Triple Wall and Double Wall Polypropylene Pipe-Joint Infiltration Tests

ADVANCED DRAINAGE SYSTEM
(Triple and Dual Wall Pipes)

Final Report

by

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CONTENTS

Page No.

LIST OF FIGURES **Page No.**

LIST OF TABLES **Page No.**

Triple and Double Wall Polypropylene Water Pipe-Joint Infiltration Tests

Abstract

While numbers of small to large older cities are undertaking repairs and maintenance, several other newer cities are planning on installing wastewater systems. Infiltration due to leaking pipes, manholes, laterals and other components of a wastewater system will add to the problem of overflow and substantially load the treatment facilities. Frequent overflows not only lead to regulatory problems but also increase treatment cost. Leaking systems will result in the erosion of soils through the leaking joints leading to the settlement of the ground surface, formation of sinkholes and damage to surrounding pavements and structures. Literature review indicated that Standard ASTM pipe-joint tests varied with the type and size of pipes.

In order to quantify the infiltration at various types of pipe-joints, a unified testing program was developed to test 30-in. diameter sewer pipe–joint up to a hydrostatic pressure of 7 psi. A testing protocol was developed and approved by a steering committee with representation from the EPA, pipe associations, cities and consulting engineers. The testing protocol outlined the procedures to determine the leakage rates at pipe –joints under shear loading and angular deflection. A testing facility was designed and constructed in the CIGMAT Laboratory at the University of Houston, Houston, Texas to perform the pipe joint tests in duplicate.

In this study, two types of polypropylene (PP) pipes (triple wall and double wall) were tested. Total of four pipe joints were tested. Based on the test results, there was no leakage at the 30-in. PP pipe-joints when the joints were tested with and without shear

loading and angular deflection. During the straight test (unloaded joint) the joint was subjected to hydrostatic pressure incrementally to a maximum hydrostatic pressure of 7 psi with a total testing time of 30 minutes and there was no leak. During the shear test, the joint was subjected to incremental shear loading. The maximum shear forces that were applied to the joints varied from 2268 lbs to 2899 lbs. The total shear testing time was 2.5 hours and the joint was subjected to a maximum hydrostatic pressure of 7 psi at every increment of shear load and there was no leak at the four joints tested. During the angular test, the joint was subjected to angular in steps of 0.5^o to a maximum rotation of 2^o at the joint. The total testing time was 2 hours for each pipe joint and the joint was subjected to a maximum hydrostatic pressure of 7 psi and the maximum shear load at the joint varied from 292 to 533 lbs. during the angular test. There was no leak at the joints.

2. INTRODUCTION

Polypropylene $(C_3H_6)_n$ is part of the polyolefins family. It is a versatile thermoplastic material used in many commercial applications (Hoppe, 2011). It is produced by polymerizing propylene in the presence of a catalyst. The starting material, propylene, is called the monomer, and the final compound is called the polymer. A long, linear polymer chain of carbon atoms is formed, with methyl $(C_2H_5)_n$ groups attached to every other carbon atom of the chain (Hoppe, 2011).

After decades of operation, the structural state of many urban drainage systems is in a state of disrepair. To maintain their functional efficiency, sewer systems are rehabilitated. Sewer rehabilitation is often based on visual inspections (e.g. from CCTV) and estimates of groundwater infiltration or rainwater infiltration and inflow (I/I) (Lee et al., 2009;

Wirahadikusumah et al., 1998), which are considered problematic. Groundwater enters combined and sanitary and storm sewer systems through defects located in saturated soil. In contrast, rainwater inflow and infiltration mostly concerns sanitary and storm sewers. Rain-induced infiltration also gets into the storm sewers through defects, false plumbing connections or openings in manhole covers (Staufer et al. 2012). Infiltration due to leaking pipes, manholes, laterals and other components of a wastewater and storm water systems will add to the problem of overflow and substantially load the treatment facilities. Frequent overflows not only lead to regulatory problems but also increase the treatment cost (Water Environmental Federation, 1999). Leaking systems will result in the erosion of soils through the leaking joints leading to the settlement of the ground surface, formation of sinkholes and damage to surrounding pavements and structures. Erosion of soil materials around the pipes and manholes can lead to formation of void and settlement of pipes accelerating the damage. Eroding soils entering the wastewater system through the leaking joints can cause problems within the wastewater system. The test methods cover pipe sizes from 3 to 144 inches. Both air and water have been recommended for use in infiltration/exfiltration tests. Of the test methods reviewed, most tests were exfiltration (85%) and only less number of tests (23%) was infiltration tests. Test methods for plastic, fiberglass, concrete and clay pipes have also recommended misalignment (angular) and shear force tests at the joints. The testing pressure varied from 3.5 to 40 psi. Acceptable leak rates varied based on type of pipe and application.

Literature review indicated that each type of pipe is tested differently in determining the infiltration rate at the pipe joint. Hence it was necessary to develop a unified testing method to better quantify the infiltration at various pipe joints under more

realistic joint-loading conditions. Since several factors in the field can affect the performance of pipe joint, it is important to identify the important factors through controlled experiments where important variables are studied one at a time. Based on the review of the literature and ASTM testing standards, a testing protocol for determining the infiltration at the pipe-joint must be developed.

Based on the preliminary testing at the University of Houston, a comprehensive testing protocol was developed and submitted to the steering committee for review and approval. The steering committee members were representing the USEPA, cities, consulting engineers, general contractors, professional associations and pipe industries. Once the testing plan was reviewed and approved by the steering committee, pipe-joints were tested under this test plan.

3. OBJECTIVES

The overall objective was to determine, through controlled laboratory tests, the infiltration leak-rates for two types of 30-in. diameter sewer pipe-joints under various loading conditions. The specific objectives were as follows:

1. Use the CIGMAT testing protocol developed for an EPA study to determine the infiltration at the pipe-joint under the following conditions:

    a. Straight joint (Method A)

    b. Angular deflection (Method B)

    c. Shear load (Method C)

2. Perform tests according to the testing protocol on pipe joints assembled by the pipe company representative. Quantify the shear loading at the pipe joints during various testing conditions.

3. Analyze the test results.

4. TESTING PROGRAM

Two instrumented test stands were available at the CIGMAT laboratory, University of Houston (http://cigmat.cive.uh.edu). Each test stand was capable of accommodating two three-foot lengths of 30-inch or greater diameter pipe joined together for testing. Provisions were made to constrain the pipe from moving laterally. The loading points were instrumented with 15,000 pound load cells to measure the applied and reaction loads (Figs. 1 and 2). Test stand provisions will also allow the pipe-joint to be tested under deflection and shear load in accordance with the test protocol. The pipe-joint was first tested under no load followed by the shear test and angular test.

