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Potable Water Pipe Condition Assessment For a High Rise Condominium in The Pacific Northwest

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Introduction

This study was commissioned by a homeowners association to perform a condition assessment on the potable water piping system for high-rise condominium in the Pacific Northwest region of the United States. The results published here were presented to a quorum of the HOA Board in November 2012.

The purpose of this condition assessment was to establish a minimum baseline condition for the potable water system. This condition is used to define the current condition of the potable water system. Such a measure is useful for the HOA in considering future remediation options as well as for future engineers and contractors to recommend technologies to improve the system. Such technologies may include epoxy coating, polyurethane, copper re-pipe, or alternate materials such as PEX, polypropylene; or a combination of several technologies.

The original piping system is between 40-50 years old and fabricated of Galvanized Steel. We determined that a visual extraction and physical bi-section of a representative sample of the piping system would provide a superior condition baseline over non-destructive testing such as ultrasound, borescope, or "opportunity" samples. Our goal was to identify a several different operating conditions within the system and remove random samples of each. This method would allow us to assess the condition of the entire system by observing a relatively small sample.

It must be emphasized that this report represents a comprehensive condition assessment and not a system analysis. Metallurgists, corrosion specialists, liner coating applicators, or plumbing contractors may use the observations and data acquired in this assessment toward further analysis as needed. Our attempt has been to discover a baseline condition and provide a meaningful decision making tool for the client Home Owners Association.

This report is divided into multiple sections of increasing detail. The web-based version includes larger photographs, active links, and possible video. The PDF version is a complete rendition of all relative content.

*(**Note:** This report has been modified to omit the identity and location of the client and structure. Some hyperlinks may be switched off)*

Summary Conclusions

The potable water system for this structure is stable but fragile. Corrosion of the interior of all pipes is evident or suspected throughout the system. Serviceability of the system should be considered severely limited due to corrosion in valves. Water quality results are consistent with widespread corrosion of galvanized steel piping and components. The following paragraphs represent several ways that the system may fail in the future due to extensive corrosion.

Water Quality:

A single-draw water sample was analyzed for the presence of controlled metals by an accredited laboratory. The contaminants that are most typically associated with the corrosion of water service systems include: Copper, Lead, Zinc, Nickel, and Iron. The presence of lead is slightly more than 1/2 of the EPA allowable. While not alarming, zero presence of lead would clearly be optimal. All of the regulated metal contaminants were present at levels that are *within the maximum allowable concentrations published by the EPA*. However, these elements are not present in the published city water quality analysis suggesting the piping system may be responsible for some of the contamination [2].

Corrosion:

The protective zinc coating has long been eroded from a majority of this water system. With no cathodic protection, the existing mild steel (ferrous) surfaces are corroding freely in an oxygen rich environment. Pitting of the interior surface is extensive and widespread. Pitting depths, frequently exceeding 1/2 of the remaining material, are routinely observed. In many cases, as little as .05 inches (about 1 mm) - and less than 25% of original material - remains. Extrapolating for the surface area of the entire system, it is more likely than not that such deep pitting incidents could number into the thousands of incidents [5].

Leakage due to pitting:

Substantial pitting appears throughout the system. However, the danger of leakage due to pitting appears most susceptible in the smaller diameter piping where original wall thickness is less than larger pipes and remaining material is less in proportion to pit depth. The first indication of failure may be a pin-hole leak that grows to a small spray inside or near a living unit. It is likely that a resident would discover the leak before major damage occurs.

Pipe Breakage:

Threaded areas of pipe are more vulnerable to breakage because wall thickness is reduced at the root of the threads. Additionally, pipe threads are slightly tapered to form an interference fit and seal. This creates a pre-stressed condition at the thread interface. A failure at the thread would likely spread along the thread root following a path around the circumference of the pipe. The condition would worsen where the threaded joint is supporting the weight of the pipe in bending or occurring at a flow transition such as an elbow. This condition would appear in both small and large diameter pipe. A leak due to pipe breakage would result in considerably more damage.

