Concrete Sewer Pipe-Joint Infiltration Leak-Rate Testing

1. 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 the 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 pipe.

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. Pipe joints were tested in duplicate.

Based on the test results, there was no leakage at the 30-in. concrete pipe-joint when the joint was 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 leakage. During the shear test, the joint was subjected to shear force incrementally to a maximum shear force of 4580 lb. The total testing time for each joint was 7 hours and the joint was subjected to a maximum hydrostatic pressure of 7 psi at every increment of shear load and there was no leakage. During the angular test, the joint was subjected to angular rotation in steps to a maximum rotation of 2^{o} at the joint. The total testing time was 2 hours

and the joint was subjected to a maximum hydrostatic pressure of 7 psi and the shear load at the joint varied from 400 to 1,900 lbs. during the angular test. There was no leakage.

2. **INTRODUCTION**

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 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. Several ASTM standards were reviewed and are summarized in Table A1 in Appendix A [ASTM, 2000]. 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, 85% were exfiltration and 28% were 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 (Table A1).

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 (Appendix B) 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 different types of 30-in. diameter sewer pipe-joints under various loading conditions. The specific objectives were as follows:

1. Develop a testing protocol 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. Develop a testing facility to perform the tests under external hydrostatic pressure.

3. Perform tests according to the testing protocol on pipe joints assembled by the pipe companies/representative.

4. TESTING PROGRAM

Two instrumented test stands were designed and constructed at the University of Houston. Each test stand was capable of accommodating two three-foot lengths of 30-inches or greater diameter pipe joined together for testing. Provisions were made to constrain the pipe from moving laterally. The loading points were instrumented with 20,000 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. The data sheet on the joint characteristics (from pipe manufacturer/ supplier) is in Appendix C.

5. RESULTS AND DISCUSSIONS

Two concrete pipe joints were tested (ASTM Specification: ASTM C 443 - joint, ASTM C 76 – pipe) and the properties of the joint and pipe are in Appendix C. 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 tests on concrete pipe-joints were performed during the time period of April 9, 2002 to May 2, 2002.

5.1 Test No. 1 (Concrete Pipe Joint No.1)

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

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

(b) 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. No water leak was observed at the joint during the total test period of 2 hrs. The maximum separation at the invert of the joint was about 1.7" at the end of the test. This didn't lead to any leak during the period of the test. The relationship between the angle of rotation at the joint angle and the shear load at the joint is shown in Fig. 3. With the increase in the angle rotation, the shear load decreased from 600 to 1,600 lbs at the joint.

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

The joint was tested under shear loading according to Method C (Appendix B). The load cell locations are shown in Fig. 1(c). The load was applied through Load Cell No. 1 on the pipe and was increased in steps of 1000, 2000, 3000, 4000, 5000, 6000, 7000, 8000 and 9000 lbs. The testing time under each load was 30 minutes with maximum hydrostatic pressure of 7 psi for 10 minutes. The test results are summarized in Table 2. The Shear load at the pipe joint vs. Applied load at Load Cell No. 1 is shown in Fig. 4. No water leak was observed at the joint at the maximum shear load of 4280 lbs and during the total test period of 4.5 hrs.

Test No. 1 Summary

The composite bladder performed as designed. Total testing time for Methods A, B, and C were 0.5 hour, 2 hours and 4.5 hours respectively. No water leak was observed at the tested joint for all the testing conditions. The maximum applied shear load at the joint was 4280 lb (over 140 lb/in diameter) and there was no water leak.