Since water leakage can occur under several joint conditions, three model tests were proposed to closely represent the field situations. In all the cases, after loading, infiltration was tested with a hydrostatic pressure up to 7 psi. Tests were performed in duplicates resulting in six model tests for each pipe joint.

5. RESULTS AND DISCUSSIONS

In this study total of four pipe joints were tested. Tests No.1 & No.2 were conducted on the triple wall pipes (ASTM F 2764 – 11a) with specified stiffness of 46 lb/in/in. Tests Nos. 3&4 were conducted on double wall pipes (ASTM F 2881 - 11) with

specified stiffness of 46 lb/in/in. The joints were tested under aligned (straight and shear load tests) and misaligned positions (angular test) (Fig. 1 (a), (b) and (c)). The bladders were built to fit the pipe joints using a combination of rubber and plastic sheets (Fig.2). The joints were pressurized under each mode of loading starting at 3 psi hydrostatic pressure. The four joint tests were performed during summer 2012.

5.1 Test No. 1. (PP – Triple Wall Pipe)

METHOD A: Straight Pipe Joint Test (Fig. 1 (a))

Actual test setup is shown in Fig. 2(a). The test results are summarized in Table 1. No water leak was observed at the joint during the total test period of 30 minutes with maximum hydrostatic pressure of 7 psi for 10 minutes.

METHOD B: Angular Deflection Test (Fig. 1 (b))

In the angular deflection test, the angles 0.50, 1.00, 1.50 and 2.00 degrees at the joint were tested. The testing time under each angle was 30 minutes with a maximum hydrostatic pressure of 7 psi for 10 minutes. The results of the test are summarized in Table 1. The relationship between angle of rotation and shear load at the joint is shown in Fig. 3. Shear force varied from 55 to 533 lbs at the joint. No water leak was observed at the joint during the total test period of 2 hrs.

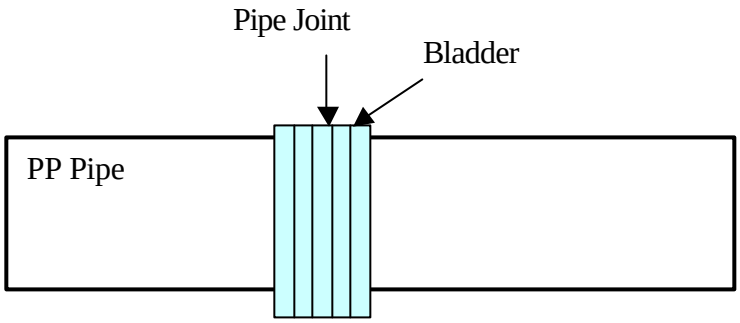
METHOD C: Shear Load Test (Fig. 1 (c))

The joint was tested under shear loading according to Method C. The load was applied at load cell No. 1 on the pipe and was increased in steps of 500, 1000, 2000, 2500 and 3500 lbs. The test results are summarized in Table 2 and the total testing time was 2.5

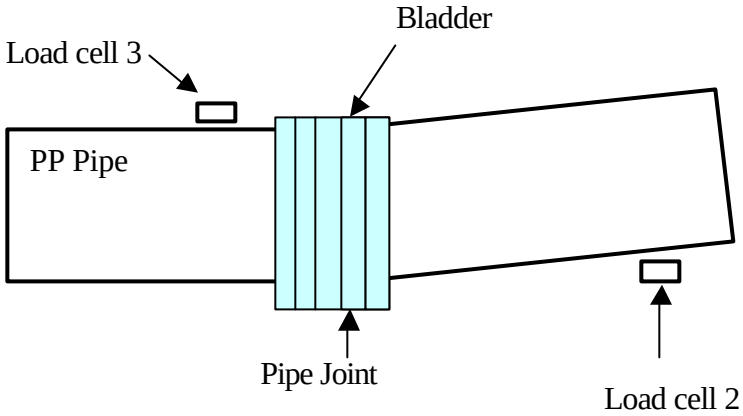
hours. The Shear load at the joint vs. applied load and the deflection of the pipe at the loading point vs. applied load are shown in Fig. 4 and Fig. 5 respectively. The maximum shear load at the joint was 2790 lbs. and there was no water leak. The maximum deflection of the pipe occurred at the point of loading (Cross-section 1-1 (Fig. 1c)) of the pipe were -1.95% (Extension) and 2.97% (Compression) (based on the pipe diameter) in the horizontal and vertical directions respectively.

Summary

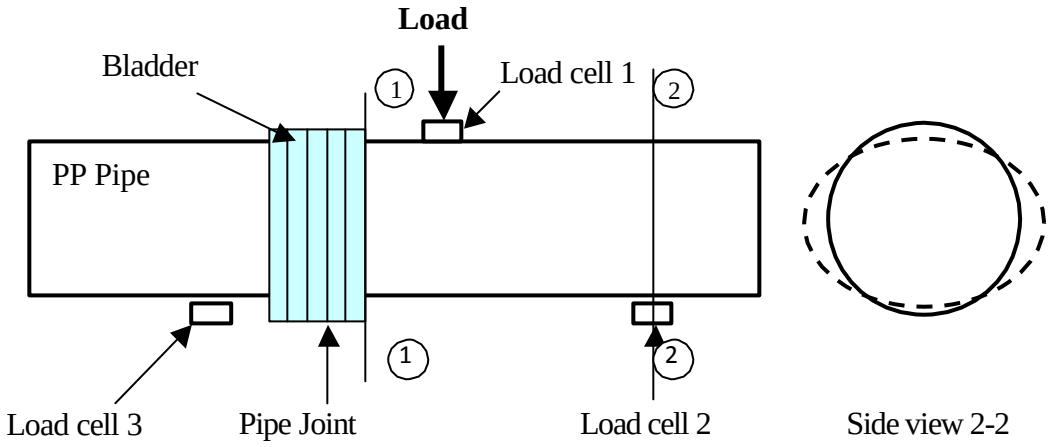
The composite bladder performed as designed. Total testing time for Method A, B, and C were 0.5 hour, 2 hours and 2.5 hours respectively. No leakage was observed at the tested joint for all the testing conditions. In the shear load test, the maximum shear load at the joint was 2790 lbs. and there was no water leak. The maximum deflection of the pipe occurred at the loading point at maximum shear load (based on the pipe diameter). The vertical and horizontal deflections at the loading point (Cross-section 1-1 (Fig. 1c)) of the pipe were -1.95% (Extension) and 2.97% (Compression) (based on pipe diameter) respectively.