Serviceability:

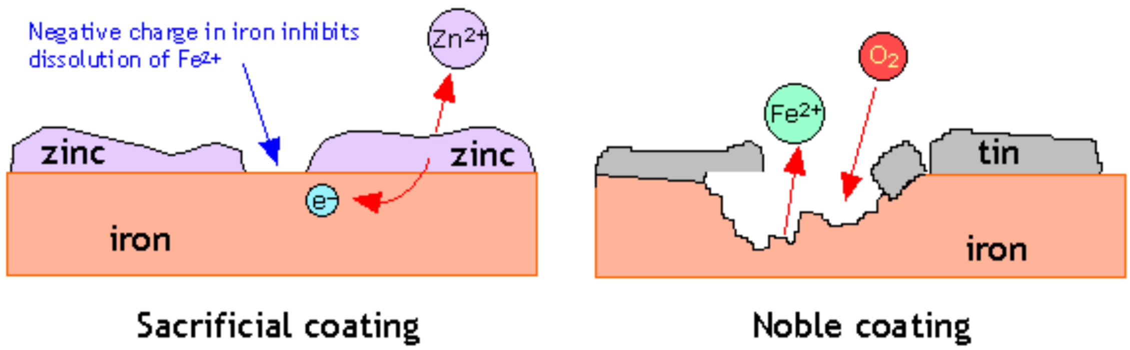
The failure of a standard brass gate valve exposed evidence of active corrosion in brass components as well. This failure resulted in the complete shut down of service to one living unit for several days. The significance is not trivial; In the event of a future leak anywhere in the system, there is a probability that attempts to isolate the leak would expose larger valves to similar failure thereby depriving additional living units of their water service. Ultimately, more frequent full service shut-downs on increasingly short notice, may be experienced.

Recommendation:

The baseline condition is established as a wall thickness of less than 25% of its original size. In 2-inch and 1-inch sized pipe, several instances were found where the remaining wall thickness was less than .05 inches (or roughly 1 mm) on a qualified random sample. It can be extrapolated that hundreds, if not thousands, of instances of this condition may exist throughout the system. The 5 failure modes identified here are considered likely: Corrosion (breaking and pitting), Serviceability, and Water Quality. It is recommended that remediation of these conditions are concluded within the next 5 years [6].

Condition Assessment Method

Many Residential structures currently rely on galvanized piping systems that have been in service for 40-50 years or more. Galvanized pipe is steel that has been plated with zinc. The zinc acts as a corrosion inhibitor by both coating the pipe and redirecting electrons that would otherwise accelerate the corrosion of iron. Many boaters are familiar with the application of "zincs" that corrode away from the salt water so that the rest of the boat does not.



The potable water system in this structure is more than 40 years old and has largely lost the zinc protection and rusting is active in the underlying iron pipes. The rate at which the rusting process advances depends on many factors from the quality of the water (hardness, PH Balance, Chlorine, etc) to the presence of oxygen, turbulence, and rapid changes in direction of flow. The process of corrosion also may introduce contaminants into the water, which would be tested with a separate laboratory water quality assessment.

Testing Method:

The testing/sampling technique is a modification of the stratified sampling method. Because we were testing a system, we selected a set of eight different operating conditions representative of the system. From those eight segments, a random length of pipe was selected in proportion to the amount of pipe in the system. The sections were split on half, back at our lab. For the pipes that were situated horizontally in service, the blade was passed through the top and bottom, respectively.

The final selection of the pipe to be removed was determined by professional engineering opinion taking into consideration the disruption to the community, accessibility of the sample (and repair), and relevance of the sample to the targeted operating conditions.

