Offset

2 TEST METHOD DEVELOPMENT

2.1 Testing Concept

To simulate infiltration, a small annular space is created outside the primary gasket of the RCP joint. A secondary gasket is introduced to seal the annular space and permit testing pressure to build up. Because the joint design will vary depending on the type of RCP, the secondary gasket needs to be properly selected based on the available space and the joint design. The gasket supplier is consulted for the adequate style based on the target testing pressure, material properties, and available space. Small inlet and outlet holes are drilled in opposite sides of the RCP joint, between the gaskets, to allow the water to be introduced into the annular space. Figure 1 shows the annular space of a conventional RCP joint.

The design of the test also maintains a safe operating environment. The equipment was designed to handle a maximum pressure of 685 kPa. To ensure a safe operating environment, the small amount of water in the enclosed annular space does not pose a flooding hazard of the testing area when failure occurs. Pressure is created by using compressed air to push the water into the annular space. The pressurization system scheme is shown in Figure 2.

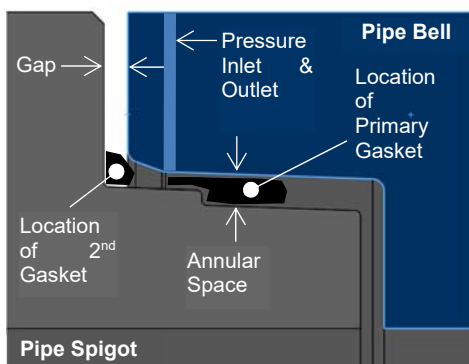


Figure 1 Typical RCP Joint

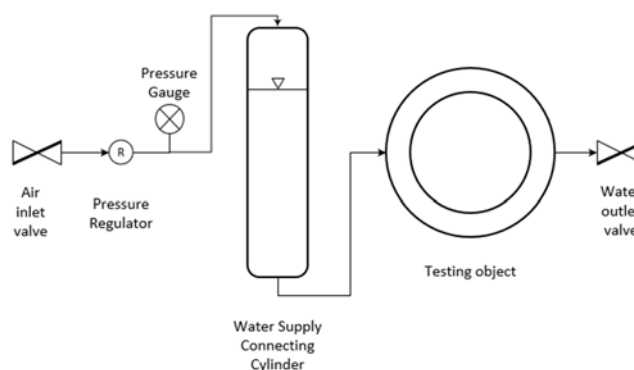


Figure 2 Pressurization System Scheme

2.2 Mechanical Apparatus and Setup

The mechanical apparatus includes an air inlet valve, pressure regulator, pressure gauge, water supply connecting cylinder (WSCC), connecting hosts, and water outlet valve. The air inlet valve is connected to a compressed air line where air pressure is introduced to the system. The pressure regulator allows the operator to control the target testing pressure. The pressure gauge displays the pressure level in the system with an accuracy of 2.5 kPa. WSCC made of a 4-inch diameter transparent fiber glass pressure cylindrical chamber contains sufficient water to supply the water demand in the annular space. The cylinder allows the operator to monitor water loss if a system leakage and/or joint leakage occur during the test. Water outlet valve allows the input of the water source during the setup process. The valve is kept closed during the test. Figure 3 and Figure 4 display the actual equipment and setup.

In the test setup, two pipe sections consisting of a bell end and spigot end are stacked vertically (Figure 4 and

Figure 5). The total height of the combined pipe sections is between 700 and 1000 mm for ease of assessment and monitoring during the test. The test joint was created by homing two pipe sections sealed with a primary gasket and a secondary gasket. The secondary gasket (

Figure 6) was placed between the shoulder of the pipe spigot and the bell end face to create a confined space for pressurization. Both homed pipe sections are tied down to the supporting steel base frame. Due to the internal pressure generated, the tremendous amount of uplift force is expected. The number of tie down straps and the strap rating are calculated based on the target testing pressure and the geometry of the annular space. The base frame is especially designed to carry the expected forces from the strap. Before the start of the test, the water shall be introduced from the outlet to the inlet and fill up the WSCC. This process is to ensure that the entire annular space is filled. It is suggested to pressurize the setup to a minimum of 50 kPa before the formal start of the test. The frame used in this research was designed for maximum pipe size with 1829 mm outer diameter tested to 685 kPa.