(a) Method A: Straight Pipe Joint Test



(b) Method B: Angular Deflection Test



(c) Methods C: Shear load Test

Figure 1. PP Pipe-Joint Test Configurations

(a) Method A: Straight Alignment Test

(b) Method B: Angular Deflection Test

Figure 2. Views of the Triple Wall PP Pipe Joint Tests and Loading Frame

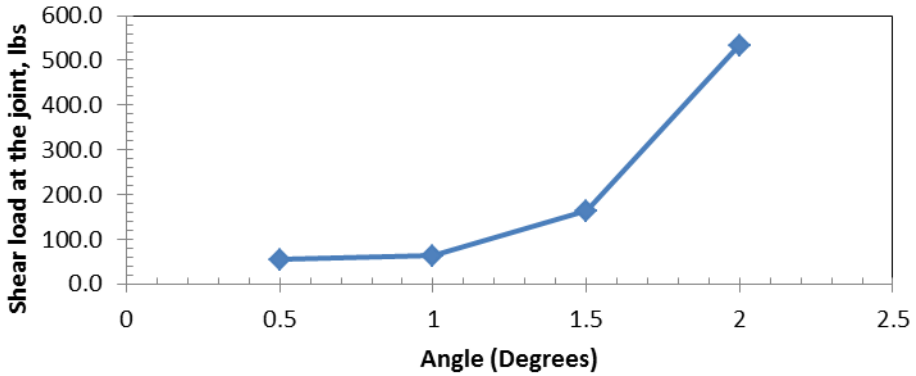


Figure 3. The Relationship between Angle and Shear Load in Test No. 1

Table 1 Results from Straight and Angular Deflection Test (Test No. 1)

Method	Angle (^{o})	Pressure (psi)	Time (min)	Leakage	Remarks
A	0	3	5	No	Total testing time was 30 minutes. No leakage.
		4	5	No	
		5	5	No	
		6	5	No	
		7	10	No	
B	0.5	3	5	No	Total testing time was 30 minutes. No leakage.
		4	5	No	
		5	5	No	
		6	5	No	
		7	10	No	
	1.0	3	5	No	Total testing time was 30 minutes. No leakage.
		4	5	No	
		5	5	No	
		6	5	No	
		7	10	No	
	1.5	3	5	No	Total testing time was 30 minutes. No leakage.
		4	5	No	
		5	5	No	
		6	5	No	
		7	10	No	
	2.0	3	5	No	Total testing time was 30 minutes. No leakage.
		4	5	No	
		5	5	No	
		6	5	No	
		7	10	No	
Remark	Up to 2^{o}	3 to 7 psi	Total 2.5 hrs	No Leak	No water leak, Bladder performed as designed

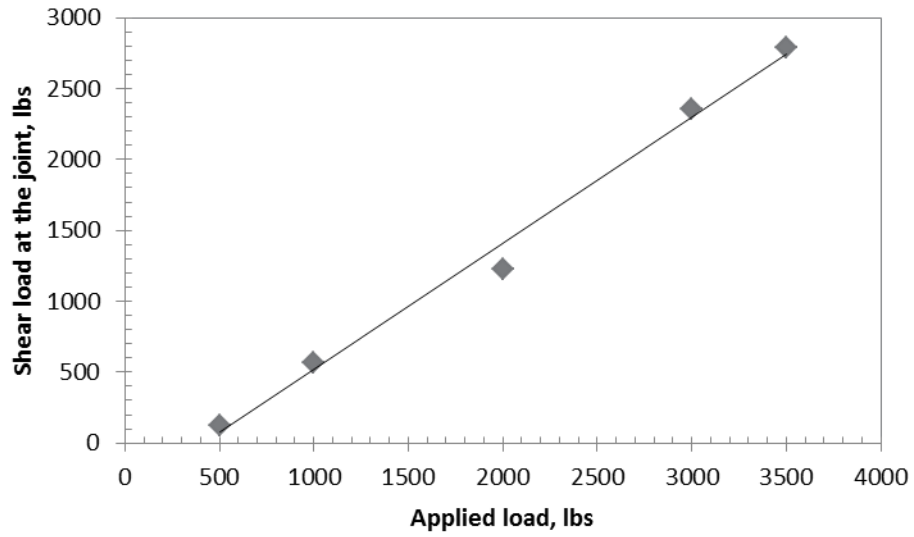


Figure 4. Applied Load vs. Shear Load in Test No. 1

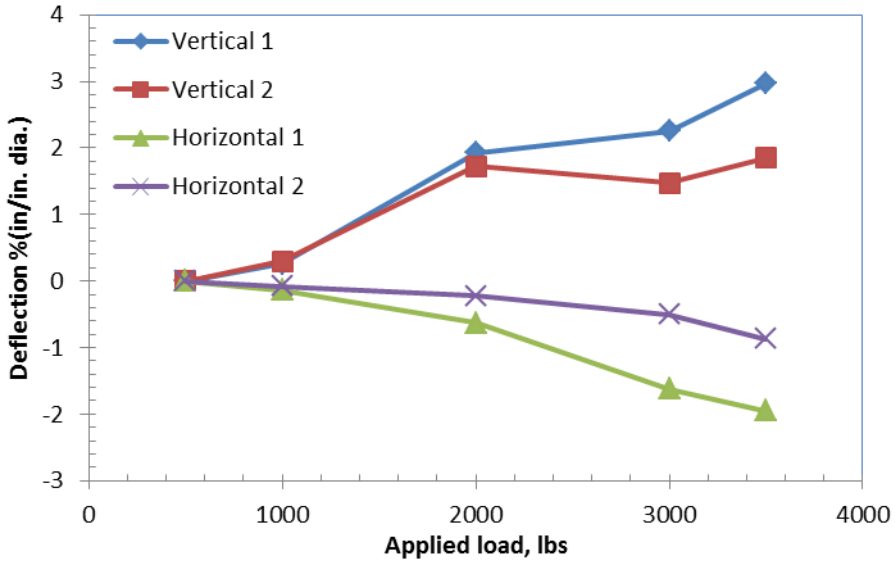


Figure 5. Applied Load vs. Deflection at the Loading Point during Test No. 1

Table 2. Results from Shear Load Test (Test No. 1)