Operating Conditions:

1. by design, this high-rise tower is segmented into three distinct water systems.
   - The bottom third of the structure is supplied by city pressure via **4** risers
   - The remaining upper floors are supplied by a system of booster pumps and pressure reducers via **4** risers
   - Several adjacent single story structures are fed from **1** horizontal ground level supply
2. The pipes operate under 2 pressure domains:
   - Approximately 20-30 (psi) service
   - Approximately 170-190 (psi) pump boosted to upper floors
3. Pipe appear primarily in 4 different diameters. The original installation is presumed to be schedule 40
   - 3 Inch main supply lines
   - 2-1/2 inch riser lines
   - 1 inch multi unit supply
   - 3/4 in cold and hot water supply

4. Pipe service and orientation

- Horizontal
- Vertical
- Hot and Cold

Sample Limitations: A representative sample would include at least one example of each representative condition. It would not be necessary to isolate any of the above variables individually because:

- Corrosion is assumed to be uniform as seen in other structures by industry precedent.
- If any unexpected conditions were found, that would prompt follow-on analysis.
- The marginal value of extracting additional samples diminishes after about 6-8 samples.

Introduction of Bias: Some bias was intentionally introduced to the random sample. None is considered to have an impact on the applicable selection of suitable specimen:

- Necessity to select locations that were easily accessible for the mechanical contractor to extract and repair.
- Necessity to select locations that were minimally intrusive to the residents of the building.
- Necessity to select locations where any possible leak or water spill could be adequately isolated from personal belongings [of the residents] and which could be easily cleaned and drained in the event of a spill.

Samples were collected from the following locations:

1. City Water
    - ¾" vertical (@Unit 5H)
    - 2" Vertical (@Unit 5H)
    - 3" Horizontal (@Pump Room)
2. Town Homes
    - ¾" Horizontal (@Maintenance Shop)
    - 2" Horizontal (@Maintenance Shop)
3. Pump Boost
    - 3" Horizontal (@pump room)
4. Unit service water
    - 1/2" Vertical Hot Water (unit 1D)
    - 2" Vertical (Near unit 16F)

Procedure

1. Initial Planning: Several system isolation scenarios were considered based on impact on the residents vs. system serviceability. However, due to unknown conditions of the isolation valves, it was considered substantially less risk to shut down water service at the street restricting service to the whole building.

2. Pipe was exposed where needed by a reputable local paint and restoration contractor

3. Water Sample 1 was drawn from sink of unit 1C

4. City Water Department shut the water down at the street level

5. Water sample 2 was drawn from a draining riser in the mechanical room

6. Pipe samples were extracted and repaired by a reputable local mechanical/plumbing contractor over the course of a single day.

7. Each sample was labeled by location, orientation (vertical,horizontal, top/bottom) and direction of flow.

8. Samples were photographed intact upon removal from the system and prepared for shipment.

9a. Service was restored to building.

9b. Two leaks and a broken value were discovered as a result of the extraction. One leak measured at approximately 1 drip per 5 minutes and the other measured 1 drip per 12 minutes. Root cause was determined and repair was performed two days later resulting in limited service to a single unit (by valve failure) and resulting in an additional building shut down.

10. Each sample was returned to Coles Consultants, LLC in Seattle. The pipes were sawn in half in order to expose surface condition and wall thickness (most rust nodulation was knocked off during the slicing process). Each section was

welded to its corresponding half. Several portions of interior surfaces were mechanically descaled.

11. The valve was disassembled and reviewed for root cause.

12. Sections of the surface were further cleaned with a wire wheel on a Dremel tool. Specimens where photographed in repose and with a microscope camera at about 50X

13. Findings prepared in a draft assessment and presented to a quorum of the HOA Board and several community members on November 28, 2012.

Piping Condition Assessment Results

Baseline Water Quality: A single water sample was drawn from unit 1C and analyzed by Fremont Analytical, Inc, an accredited Laboratory in Seattle. This sample demonstrated a controlled and stagnant water sample. A second sample taken from the draining riser is on hold. Additional samples can be taken if deemed necessary in the future with little disruption to the residents.

Water was tested for metals consistent with the active corrosion of galvanized pipe. The water quality of the City Water Supply is referenced and cited. Of particular concern would be the presence of lead. While levels are elevated in the sample, they do not exceed EPA maximums [2].