Figure 3 Testing apparatus



Figure 4 Base frame and test pipe setup



Figure 5 Inside view of test pipe



Figure 6 Testing and secondary gasket setup

2.3 Procedures

2.3.1 General

Considering that the groundwater pressure acting on the RCP pipeline is a sustained pressure, there is need to develop a process to evaluate both the ultimate and operation pressure. Using existing concepts from AWWA C302 and ASTM C361, the operating pressure is set not to exceed 80% of the ultimate pressure. None of the existing standards evaluates the ultimate capacity of the joint. The intent of the ultimate test is also to evaluate the capacity of the gasket and the joint design under the testing condition.

2.3.2 Ultimate Pressure

The first pressure stage is selected based on the expected ultimate pressure. Because there is no previous test results available for RCP joints, 100 kPa was selected based on the typical internal hydrostatic test from existing standards. The initial pressure is then incrementally increased by 25 kPa until failure. At each incremental attempt, the pressure is held for at least 10 minutes. Again, this duration is selected based on existing standard tests for exfiltration. Visual inspection for leakage, measurement of the water level in the WSCC and joint gap measurements are conducted in between each incremental attempt. Any leakage found is recorded. If the leak is found from the inside of the pipe joint, the pressure rating of the principle test gasket is determined to be the pressure value from the previous attempt. All other leakage, such as the outside joint, testing inlet and/or outlet or other locations will not be considered a failure. Adjustment of the strap shall be made to limit or eliminate the exterior leakage so the test can be continued. Time for each incremental attempt was recorded by the operator using a stop watch.

2.3.3 Operating Pressure

The operating pressure can only be conducted after the ultimate pressure is established. The operating pressure target shall be set to 80% of the ultimate pressure. Both the primary and secondary gaskets shall be replaced with new ones to avoid any possible damage incurred during the establishment of the ultimate pressure. To begin the test, the setup is recommended to be tested at a lower pressure level of 100 kPa followed by 70% of the ultimate pressure for 10 minutes. This is to ensure that the test setup is performing as expected. If no leakage is observed, pressure is increased to 80% of the ultimate. Visual inspection for leakage is completed and the target pressure is held for the next 20 hours with periodic visual inspection for leaks. Upon completion of the 20 hours, full inspection is carried out by the operator. Observation and measurement of the water level and joint gap shall be recorded. If no leakage is evident from the inside of the pipe, the test is successful, and the working pressure of the joint can be pressure rated at 80% of the ultimate pressure.

2.4 Measurements

The primary measurement in this test is the hydrostatic pressure inside the annular space. The analogue pressure gauge is used within the apparatus as the measurement device. Time can be measured using a digital stop watch of a smart phone. It is believed that the joint gap plays an important role in pressure capacity. Pipe joint movement is monitored using a predefined reference and measured by the operator manually using a caliper (Figure 8). The use of crack gauge and laser were attempted, but these methods did not provide the required precision.



Figure 7 Pressure Gauge and Time Measurement



Figure 8 Joint Gap Measurement During the Test

2.5 Sample Sections

Eight tests were performed using conventional RCP ranging having 600 mm, 900 mm and 1200 mm diameter. Single-offset pre-lubricated gaskets provided by two different suppliers were examined. In the routine quality hydrostatic performance test (CSA A257, 2014), the gasket is usually pressurized to 105 kPa, 90 kPa, and 35 kPa internally with straight, deflected and offset alignment, respectively for 10 minutes. The gaskets and pipes tested in this research are listed in Table 2.

Table 2 List of Gaskets Used in the Research

ID	Gasket Name / Model	Type	Supplier	Design Capacity	Remark
S01	7SOC	Wedge	1		Secondary
S03	158-4G	Wedge	2		Secondary
S04	210-4G	Wedge	2		Secondary
T02	TSS 135	Single Offset	1	105	Primary
T03	RFS 165	Single Offset	2	105	Primary
T04	RFS 185	Single Offset	2	105	Primary
T06	RFS 135	Single Offset	2	105	Primary
T07	TSS 185	Single Offset	1	105	Primary

3 RESULTS AND DISCUSSION

3.1 Joint Hydrostatic Capacity

Table 3 exhibits the summary of the infiltration tests conducted and their ultimate and operating pressure results. Total of eight tests were conducted using the equipment and procedure. Three tests were terminated before reaching the ultimate capacity of the testing setup. As part of testing the equipment, the maximum testing pressure was increased from 70% to 95% of the design capacity of the equipment. The other reason for test termination is the displacement of the secondary gasket. For the operating pressure test where the pressure was sustained at 80% of the ultimate pressure, four tests were completed for the minimum 20 hours of duration. Those tests failing to meet the 20-hour hold period were due to the failure of the primary or secondary gasket.