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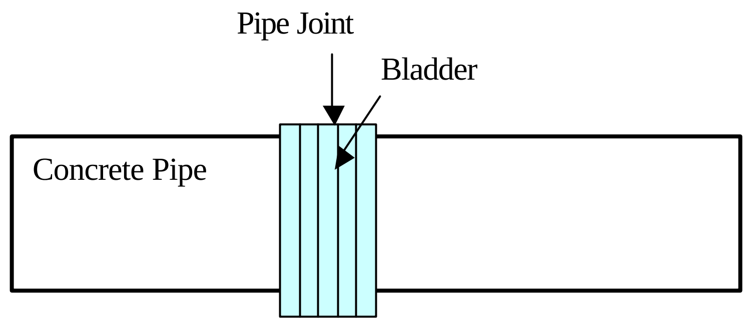
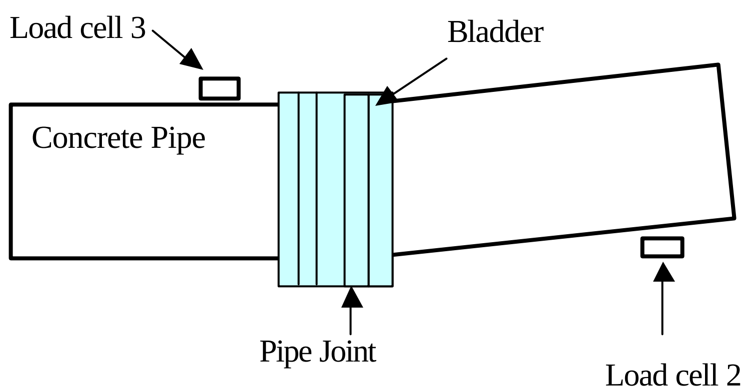
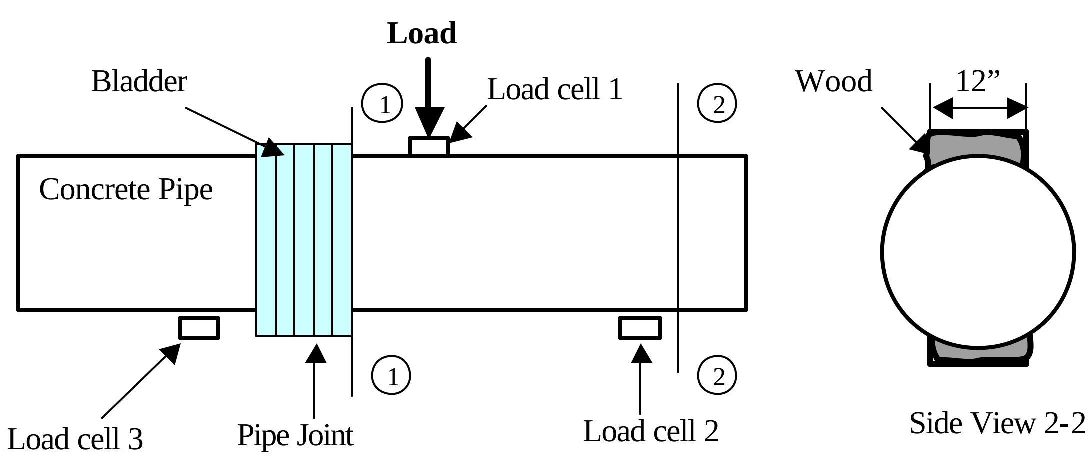