Intended Load (lb)	Pressure (psi)	Time (min)	Leakage	Actual Load Applied (lb)	Shear Load(lb)	Remarks
500	3	5	No	497	126	Total test time was 30 minutes. No leak was observed.
	4	5	No			
	5	5	No			
	6	5	No			
	7	10	No			
1000	3	5	No	994	564	Total test time was 30 minutes. No leak was observed.
	4	5	No			
	5	5	No			
	6	5	No			
	7	10	No			
2000	3	5	No	1815	1227	Total test time was 30 minutes. No leak was observed.
	4	5	No			
	5	5	No			
	6	5	No			
	7	10	No			
3000	3	5	No	2998	2352	Total test time was 30 minutes. No leak was observed.
	4	5	No			
	5	5	No			
	6	5	No			
	7	10	No			
3500	3	5	No	3495	2790	Total test time was 30 minutes. No leak was observed.
	4	5	No			
	5	5	No			
	6	5	No			
	7	10	No			
Remarks	Up to 7 psi	Total 2.5 hrs.	No leak	Maximum load 3495 lb.	Maximum shear 2790 lb	No water leak

5.2 Test No. 2. (PP – Triple Wall Pipe)

METHOD A: Straight Pipe Joint Test (Fig. 1 (a))

Actual test setup is shown in Fig. 2(a). The test results are summarized in Table 3. No water leak was observed at the joint during the total test period of 30 minutes with maximum hydrostatic pressure of 7 psi for 10 minutes.

METHOD B: Angular Deflection Test (Fig. 1 (b))

In the angular deflection test, the angles 0.50, 1.00, 1.50 and 2.00 degrees at the joint were tested. The testing time under each angle was 30 minutes with a maximum hydrostatic pressure of 7 psi for 10 minutes. The results of the test are summarized in Table 3. The relationship between angle of rotation and shear load at the joint is shown in Fig. 6. Shear force varied from 162 to 292 lbs at the joint. No water leak was observed at the joint during the total test period of 2 hrs.

METHOD C: Shear Load Test (Fig. 1 (c))

The joint was tested under shear loading according to Method C. The load was applied at load cell No. 1 on the pipe and was increased in steps of 500, 1000, 2000, 2500 and 3500 lbs. The test results are summarized in Table 4 and the total testing time was 2.5 hours. The Shear load at the joint vs. applied load and the deflection of the pipe at the loading point vs. applied load are shown in Fig. 7 and Fig. 8 respectively. The maximum shear load at the joint was 2870 lbs. and there was no water leak. The maximum deflection of the pipe occurred at the point of loading (Cross-section 1-1 (Fig. 1c)) of the pipe were

-1.92% (Extension) and 2.25% (Compression) (based on the pipe diameter) in the horizontal and vertical directions respectively.

Summary

The composite bladder performed as designed. Total testing time for Method A, B, and C were 0.5 hour, 2 hours and 2.5 hours respectively. No leakage was observed at the tested joint for all the testing conditions. In the shear load test, the maximum shear load at the joint was 2870 lbs. and there was no water leak. The maximum deflection of the pipe occurred at the loading point at maximum shear load (based on the pipe diameter). The vertical and horizontal deflections at the loading point (Cross-section 1-1 (Fig. 1c)) of the pipe were -1.92% (Extension) and 2.25% (Compression) (based on pipe diameter) respectively.

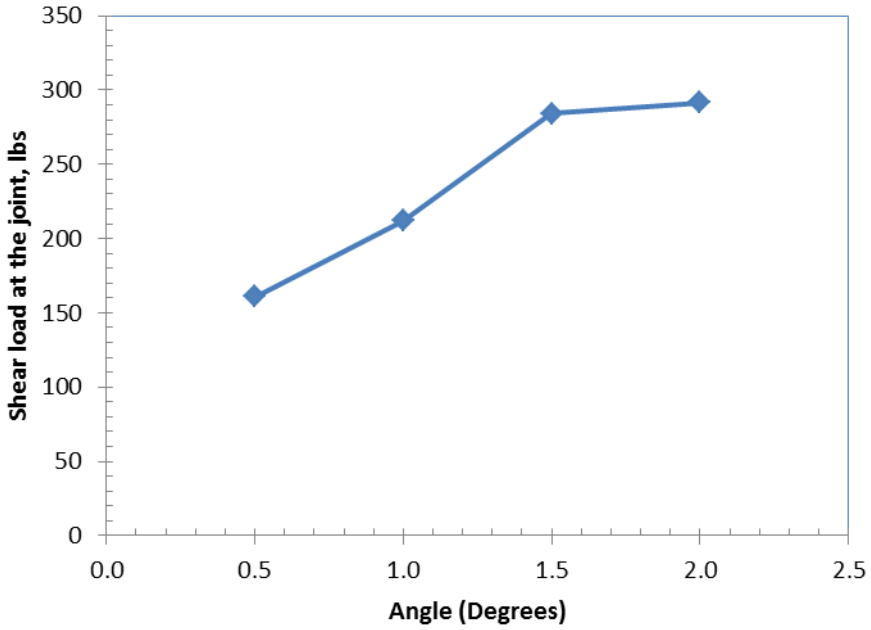


Figure 6.The Relationship between Angle and shear Load in Test 2

Table 3. Results from Straight and Angular Deflection Tests (Test No. 2)

Method	Angle (^{o})	Pressure (psi)	Time (min)	Leakage	Remarks
A	0	3	5	No	Total testing time was 30 minutes. No leakage.
		4	5	No	
		5	5	No	
		6	5	No	
		7	10	No	
B	0.5	3	5	No	Total testing time was 30 minutes. No leakage.
		4	5	No	
		5	5	No	
		6	5	No	
		7	10	No	
	1.0	3	5	No	Total testing time was 30 minutes. No leakage.
		4	5	No	
		5	5	No	
		6	5	No	
		7	10	No	
	1.5	3	5	No	Total testing time was 30 minutes. No leakage.
		4	5	No	
		5	5	No	
		6	5	No	
		7	10	No	
	2.0	3	5	No	Total testing time was 30 minutes. No leakage.
		4	5	No	
		5	5	No	
		6	5	No	
		7	10	No	
Remark	Up to 2^{0}	3 to 7 psi	Total 2.5 hrs	No Leak	No water leak, Bladder performed as designed

