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PVC Pipe Assessment

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BACKGROUND:

The Dallas Meadows Community was established in the 1980's, with PVC piping used as the water distribution. As indicated through correspondence, there have been several breaks/leaks over the years but occurred in the early years of the community, most likely the result of ground movement and settling.

As an ongoing effort of the community to improve and ensure longevity of the system, PNL was requested to assess the condition of the PVC piping to aid in a life assessment of the water distribution system.

SAMPLE COLLECTION:

Several sections of the PVC water distribution pipe were removed and delivered to PNL for examination. The process of removal required excavation of several sites to expose the pipe, as seen in the client supplied images, Figures 1 and 2.

Figure 3 is an overview of the pipe sections taken for examination, labeled 1, 2 and 3 (note two samples of pipe were labeled 3). No other information regarding the sites and their relation to each of pipe sections was provided; assumed that information was gathered and retained by the client for future reference.



Figure 1: Overview of pipe excavation on site



Figure 2: Overview of exposed pipe



Figure 3: Overview of pipe sections taken for analysis

SCOPE OF EXAMINATION:

The purpose of the pipe examination was to assess the condition of the pipe based upon industry standards for PVC pipe used in water distribution as well as observations based upon known and accepted scientific practices and techniques.

The following summarizes the testing procedures proposed and agreed upon by the client:

- Visual Examination
    - The pipes were visually examined for any notable defects or other features of interest.
- Mechanical Testing per ASTM Standards
    - Multiple ASTM standards exist which cover PVC pipe, such as ASTM D1785 and ASTM D2665.
        - ASTM D1785: Standard Specification for Poly(Vinyl Chloride) (PVC) Plastic Pipe, Schedules 40, 80 and 120.
        - ASTM D2665: Standard Specification for Poly(Vinyl Chloride) (PVC) Plastic Drain, Waste and Vent Pipe and Fittings.
            - A test procedure/criterion was found consistent in each of the standards: the 'flattening' test. This test involves crushing the pipe under a controlled environment to assess if any cracking, splitting or breaking occur which would be an indication of degradation and/or poor-quality pipe material.
    - Based upon the request, the flattening test would be the most efficient and economical mechanical test procedure to assess the condition of the pipe.
        - ASTM D1785, Section 8.6, requires that none of the flattened specimens show evidence of splitting, cracking or breaking. No other criteria or measurable values for this test procedure are outlined in the standard.
        - ASTM D2665 goes into further detail of the test procedure, referencing test methods outlined in ASTM D2412, as well as provides measurable quantities for pipe stiffness, Table 3, for various sized pipes.
            - ASTM D2412: Standard Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading.
- Chemical analysis by Fourier-Transform Infrared Spectroscopy (FTIR).
    - The interior and exterior of each pipe sample were examined for comparison purposes to determine if any evidence of degradation or variations exist.

EXAMINATION:

Figure 4 is an overview of the pipe sections, as received by PNL, which correspond to the sections in the client received image. Figures 5-13 are closer views of the markings found on each of the pipe sections.

Section 1 is a three inch diameter pipe with the following markings: 3" ROBINTECH 2099 SCH 40 PVC 1120 ASTM 1785.

Sections 2 and 3 are both two inch diameter pipe sections.

Section 2 markings are as follows: M.P.I 2" PVC-1120 TiG1 SCH40 ASTM D2665 138 783 A. One side of the markings on Section 2 show evidence of being partially removed/scraped, assumed part of the removal process (Figure 14).

Section 3 markings have been smeared/damaged but has similar characteristics to the ROBINTECH pipe (Section 1) with legible markings: 2099 SCH 40 PVC 1120 ASTM D2665.

As seen in Figure 15, notable damage/scratches are seen on the long section of Section 3 such that one end has been partially flattened; the portion containing the solvent welded connection shows damage at the pipe end and fitting, assumed related to the removal process.

Visual examination of the exterior of the pipes, sans the mechanical damage such as minor nicks and scraps, shows no readily visible discoloration or other indications of any defects in the workmanship of the pipes.

The interior of the pipes shows no evidence of any defects or notable discoloration (after water cleaning); only discoloration was due to settlement and deposits from either the removal process or contents of fluid, see Figures 16-18 which were as-received.