Element	CTY Source	Client Structure	EPA Maximum
Arsenic	<.50	ND	10
Copper	< 2.0	37.7	1300
Lead	<.02	**8.32**	15
Zinc	NR	165	5000
Nickel	<.2	10.5	NA

All units in micrograms per liter (ug/l) which is the same as parts per billion (ppb) in referenced report ND = none detected. NA - not applicable, NR = not regulated, CWS = City Water Supply

Baseline Corrosion: All pipe segments demonstrated substantial corrosion and pitting. It is not possible to measure original material but the wall thickness is presumed to be schedule 40. Larger pipe have a greater wall thickness in proportion to their surface area and are less likely to fail by pitting than smaller diameter pipes. Larger pipes appear are more likely to grow larger nodules possibly due to lower velocity flow but may also contribute significantly to water quality issues.

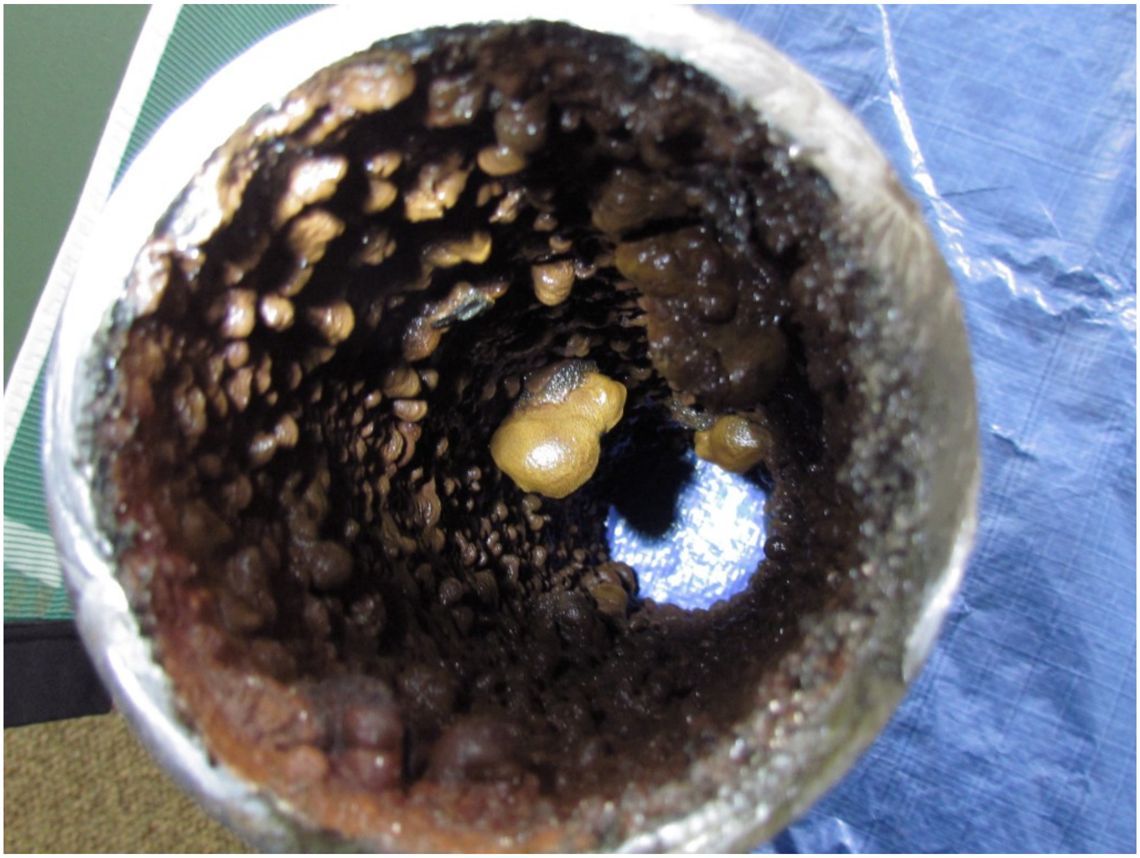


Figure 1a: *All 3-inch pipe showed similar nodulation and pitting. However, schedule 40 wall thickness leaves substantial material remaining. The large surface area and widespread rusting would likely be a source of metallic contaminants. Large nodules break off easily and could restrict flow in elbows, valves and settle in low spots.*