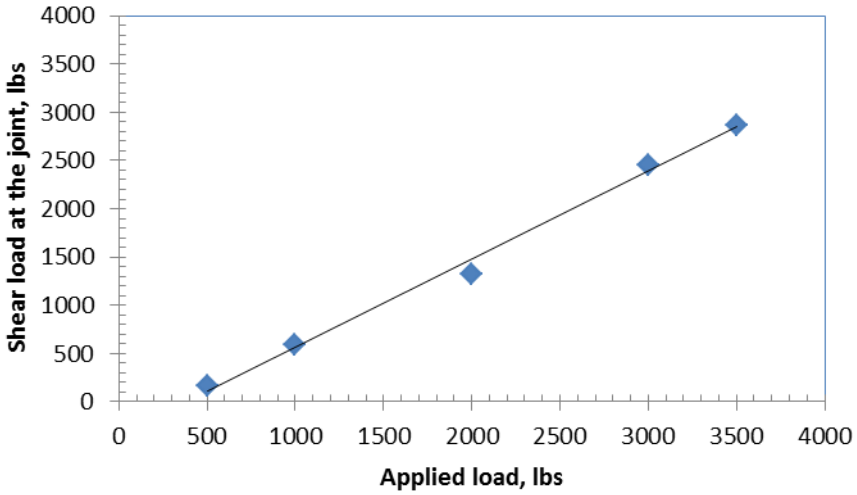


Figure 7. Applied Load vs. Shear Load in Test No. 2

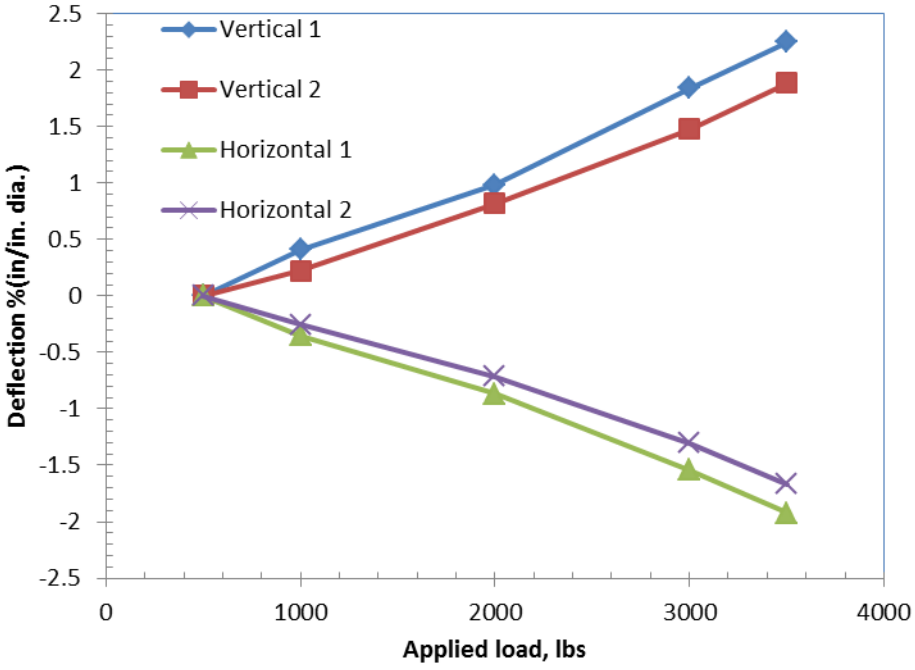


Figure 8. Applied Load vs. Deflection at the Loading Point during Test No. 2

Table 4. Results from Shear Load Test (Test No.2)

Intended Load (lb)	Pressure (psi)	Time (min)	Leakage	Actual Load Applied (lb)	Shear Load(lb)	Remarks
500	3	5	No	497	162	Total test time was 30 minutes. No leak was observed.
	4	5	No			
	5	5	No			
	6	5	No			
	7	10	No			
1000	3	5	No	994	593	Total test time was 30 minutes. No leak was observed.
	4	5	No			
	5	5	No			
	6	5	No			
	7	10	No			
2000	3	5	No	1815	1328	Total test time was 30 minutes. No leak was observed.
	4	5	No			
	5	5	No			
	6	5	No			
	7	10	No			
3000	3	5	No	2998	2453	Total test time was 30 minutes. No leak was observed.
	4	5	No			
	5	5	No			
	6	5	No			
	7	10	No			
3500	3	5	No	3495	2870	Total test time was 30 minutes. No leak was observed.
	4	5	No			
	5	5	No			
	6	5	No			
	7	10	No			
Remarks	Up to 7 psi	Total 2.5 hrs.	No leak	Maximum load 3495 lb.	Maximum shear 2870 lb	No water leak

5.3 Test No. 3. (PP – Double Wall Pipe)

METHOD A: Straight Pipe Joint Test (Fig. 1 (a))

Actual test setup is shown in Fig. 2(a). The test results are summarized in Table 5. No water leak was observed at the joint during the total test period of 30 minutes with maximum hydrostatic pressure of 7 psi for 10 minutes.

METHOD B: Angular Deflection Test (Fig. 1 (b))

In the angular deflection test, the angles 0.50, 1.00, 1.50 and 2.00 degrees at the joint were tested. The testing time under each angle was 30 minutes with a maximum hydrostatic pressure of 7 psi for 10 minutes. The results of the test are summarized in Table 5. The relationship between angle of rotation and shear load at the joint is shown in Fig. 9. Shear force varied from 226 to 350 lbs at the joint. No water leak was observed at the joint during the total test period of 2 hrs.

METHOD C: Shear Load Test (Fig. 1 (c))

The joint was tested under shear loading according to Method C. The load was applied at load cell No. 1 on the pipe and was increased in steps of 500, 1000, 2000, 2500 and 3500 lbs. The test results are summarized in Table 6 and the total testing time was 2.5 hours. The Shear load at the joint vs. applied load and the deflection of the pipe at the loading point vs. applied load are shown in Fig. 10 and Fig. 11 respectively. The maximum shear load at the joint was 2899 lbs. and there was no water leak. The maximum deflection of the pipe occurred at the point of loading (Cross-section 1-1 (Fig. 1c)) of the pipe were

-2.22% (Extension) and 2.96% (Compression) (based on the pipe diameter) in the horizontal and vertical directions respectively.