Figure 4: Overview of pipes, as received

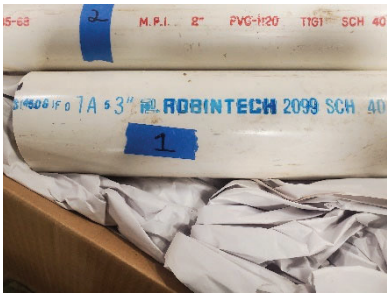


Figure 5: Section 1, markings



Figure 6: Section 1, markings

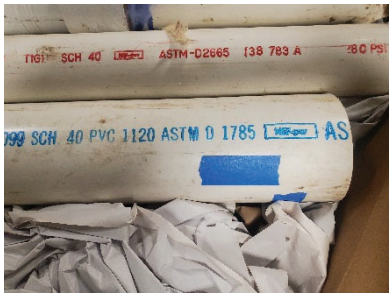


Figure 7: Section 1, markings



Figure 8: Section 2, markings



Figure 9: Section 2, markings



Figure 10: Section 2, markings



Figure 11: Section 3, markings



Figure 12: Section 3, markings



Figure 13: Section 3, markings

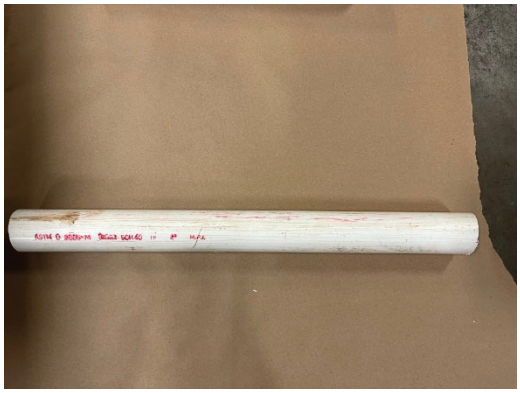


Figure 14: Scrap marks/deformation, Section 2

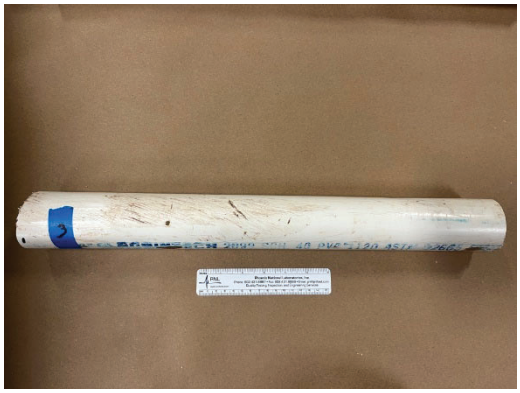


Figure 15: Scrap marks/deformation, Section 3

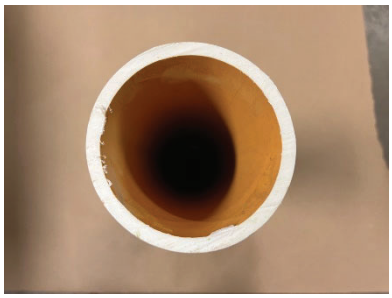


Figure 16: Section 1, interior



Figure 17: Section 2, interior

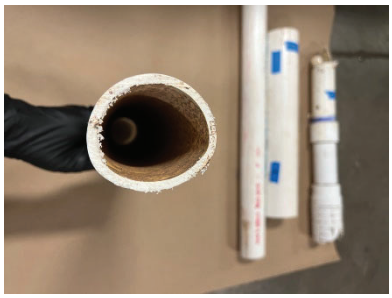


Figure 18: Section 3, interior, flattened end

MECHANICAL TESTING:

Per ASTM D2665 and D2412, sections of pipe were cut and deburred for measurements and load testing. As Section 3, long piece, contained notable flattening at one end which was not used for testing; the portion containing the least amount of damage was sectioned into two pieces and the third piece for testing was taken from the solvent welded portion.

Per the ASTM standards, the length of the sections cut for testing were 6 ± ¼" and measured at four equally spaced points around the circumference. The wall thickness was measured at eight equally spaced points around the circumference on both ends; an origin point was made for reference between both ends to determine if a line of minimum wall thickness was present.