Table 3 Summary of Test Results

Pipe Size	Pri. Gskt.	2nd Gskt.	Infiltration						
			Gap	Straight Alignment (10 mins)			Straight Alignment (20 Hours)		
				mm	kPa	psi	Term. Reason	kPa	Dur.
600mm RCP	T02	S01	8.6	225	32.6	T02 displaced	180	20 hr	Completed
600mm RCP	T02	S01	10.0	250	36.3	T02 displaced	175	8 min	T02 displaced
600mm RCP	T06	S03	5.5	650	94.3	95% of equip. cap.	525	20 hr	Completed
900mm RCP	T02	S01	9.0	425	61.6	T02 displaced, blow-out	300	0 min	T02 displaced
900mm RCP	T06	S03	8.5	550	79.8	S03 displaced	440	7 min	S03 Displaced
1200mm RCP	T07	S01	11.0	350	50.8	T07 displaced	280	2 min	T07 displaced
1200mm RCP	T04	S04	7.3	500	72.5	73% of equip. cap.	414	20 hr	Completed
1200mm RCP	T03	S03	8.0	480	69.6	70% of equip. cap.	414	22 hr	Completed

1.1 Joint Gap Monitoring

Joint gap was monitored by physical measurement during tests. The average joint gap measured at the time of actual primary gasket failure ranged between 8.6 and 11.0 mm. With less than a maximum 8.0 mm joint gap, the primary gasket did not reach actual failure. The joint gap exhibited an increase of 1 and 2 mm with respect to pressure during the test. This observation is due to the flexible straps and the certain degree of compression of the gasket.

1.2 Leakage Monitoring

Leakage was monitored during the test by visual inspection at each pressure stage and by inspection of the water level displayed in the WSCC.

Figure 9 shows typical failure of the testing gasket when the ultimate pressure is determined. Infiltration leakage appears on the inner face of the pipe when the testing gasket is unable to withstand the pressure.

Figure 10 illustrates typical failure of the secondary gasket essentially due to its displacement. Failure starts when a water mark appears in between the gasket through the gap. Water seeps through the gap and drips down the outside surface of the concrete. When the water drips down slowly, the tie down straps are adjusted to recompress the secondary gasket. If an improvement is made, the water mark on the surface will evaporate. If the water continues to seep out, pressure is held and the reduction in water level in the cylinder is in a steady pace, the test continues.



Figure 9. 600mm RCP with T02 at 250 kPa



Figure 10. 900 mm RCP Test at 600 kPa

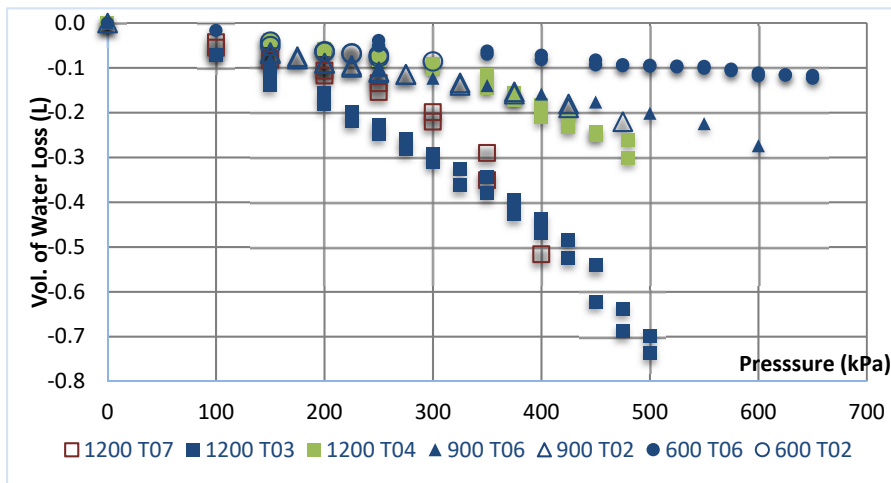


Figure 11 Volume of Water Reduction in the Water Supply Connecting Cylinder

The water level in the WSCC is also used in monitoring the leakage. The water level drops as the pressure increases. Figure 11 shows the volume of water loss calculated based on the water level change in the WSCC plotted against the pressure increase. The relationship is linearly correlated at different rates. The reduction of water volume is attributed to: (a) volume reduction of water under pressure, (b) absorption of concrete, (c) compression of rubber causing increase in annular space, (d) increase in joint gap causing increase in annular space, (e) displacement of the primary gasket, and (f) leakage. The differences in reduction rate reflected in the tests are likely related to displacement of the primary test gasket in its annular space. The single offset pre-lubricated gasket is designed to roll into the narrower gap from the step of the spigot during the homing process of the pipe. This leaves space behind the gasket from the inside of the pipe bell. The joint is more favorable to withstand the internal pressure but not favorable in resisting external pressure as the pressure pushes the gasket towards to the inside of the bell. With this observation, other