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Figure 1b: *This section was taken from the 3-inch cold water horizontal line in the mechanical room. The surface demonstrates heavy growth of rust nodules. Most of the larger ones fell off during the cutting process. Note: The side walls show evidence of deep pitting in the wall thickness profile.*

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Medium: 2 inch diameter pipe shows widespread rusting and pitting. Pitting in the 2 -inch pipe samples appear deeper as a proportion of existing material than the 3-inch sections.

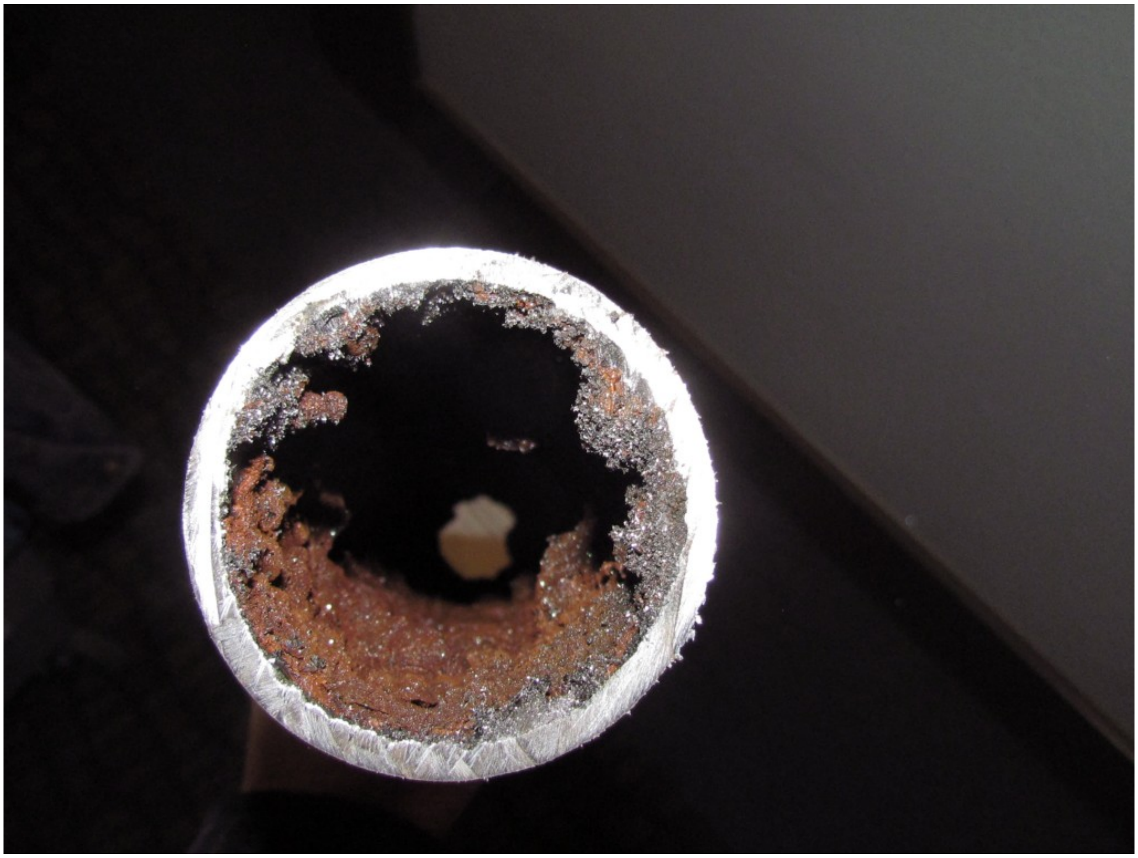

Figure 2a: *Flow restriction reduce effective bore and promotes turbulent flow which is erosive. Large nodules can break off easily and could restrict flow in in elbows, valves or settle in low spots.*