If a line of minimum wall thickness was determined, it was marked for orientation during the mechanical testing, such that second two test samples were rotated 35 and 70 degrees during the load testing, per the standard. As no value tolerance was specified for line of minimum wall thickness, a difference of 0.02" was used as a value; only Section 2 showed a notable line of minimum wall thickness and therefore was tested accordingly.

Inner and outer diameters were measured directly, taking eight measurements around the circumference.

Table 1 lists the values of these measurement for each test sample. All units are in inches unless otherwise specified.

TABLE 1: Physical Measurements (in)									
	1	2	3	4	5	6	7	8	Average
Section 1.1									
End 1	0.243	0.238	0.231	0.232	0.233	0.236	0.231	0.236	0.235
End 2	0.240	0.233	0.235	0.235	0.238	0.236	0.237	0.236	0.236
OD	3.539	3.474	3.527	3.476	3.484	3.495	3.481	3.527	3.500
ID	3.066	3.000	2.992	3.005	3.013	3.050	3.060	3.071	3.032
Length	6.033	5.970	5.910	5.964					5.969
Section 1.2									
End 1	0.244	0.237	0.236	0.238	0.231	0.237	0.237	0.232	0.237
End 2	0.240	0.238	0.238	0.236	0.231	0.234	0.236	0.233	0.236
OD	3.505	3.516	3.467	3.541	3.478	3.577	3.504	3.530	3.515
ID	3.007	2.992	3.058	3.052	3.007	3.001	3.010	2.988	3.014
Length	5.962	5.971	5.991	5.964					5.972
Section 1.3									
End 1	0.236	0.232	0.240	0.236	0.229	0.226	0.230	0.239	0.234
End 2	0.236	0.233	0.235	0.232	0.228	0.225	0.238	0.235	0.233
OD	3.507	3.485	3.474	3.484	3.495	3.517	3.543	3.527	3.504
ID	3.040	2.991	3.006	3.023	3.016	3.043	3.038	3.051	3.026
Length	5.857	5.906	5.898	5.867					5.882
Section 2.1									
End 1	0.172	0.174	0.171	0.172	0.171	0.152	0.158	0.156	0.166
End 2	0.166	0.181	0.174	0.176	0.168	0.155	0.151	0.158	0.166
OD	2.358	2.368	2.388	2.357	2.386	2.358	2.385	2.364	2.371
ID	2.030	2.064	2.035	2.059	2.039	2.060	2.053	2.060	2.050
Length	5.973	5.984	5.941	5.967					5.966
Section 2.2									
End 1	0.177	0.172	0.163	0.159	0.151	0.165	0.177	0.175	0.167
End 2	0.179	0.171	0.164	0.157	0.152	0.165	0.177	0.174	0.167
OD	2.390	2.370	2.356	2.374	2.355	2.394	2.393	2.361	2.374
ID	2.056	2.023	2.023	2.059	2.064	2.058	2.046	2.022	2.044
Length	6.004	6.017	6.013	6.003					6.009
Section 2.3									
End 1	0.172	0.155	0.150	0.157	0.165	0.175	0.176	0.178	0.166
End 2	0.172	0.154	0.152	0.162	0.163	0.177	0.172	0.177	0.166
OD	2.357	2.392	2.367	2.380	2.355	2.362	2.356	2.360	2.366
ID	2.032	2.066	2.057	2.050	2.037	2.073	2.033	2.063	2.051
Length	5.939	5.900	5.904	5.930					5.918
Section 3.1									
End 1	0.171	0.171	0.165	0.158	0.163	0.165	0.166	0.167	0.166
End 2	0.172	0.174	0.165	0.162	0.165	0.163	0.165	0.167	0.167
OD	2.374	2.380	2.378	2.382	2.380	2.377	2.379	2.372	2.378
ID	2.110	2.024	2.032	2.053	2.092	2.051	2.056	2.029	2.056
Length	5.973	5.966	6.065	6.010					6.004
Section 3.2									
End 1	0.178	0.168	0.169	0.180	0.177	0.180	0.176	0.172	0.175
End 2	0.167	0.164	0.165	0.171	0.173	0.174	0.169	0.166	0.169
OD	2.375	2.370	2.364	2.350	2.368	2.390	2.391	2.379	2.373
ID	2.048	2.033	2.025	2.020	2.051	2.064	2.068	2.058	2.046
Length	5.888	5.917	5.942	5.907					5.914
Section 3.3									
End 1	0.171	0.173	0.165	0.159	0.164	0.166	0.163	0.167	0.166
End 2	0.172	0.174	0.164	0.159	0.165	0.167	0.164	0.166	0.166
OD	2.374	2.397	2.408	2.408	2.398	2.355	2.330	2.349	2.377
ID	2.046	2.073	2.083	2.080	2.052	2.046	2.013	2.025	2.052
Length	5.962	5.941	5.932	5.972					5.952

All measurements for wall thickness and OD are within tolerances per ASTM D1785 (Table 1 and 2) and D2665 (Table 2) for Schedule 40 PVC pipe.