(a) Method A: Straight Pipe Joint Test

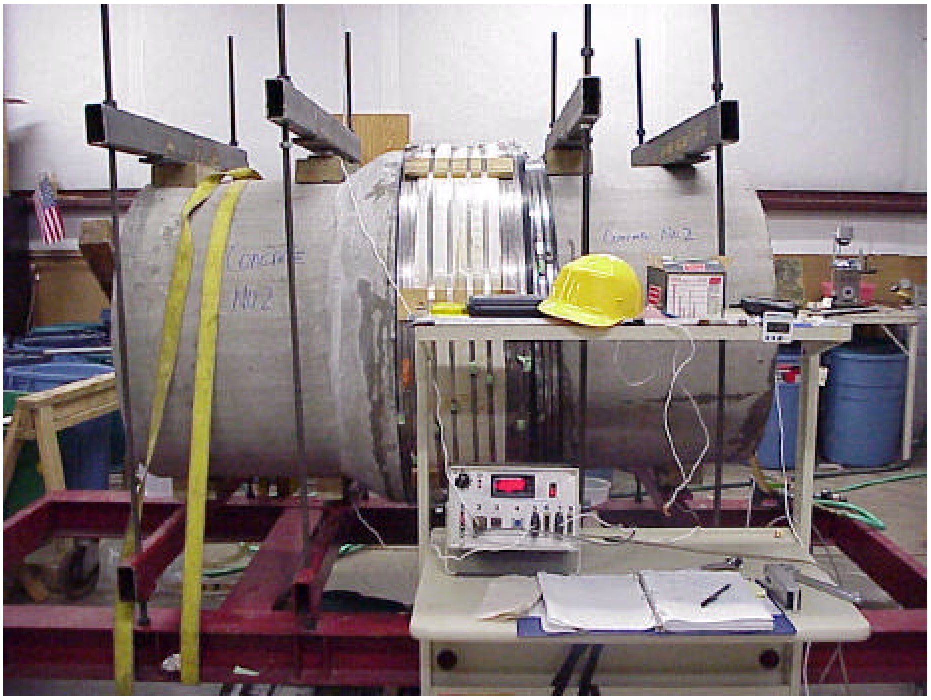


(b) Method B: Angular Deflection Test

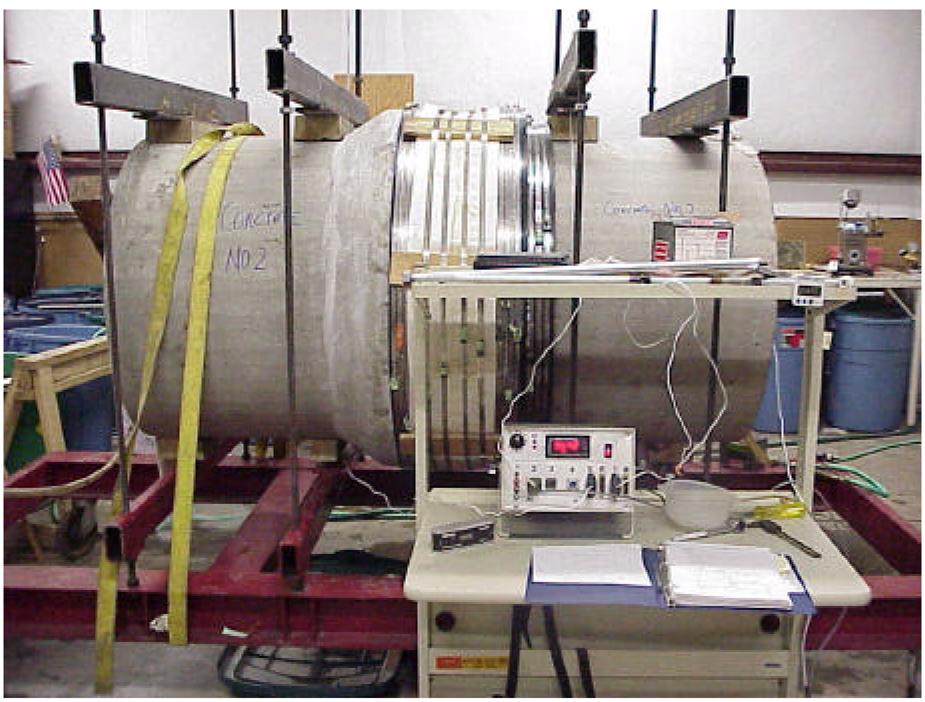


(d) Method C: Shear Load Test

Figure 1. Concrete Pipe-Joint Test Configurations



Method B: Angular Deflection Test



Methods A and C: Straight Alignment and Shear Load Tests

Figure 2. Views of the Concrete Pipe Joint Tests and Loading Frame

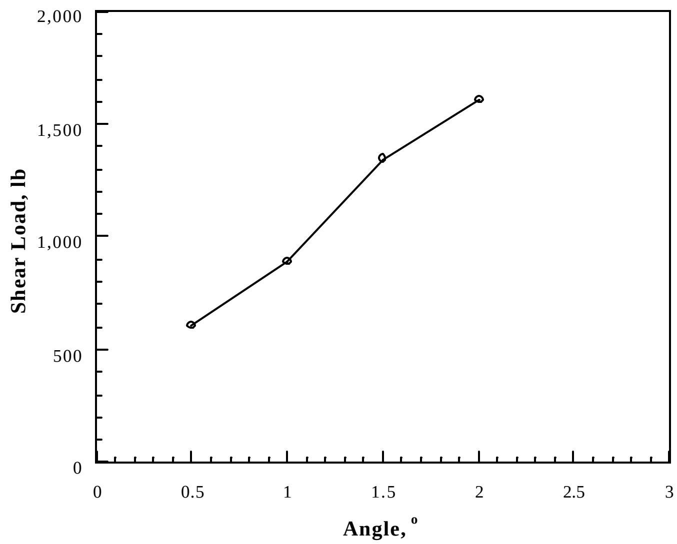


Figure 3. The Relationship between Angle and Applied Load in Test No. 1

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

Method	Angle (°)	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	
Remarks	Up to 2°	3 to 7 psi	Total 2.5 hrs	No Leak	No water leak

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

Intended Load (lb)	Pressure (psi)	Time (min)	Leakage	Actual Load, (lb)	Shear at joint, (lb)	Remarks