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Figure 2b: *This section was taken from the vertical cold water riser at the 16th floor. Nodules and rust debris dislodging from this height may sink to lower floors or pass into the water system. Remaining wall thickness is frequently less than 1/2 of the original dimension. Note: shiny areas have been cleaned for inspection.*

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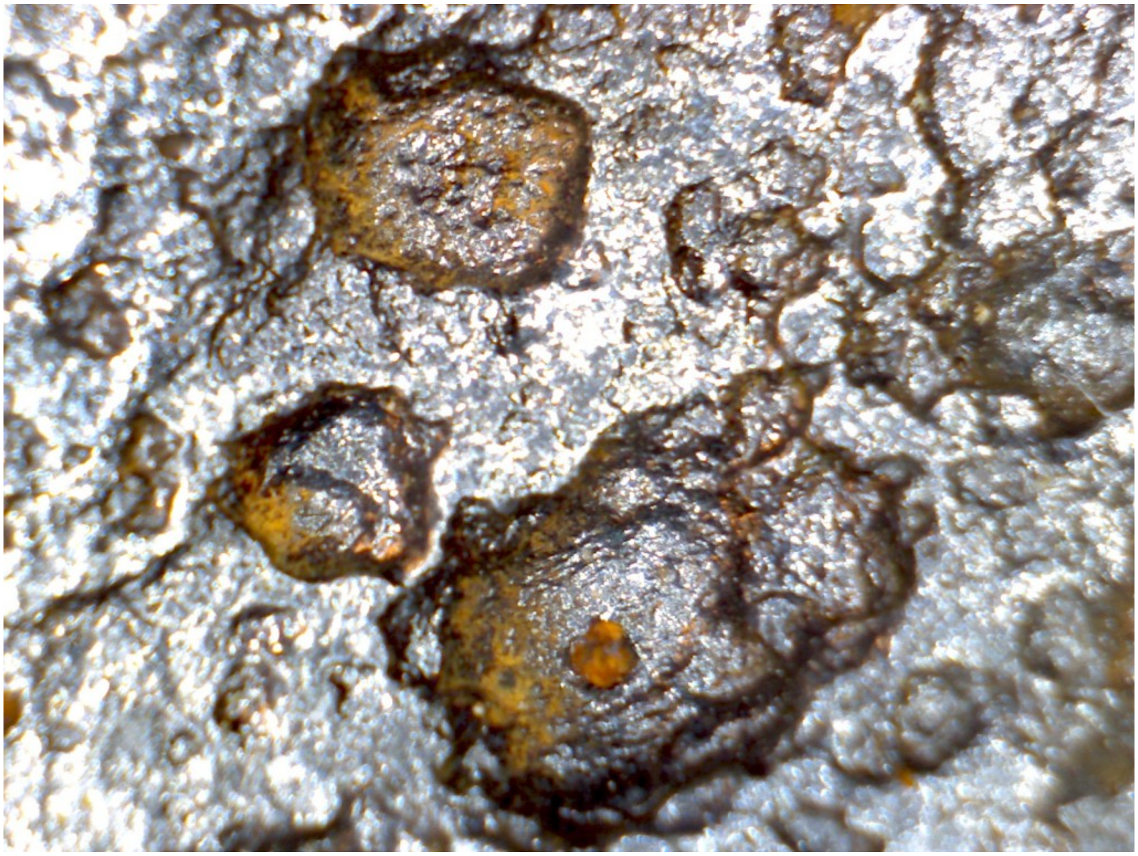

Figure 2c: *Surface was cleaned with a pneumatic scaler and polished with a wire wheel. Resulting profile demonstrates widespread pitting. These three examples were found within a larger crater (such as seen in profile view). The diameter of the larger pit shown here is about 1/4 of an inch at widest.*

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Smaller Diameter Pipe: All 1-inch and 3/4 inch schedule 40 pipe showed widespread rusting and pitting. Nodules are comparatively smaller but scaling is more apparent. Pitting is similar in frequency and possibly in depth. However, original wall thickness was much less, therefore, remaining material is likely to be proportionally less as well.