For the flattening test, each sample was loaded into the Instron universal test machine (Frame SN 5985U1246, 250 kN Load Cell SN 203548). Figures 23 and 24 are overviews of the test setup, at the initial and final stages, respectively. Test conditions followed ASTM standards with a laboratory atmosphere of 73.4 ± 3.6°F and 50 ± 10% relative humidity; the samples had been conditioned in the same environment for 40hrs. Per the standards, the rate of loading was 0.50 ± 0.02 in/min.

ASTM D2665 contains a measurable value of pipe stiffness for various sized pipes at 5% deflection, see Figure 19. Additional pipe stiffness (PS) and stiffness factor (SF) were collected for both the 5% and 10% deflection, per ASTM D2412. Percentage deflection is indicated when the initial diameter is reduced by said percentage. Flattening is specified to be with the diameter is deflected by 60% of the original value at which point the testing is complete.

During the test procedure, the section of pipe is viewed to assess if any linear cracking/crazing, wall cracking, wall delamination and/or rupture is observed; if any of these features are observed during the test, note is to be made of the load and deflection at which point the feature are observed.

TABLE 3 Pipe Stiffness Requirements for PVC DWV Pipe[A]

Nominal Pipe Size, in.	Pipe Stiffness, min, psi (kPa)
1¼	1400 (9650)
1½	1010 (6960)
2	600 (4140)
3	510 (3520)
4	310 (2140)
6	150 (1030)
8	100 (690)
10	78 (530)
12	63 (430)
14	60 (415)
16	60 (415)
18	60 (415)
20	51 (350)
24	45 (315)

[A] Measured at 5 % deflection.

Figure 19: ASTM D2265-20, Table 3

Table 2 is a list of the results for each of the nine sections tested per ASTM D2412. All nine samples showed pipe stiffness (PS) above the minimum specified valued from Table 3 for 2" and 3" nominal pipe sizes at 5% deflection. Figures 20-22 are the graphical outputs of the each of the test samples during loading which showed consistent loading characteristics for each sample set. Section 3 did show lower values for the two of the three samples which is most likely related to the imparted damage in the as-received condition.

Sample 3.2 contained a portion of the solvent welding primer on the exterior. After testing, the area containing the primer showed no evidence of any visible cracking or other features of interest (Figure 25). Note that this sample had values more consistent with Section 2 as it did not contain the damage seen to the remaining portions of Section 3.

For Sample 3.3, which contained the notable deformation/scratches and partial flattening, the area of these features was placed along the edge (area of highest stress). Only near the very end of the test, at the 60% flattening mark, did evidence of any linear cracking begin to appear, see Figure 26. The scratches and deformations acted as stress risers for the cracking to initiate but even with the formation of the observed cracking, the stiffness factor was still above the minimum requirement.

TABLE 2: Mechanical Test Results								
Sample	Nom Pipe Size	Force @ 5% (lbf)	PS @ 5% (psi)	SF @ 5% (lbf-in)	Force @ 10% (lbf)	PS @ 10% (psi)	SF @ 10% (lbf-in)	Max Force @ 60% (lbf)
1.1	3”	617.60	683	443	1077.99	596	386	2054.95
1.2		631.12	695	456	1100.99	606	398	2000.89
1.3		597.74	669	436	1055.14	590	385	2077.38
2.1	2”	494.33	813	162	881.42	725	145	1568.23
2.2		492.09	803	161	884.04	721	144	1549.90
2.3		479.69	797	158	863.53	717	142	1508.51
3.1	2”	415.96	677	137	787.06	641	129	1528.60
3.2		450.39	751	149	837.39	698	139	1460.28
3.3		419.55	689	139	795.23	653	132	1425.07