1000	3	5	No	1067	514	No water leak
	4	5	No			
	5	5	No			
	6	5	No			
	7	10	No			
2000	3	5	No	2191	1121	No water leak
	4	5	No			
	5	5	No			
	6	5	No			
	7	10	No			
3000	3	5	No	3312	1513	No water leak
	4	5	No			
	5	5	No			
	6	5	No			
	7	10	No			
4000	3	5	No	4433	2023	No water leak
	4	5	No			
	5	5	No			
	6	5	No			
	7	10	No			
5000	3	5	No	5405	2450	No water leak
	4	5	No			
	5	5	No			
	6	5	No			
	7	10	No			
6000	3	5	No	6483	2804	No water leak
	4	5	No			
	5	5	No			
	6	5	No			
	7	10	No			
7000	3	5	No	7602	3232	No water leak
	4	5	No			
	5	5	No			
	6	5	No			
	7	10	No			
8000	3	5	No	8414	3592	No water leak
	4	5	No			
	5	5	No			
	6	5	No			
	7	10	No			
9,000	3	5	No	9753	4278	No water leak
	4	5	No			
	5	5	No			
	6	5	No			
	7	10	No			
Remarks	Up to 7 psi	Total 4.5 hrs.	No leak	Maximum load 9753 lb.	Maximum shear 4278 lb	No water leak