than leakage, the change in water level in the WSCC due to (a), (b) and (c) is trivial. The joint gap movement during tests seems to consist of very small movement and is believed to be due to the primary gasket displacement causing an increase in the volume of the annular space. It is also observed in the 900 mm RCP test with T02 gasket that the joint failed when the joint gap is greater than 9 mm and the gasket has left the annular space. The amount of displacement is likely related to the rubber mechanical properties and size, but this needs further investigation. Leakage observed in the tests may be slow and controlled at the beginning, or sudden at the time of imminent failure. This can be easily observed and measured. Figure 11 displays the water level in WSCC and the mark of the corresponding pressure.

4 CONCLUSIONS AND RECOMMENDATIONS

4.1 Existing Standards

Existing standards related to RCP joint performance prescribe minimum specification, yet none of these standard tests evaluates the ultimate hydrostatic capacity of the joint design. Although some standards required the test to be performed under straight, deflected and offset alignments, none of the existing standards evaluates the joint's hydrostatic capacity in relation to the joint gap. Tested pipes tested are pressurized internally, therefore such tests do not validate the infiltration capacity of the joint due to the joints non-symmetrical nature. The internal pressure tests mostly limit to 10 minutes which do not reflect the sustaining ground water pressure.

4.2 Testing Procedure

The present research proposes a new RCP infiltration test set up and explores the capacity of existing RCP joint designs. Tests with higher-pressure range were conducted and multiple test were repeated to validate the set-up. It was concluded that the testing procedure is valid and reliable. It is recommended that given a target design ultimate pressure, the test can begin at 10% to 20% lower than the design ultimate. This will significantly reduce the number of test pressure increments and save time.

4.3 Existing Joint Design

The existing RCP joint design and combination of gaskets can withstand higher external pressure than the design intent of 105 kPa internal pressure according to CSA A257. The absolute ultimate pressure of some of the pipe gasket combinations were not reached. However, this test procedure is conducted by controlling the joint gap and does not reflect the actual installation condition of the pipe. Further investigation that involve simulating various levels of joint gap, deflected joint, and offset joint are required to quantify more realistic joint hydrostatic infiltration capacity.

4.4 Monitoring of Leakage

Traditional hydrostatic performance tests rely on visual observation of the leakage. In the proposed test, a WSCC is used to quantify the water volumetric loss during the test. In several cases during this research, the leak was first detected by observing the pace of water reduction exceeding the recorded pace. This eliminates guess work and helps the operator to focus on the weakest point of the setup.

4.5 Joint Gap

Joint gap impacts hydrostatic performance. In conventional hydrostatic testing, CSA A257, ASTM C433, ASTM C1628, BS EN 1916 require the joint to remain watertight with a 13 mm deflection on one side in the deflected alignment test. There is no maximum acceptable joint gap defined anywhere in the specifications. Accordingly, most engineers expect similar performance under 13 mm joint gap in the field. ACPA (2014) states that the manufacturer shall define the maximum allowable joint gap. However, there is no research in the open literature that relates actual hydrostatic performance to joint gap. It is believed that the joint capacity to withstand pressure reduces as the joint gap increases. Further investigation is needed to explore whether this reduction occurs gradually or rapidly.

4.6 Future Works

The proposed test method of RCP infiltration can be the foundation for a standard test procedure for the infiltration of RCP joints. Such a standard test method does not currently exist. This test procedure sets a benchmark for this standard test development. With the encouraging results observed for existing joint and gasket designs, this testing method can allow further development in understanding the relationship between joint hydrostatic performance and joint gap. Finally, the results can be developed into the installation guidance using a quantifiable measurement - joint gap. This can help the contractor to mitigate the infiltration risk and make sound decisions based on the actual field condition. The discovery of the time-dependent gasket movement in the annular space can lead to improvements in the existing single offset joint.

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