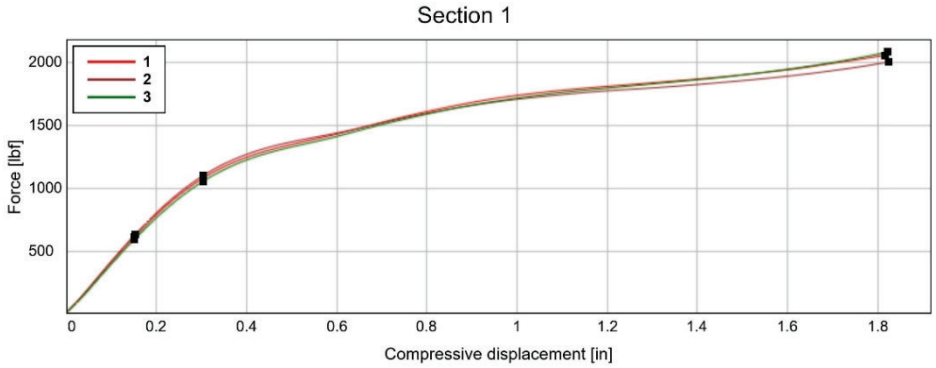


Figure 20: Section 1 samples, force v displacement

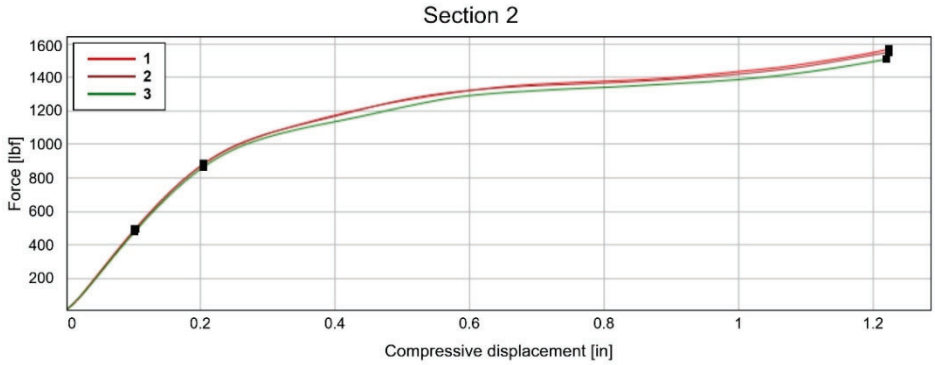


Figure 21: Section 2 samples, force v displacement

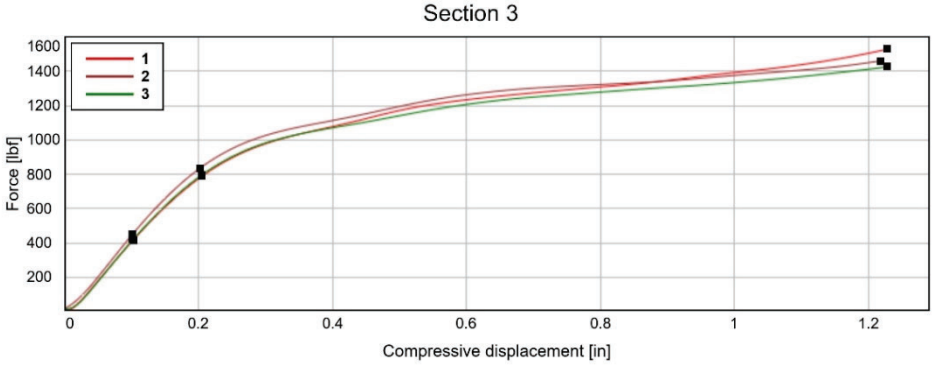


Figure 22: Section 3 samples, force v displacement



Figure 23: Overview of test setup, initial

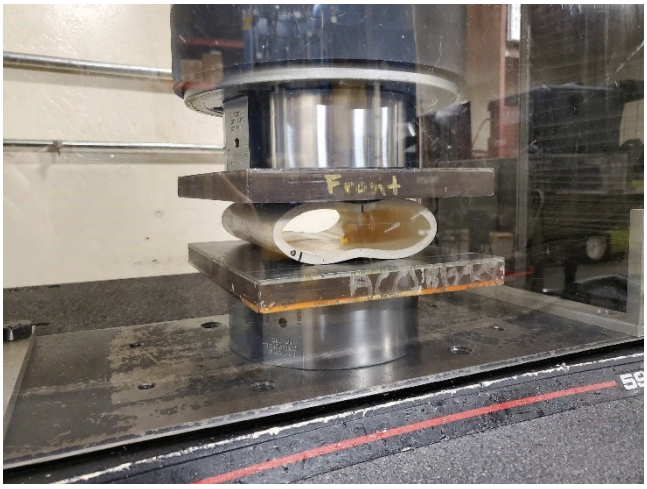


Figure 24: Overview of test setup, final



Figure 25: Sample 3.2, final

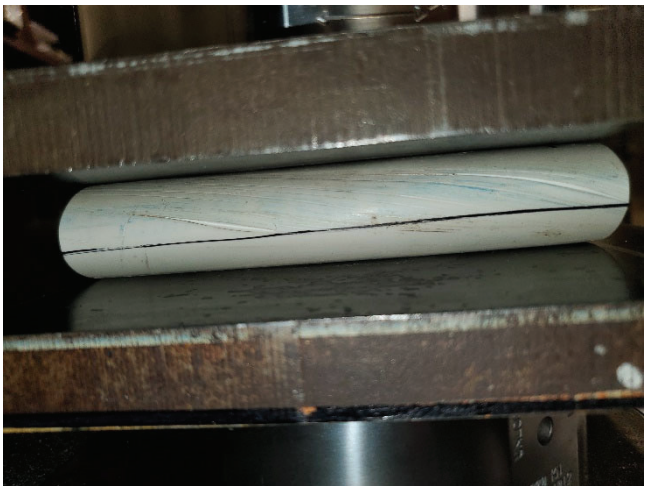


Figure 26: Sample 3.3, final

FTIR TESTING:

Samples from each pipe section were prepared for FTIR analysis; both the interior and exterior surfaces were examined.

Each sample was prepared and analyzed by attenuated total reflectance (ATR) on a Nicolet iS50 Fourier Transform Infrared Spectrometer (SN AUP2110669) with a DTGS MID-IR detector.

Figures 27-29 are the spectra collected from each section of pipe, assumed representative.

The spectra for each sample shows differences between the exterior and interior surface at ~1050 cm-1 range which indicates some variations exist between the interior and exterior surface. Analysis of the spectra with reference PVC spectra and multi-component search indicate the variations at this region of each spectrum are most likely contributed to small amounts of embedded soil material as FTIR analysis is limited to the surface; potential variations in blending agents may also be a contributing factor. The decrease in the small shelf peak at ~600 cm-1 may be an indication of the beginning of minor soil interactions.

As no notable degradation of the polymeric material was observed in the mechanical testing, the variation in the spectra between the exterior and interior each of the pipe section has shown not to be detrimental to the structural integrity of the base material.