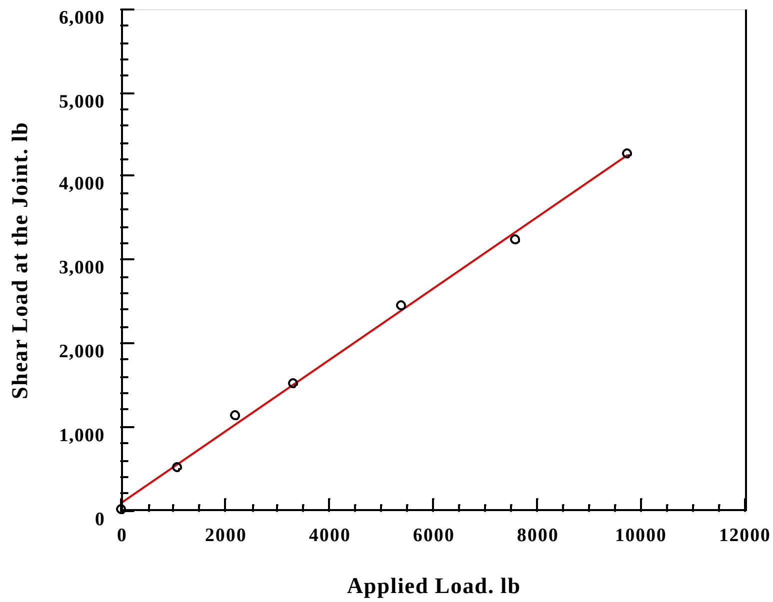


Figure 4. Shear Load vs. Applied Load in Test No. 1

5.2 Test No. 2. (Concrete Pipe Joint No. 2)

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

The results of the test 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. No water leak was observed at the joint during the total test period of 2 hrs. The maximum separation at the invert of the joint was about 1.3" at the end of the test. This didn't lead to any leak during the period of the test. The relationship between the angle of rotation at the joint angle and the shear load at the joint is shown in Fig. 5. With the increase in the angle rotation, the shear load decreased from 400 to 1,900 lbs at the joint.

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

The joint was tested under shear loading as specified in Method C (Appendix B). The load cell locations are shown in Fig. 1 (c). The load was applied at Load Cell No. 1 on the pipe and was increased in steps of 1,000, 2,000, 3,000, 4000, 5,000, 6,000, 7,000, and 8,000 lbs. in the test. The testing time under each load was 30 minutes with maximum hydrostatic pressure of 7 psi. The maximum shear load at the joint was 4580 lbs. and no water leak was observed. The test results are summarized in Table 4. The Shear load at the pipe joint vs. Applied load on Load Cell 1 is shown in Fig. 6. No water leak was observed at the joint during the total test period of 4 hrs.

Test No. 2 Summary

The composite bladder performed as designed. Total testing time for Method A, B, and C were 0.5, 2 and 4 hours respectively. No water leak was observed at the tested joint for all testing conditions. The maximum applied shear load at the joint was 4580 lbs. (over 150 lbs/in. diameter) and there was no water leak.

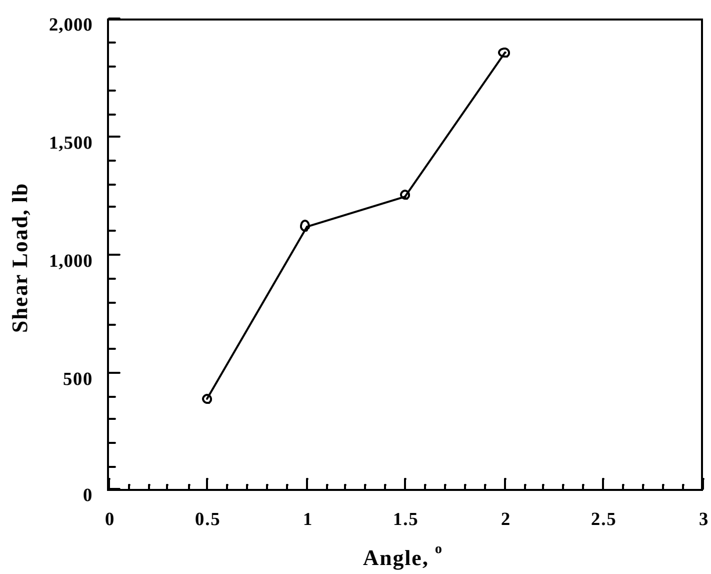


Figure 5. The Relationship between Angle and Applied Load in Test No. 2

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

Method	Angle (°)	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	
Remarks	Up to 2°	3 to 7 psi	Total 2.5 hrs	No Leak	No water leak