Summary

The composite bladder performed as designed. Total testing time for Method A, B, and C were 0.5 hour, 2 hours and 2.5 hours respectively. No leakage was observed at the tested joint for all the testing conditions. In the shear load test, the maximum shear load at the joint was 2899 lbs. and there was no water leak. The maximum deflection of the pipe occurred at the loading point at maximum shear load (based on the pipe diameter). The vertical and horizontal deflections at the loading point (Cross-section 1-1 (Fig. 1c)) of the pipe were -2.22% (Extension) and 2.96% (Compression) (based on pipe diameter) respectively.

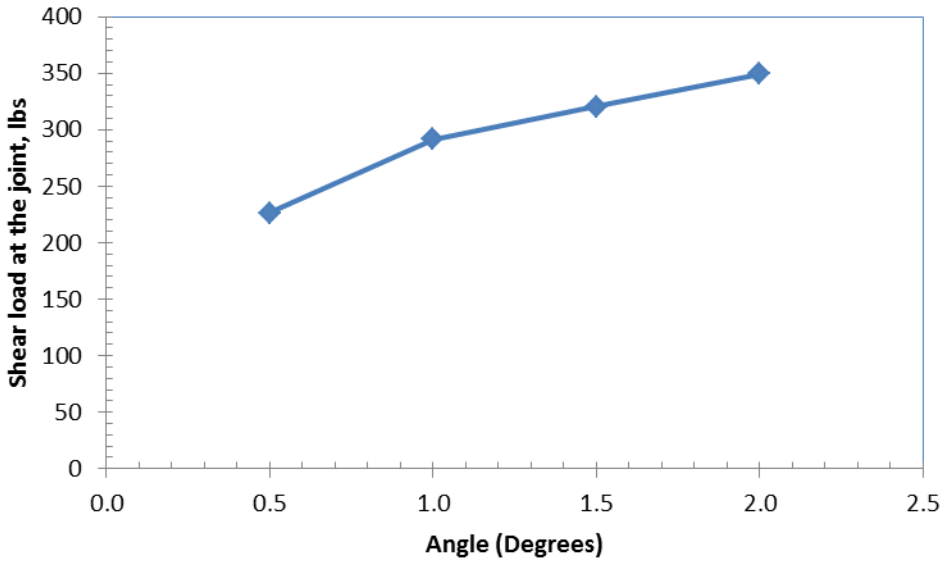


Figure 9.The Relationship between Angle and shear Load in Test 3

Table 5. Results from Straight and Angular Deflection Tests (Test No. 3)

Method	Angle (^{o})	Pressure (psi)	Time (min)	Leakage	Remarks
A	0	3	5	No	Total testing time was 30 minutes. No leakage.
		4	5	No	
		5	5	No	
		6	5	No	
		7	10	No	
B	0.5	3	5	No	Total testing time was 30 minutes. No leakage.
		4	5	No	
		5	5	No	
		6	5	No	
		7	10	No	
	1.0	3	5	No	Total testing time was 30 minutes. No leakage.
		4	5	No	
		5	5	No	
		6	5	No	
		7	10	No	
	1.5	3	5	No	Total testing time was 30 minutes. No leakage.
		4	5	No	
		5	5	No	
		6	5	No	
		7	10	No	
	2.0	3	5	No	Total testing time was 30 minutes. No leakage.
		4	5	No	
		5	5	No	
		6	5	No	
		7	10	No	
Remark	Up to 2^{o}	3 to 7 psi	Total 2.5 hrs	No Leak	No water leak, Bladder performed as designed

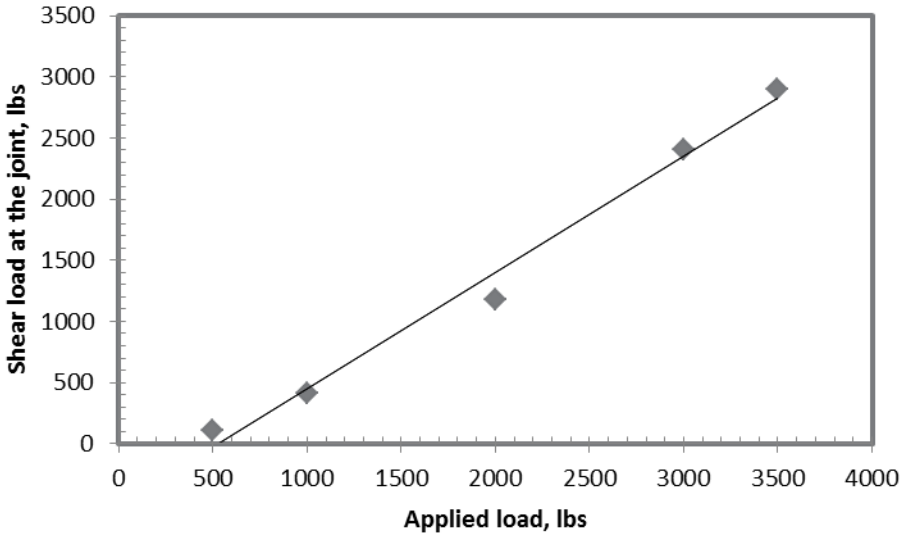


Figure 10. Applied Load vs. Shear Load in Test 3

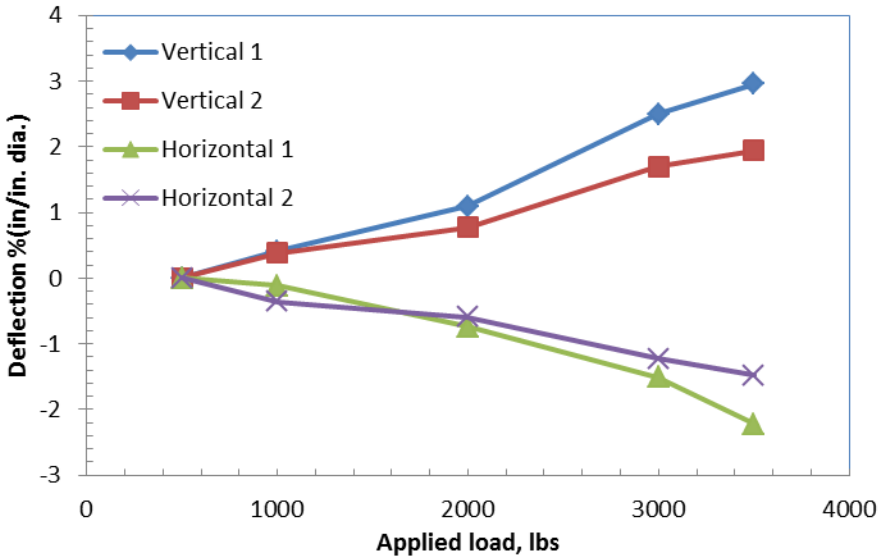


Figure 11. Applied Load vs. Deflection at the Loading Point during Test No. 3

Table 6. Results from Shear Load Test (Test No.3)