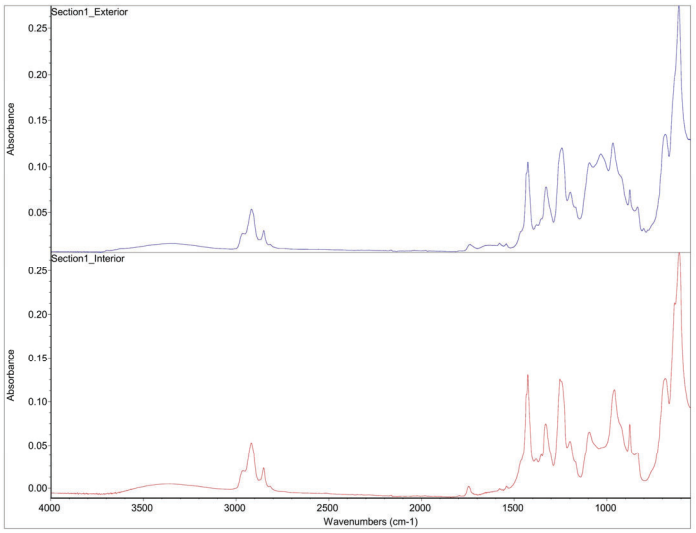


Figure 27: Section 1, FTIR Results

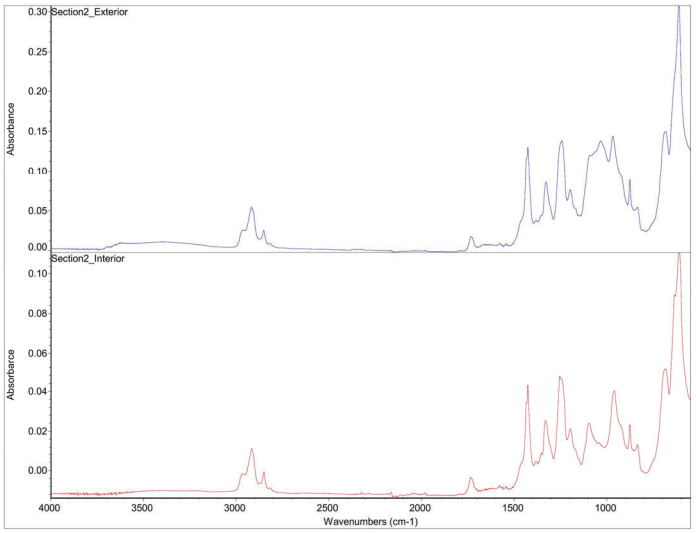


Figure 28: Section 2, FTIR Results

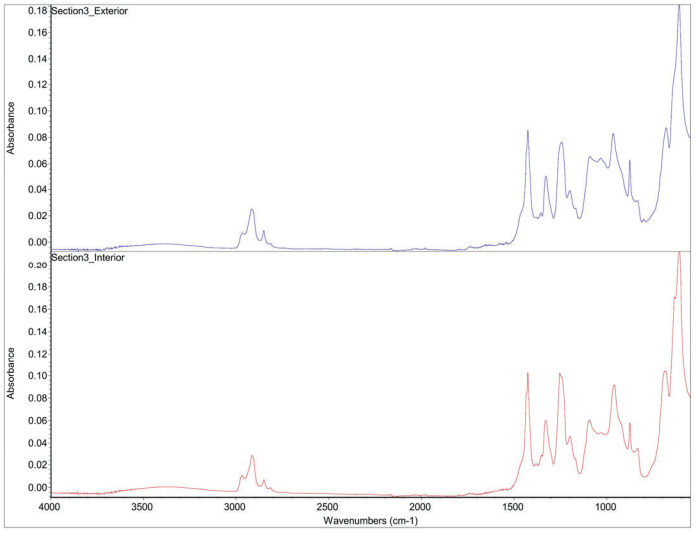


Figure 29: Section 3, FTIR Results

OBSERVATIONS & RECOMMENDATIONS:

- Examination of the pipe material showed no evidence of any visible degradation of the base PVC material.
- Mechanical testing of each of the three samples were well above the minimum specified pipe stiffness requirements per ASTM D2665.
    - No evidence of cracking or splitting was observed on samples which would be an indication of degradation of the base material.
- FTIR analysis showed some variations between the interior and exterior of the pipe samples, most likely related to surface contamination of the soil. No appreciable breakdown of the polymeric material was observed, indicating both the soil conditions and/or water conditions have not had any adverse effects to the structural integrity of the base material.

No testing or data points were collected at the time of installation, at any other point prior to the current testing or from similar piping from the time of installation. A trendline of the system as a whole with a single set of data points for remaining life expectancy cannot be determined directly from the collected data.

As the pipes have been in service for over 40yrs, as indicated by the client, the test results of each section of pipe examined show no signs of deterioration from the surrounding environment or fluid transport.

Industry standards and publications estimate PVC piping, properly designed and installed, have a life expectancy of 100 years or more. Based upon the results of the testing to date, the system should be adequate in its intended use for an extended period of time.

These results and recommendations only apply to the samples provided for testing. Conditions of other pipes are assumed to be representative in the sampling. No assessment of the fittings or other connections, repairs, etc. can be made at this time. It is also assumed that conditions will remain constant, in respect to the water and/or any treatments that may be introduced to either the soil or fluid transport; there is the possibility any changes may have an adverse effect and should be reviewed and assessed for compatibility.

It is recommended that if any future repairs are made along the system, as applicable, that samples of the original piping be retained for analysis to aid in the life assessment of the system as a whole.