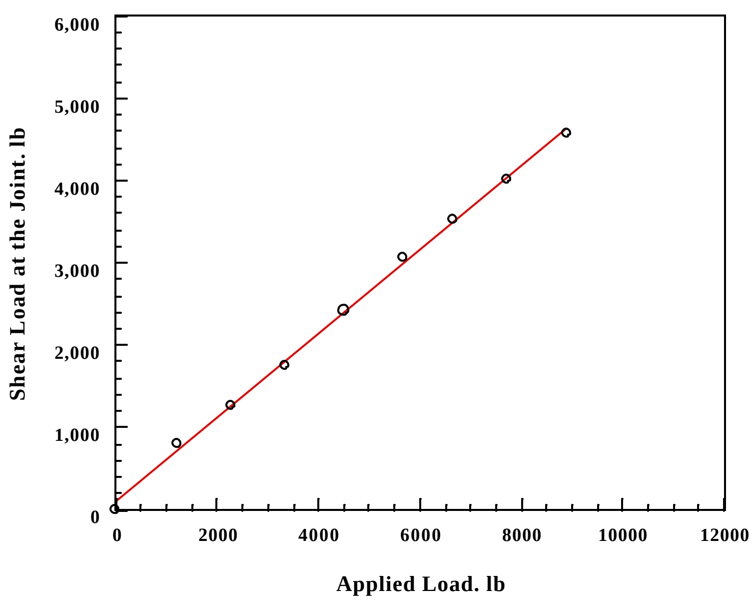


Figure 6. Applied Load vs. Shear Load in Test No. 2

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

Intended Load (lb)	Pressure (psi)	Time (min)	Leakage	Actual Load, (lb)	Shear at joint, (lb)	Remarks
1,000	3	5	No	1,208	814	No water leak
	4	5	No			
	5	5	No			
	6	5	No			
	7	10	No			
2,000	3	5	No	2,278	1,276	No water leak
	4	5	No			
	5	5	No			
	6	5	No			
	7	10	No			
3,000	3	5	No	3,335	1,752	No water leak
	4	5	No			
	5	5	No			
	6	5	No			
	7	10	No			
4,000	3	5	No	4,501	2,427	No water leak
	4	5	No			
	5	5	No			
	6	5	No			
	7	10	No			
5,000	3	5	No	7,593	3,097	No water leak
	4	5	No			
	5	5	No			
	6	5	No			
	7	10	No			
6,000	3	5	No	6,659	3,527	No water leak
	4	5	No			
	5	5	No			
	6	5	No			
	7	10	No			
7,000	3	5	No	7,720	4,008	No water leak
	4	5	No			
	5	5	No			
	6	5	No			
	7	10	No			
8,000	3	5	No	8,881	4,580	No water leak
	4	5	No			
	5	5	No			
	6	5	No			
	7	10	No			
Remarks	Up to 7 psi	Total 4 hrs.	No leak	Maximum load 8881 lb.	Maximum shear 4580 lb	No water leak

6. CONCLUSIONS

The testing of the 30-in. diameter concrete pipe-joints was performed in the CIGMAT Laboratory at the University of Houston, Houston, Texas. Based on the two joints tested the following conclusions are advanced.

1. Straight Test: There was no leakage at the 30-in. concrete pipe-joint when the joint was tested without any external loading for a total testing time of 30 minutes.

2. Shear Test: The joint was subjected to a maximum shear force of 4580 lb. (equivalent to 153 lb/in diameter) and there was no leakage. The total testing time for each joint was 4.5 hours.

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 varied from 400 to 1,900 lbs. during the angular test. There was no water leakage.

7. REFERENCES

[1] Annual Book of ASTM Standards (2000), Section 4 (Construction) and Section 8 (Plastics), ASTM, Philadelphia, PA.

[2] Water Environment Federation (1999), Control of Infiltration and Inflow in Private Building Sewer Connections, WEF, Alexandria, VA.