Intended Load (lb)	Pressure (psi)	Time (min)	Leakage	Actual Load Applied (lb)	Shear Load(lb)	Remarks
500	3	5	No	497	104	Total test time was 30 minutes. No leak was observed.
	4	5	No			
	5	5	No			
	6	5	No			
	7	10	No			
1000	3	5	No	994	412	Total test time was 30 minutes. No leak was observed.
	4	5	No			
	5	5	No			
	6	5	No			
	7	10	No			
2000	3	5	No	1815	1176	Total test time was 30 minutes. No leak was observed.
	4	5	No			
	5	5	No			
	6	5	No			
	7	10	No			
3000	3	5	No	2998	2410	Total test time was 30 minutes. No leak was observed.
	4	5	No			
	5	5	No			
	6	5	No			
	7	10	No			
3500	3	5	No	3495	2899	Total test time was 30 minutes. No leak was observed.
	4	5	No			
	5	5	No			
	6	5	No			
	7	10	No			
Remarks	Up to 7 psi	Total 2.5 hrs.	No leak	Maximum load 3495 lb.	Maximum shear 2899 lb	No water leak

5.4 Test No. 4. (PP – Double Wall Pipe)

METHOD A: Straight Pipe Joint Test (Fig. 1 (a))

Actual test setup is shown in Fig. 2(a). The test results are summarized in Table 7. No water leak was observed at the joint during the total test period of 30 minutes with maximum hydrostatic pressure of 7 psi for 10 minutes.

METHOD B: Angular Deflection Test (Fig. 1 (b))

In the angular deflection test, the angles 0.50, 1.00, 1.50 and 2.00 degrees at the joint were tested. The testing time under each angle was 30 minutes with a maximum hydrostatic pressure of 7 psi for 10 minutes. The results of the test are summarized in Table 7. The relationship between angle of rotation and shear load at the joint is shown in Fig. 12. Shear force varied from 197 to 350 lbs at the joint. No water leak was observed at the joint during the total test period of 2 hrs.

METHOD C: Shear Load Test (Fig. 1 (c))

The joint was tested under shear loading according to Method C. The load was applied at load cell No. 1 on the pipe and was increased in steps of 500, 1000, 2000, 2500 and 3500 lbs. The test results are summarized in Table 8 and the total testing time was 2.5 hours. The Shear load at the joint vs. applied load and the deflection of the pipe at the loading point vs. applied load are shown in Fig. 13 and Fig. 14 respectively. The maximum shear load at the joint was 2268 lbs. and there was no water leak. The maximum deflection of the pipe occurred at the point of loading (Cross-section 1-1 (Fig. 1c)) of the pipe were

-2.16% (Extension) and 2.61% (Compression) (based on the pipe diameter) in the horizontal and vertical directions respectively.

Summary

The composite bladder performed as designed. Total testing time for Method A, B, and C were 0.5 hour, 2 hours and 2.5 hours respectively. No leakage was observed at the tested joint for all the testing conditions. In the shear load test, the maximum shear load at the joint was 2268 lbs. and there was no water leak. The maximum deflection of the pipe occurred at the loading point at maximum shear load (based on the pipe diameter). The vertical and horizontal deflections at the loading point (Cross-section 1-1 (Fig. 1c)) of the pipe were -2.16% (Extension) and 2.61% (Compression) (based on pipe diameter) respectively.

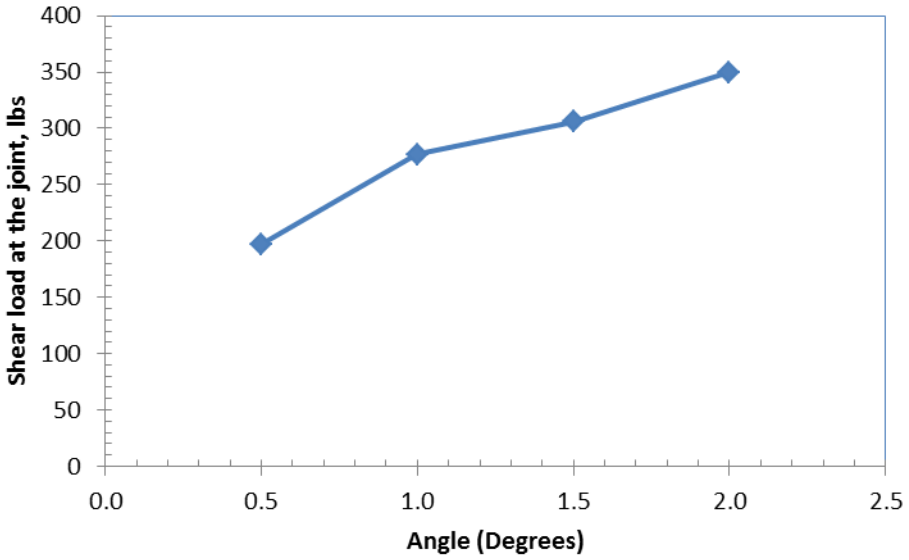


Figure 12. The Relationship between Angle and shear Load in Test 4

Table 7. Results from Straight and Angular Deflection Tests (Test No. 4)

Method	Angle (^{o})	Pressure (psi)	Time (min)	Leakage	Remarks
A	0	3	5	No	Total testing time was 30 minutes. No leakage.
		4	5	No	
		5	5	No	
		6	5	No	
		7	10	No	
B	0.5	3	5	No	Total testing time was 30 minutes. No leakage.
		4	5	No	
		5	5	No	
		6	5	No	
		7	10	No	
	1.0	3	5	No	Total testing time was 30 minutes. No leakage.
		4	5	No	
		5	5	No	
		6	5	No	
		7	10	No	
	1.5	3	5	No	Total testing time was 30 minutes. No leakage.
		4	5	No	
		5	5	No	
		6	5	No	
		7	10	No	
	2.0	3	5	No	Total testing time was 30 minutes. No leakage.
		4	5	No	
		5	5	No	
		6	5	No	
		7	10	No	
Remark	Up to 2^{o}	3 to 7 psi	Total 2.5 hrs	No Leak	No water leak, Bladder performed as designed

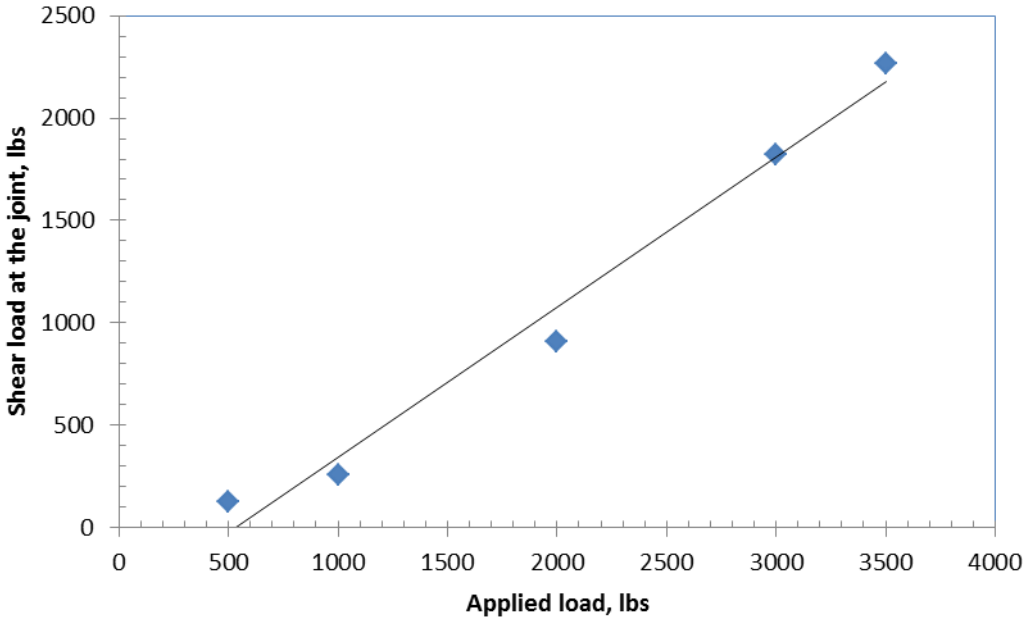


Figure 13. Applied Load vs. Shear Load in Test 4

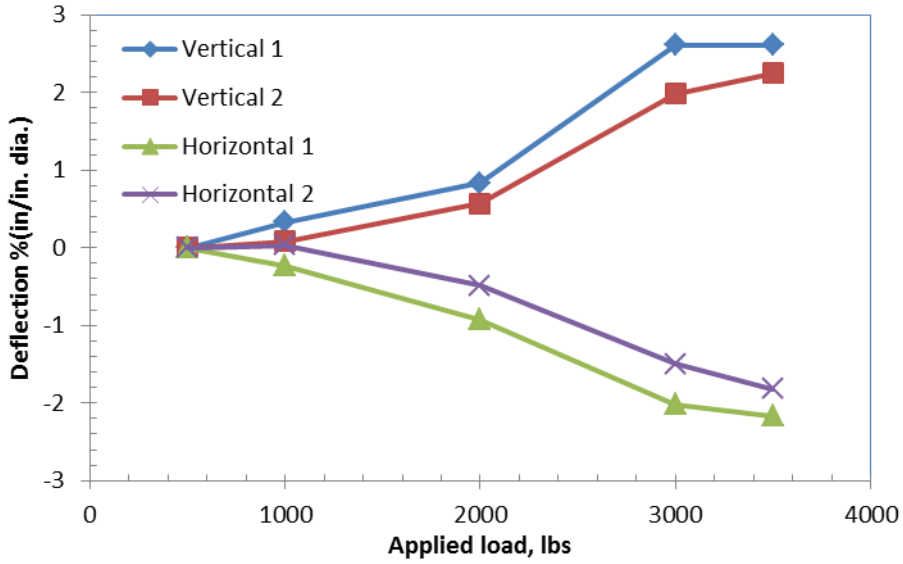


Figure 14. Applied Load vs. Deflection at the Loading Point during Test No. 4

Table 8. Results from Shear Load Test (Test No.4)

Intended Load (lb)	Pressure (psi)	Time (min)	Leakage	Actual Load Applied (lb)	Shear Load (lb)	Remarks
500	3	5	No	497	128	Total test time was 30 minutes. No leak was observed.
	4	5	No			
	5	5	No			
	6	5	No			
	7	10	No			
1000	3	5	No	994	260	Total test time was 30 minutes. No leak was observed.
	4	5	No			
	5	5	No			
	6	5	No			
	7	10	No			
2000	3	5	No	1815	908	Total test time was 30 minutes. No leak was observed.
	4	5	No			
	5	5	No			
	6	5	No			
	7	10	No			
3000	3	5	No	2998	1822	Total test time was 30 minutes. No leak was observed.
	4	5	No			
	5	5	No			
	6	5	No			
	7	10	No			
3500	3	5	No	3495	2268	Total test time was 30 minutes. No leak was observed.
	4	5	No			
	5	5	No			
	6	5	No			
	7	10	No			
Remarks	Up to 7 psi	Total 2.5 hrs.	No leak	Maximum load 3495 lb.	Maximum shear 2268 lb	No water leak

6. CONCLUSIONS

The testing of the 30-in diameter PP pipe-joints (Triple Wall and Double Wall) was performed at the CIGMAT Laboratory, University of Houston, Houston, Texas. Based on the four joints tested, following conclusions are advanced.

1. Straight Test: There was no leakage at the 30-in. PP Pipe-joints (Triple Wall and Double Wall). Each of the joint was tested without any external load for a total testing time of 30 minutes.

2. Shear Test: The Triple Wall joint was subjected to a maximum shear force of 2870 lb. (equivalent to 96 lb/in diameter) and there was no leakage. The Double Wall joint was subjected to a maximum shear force of 2899 lb. (equivalent to 97 lb/in diameter). The total testing time was 2.5 hours for each test.

3. Angular Test: During the angular test, the joint was subjected to a maximum rotation of 2^{o} at the joint. The total testing time was 2 hours and the shear load at the joint of the triple wall pipe varied from 292 to 533 lbs. during the angular test. On double wall pipe, the loading was 350 lbs for both joint tests. There was no leakage in all the tests.

7. REFERENCES

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