Figure 3a: *The following Photographs was taken from the cold vertical section at unit 1D. The very thin wall section just below the scale is magnified below.*

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Baseline wall thickness condition: The following photographs represent areas that were discovered where less than 1/20 of an inch (roughly 1 mm) or less than 25% of wall thickness material remains.

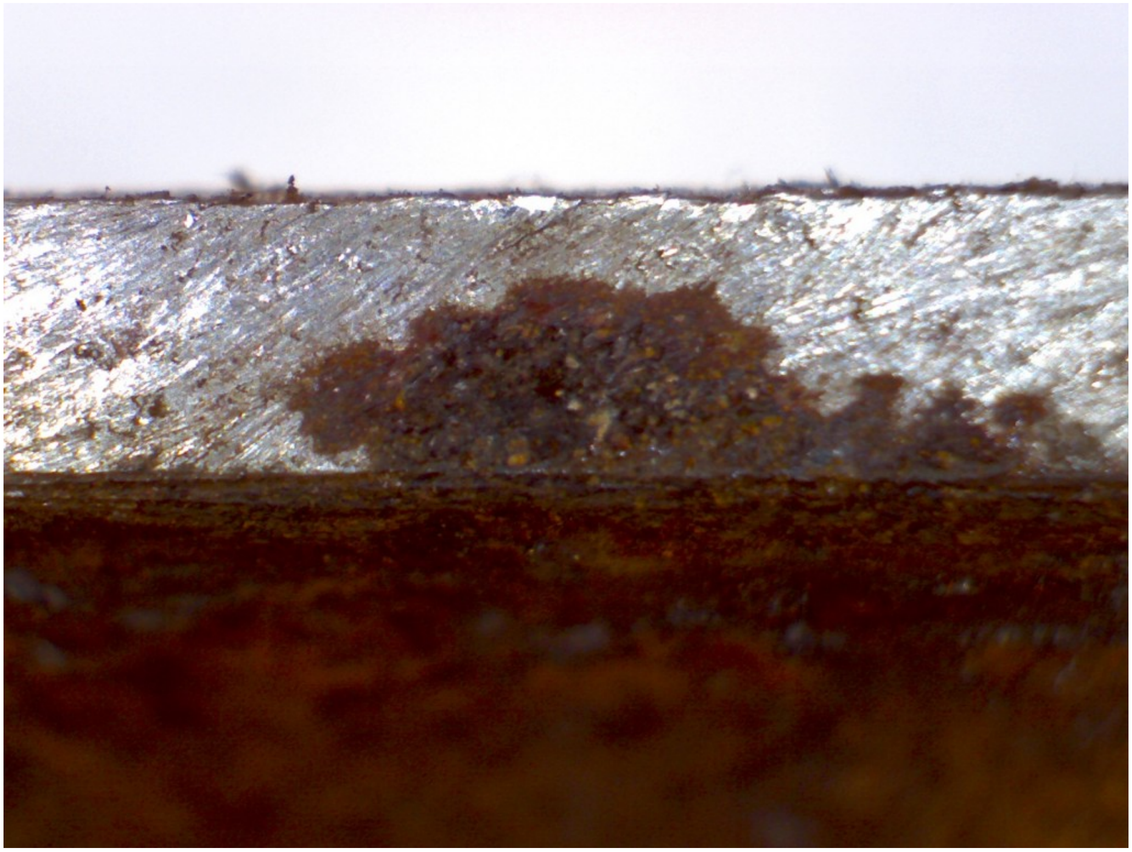

Figure 4a; *a 1-inch diameter pipe showing less than 1/20 inches (1 mm) of remaining material. It appears that 25%-30% of original material remains.*

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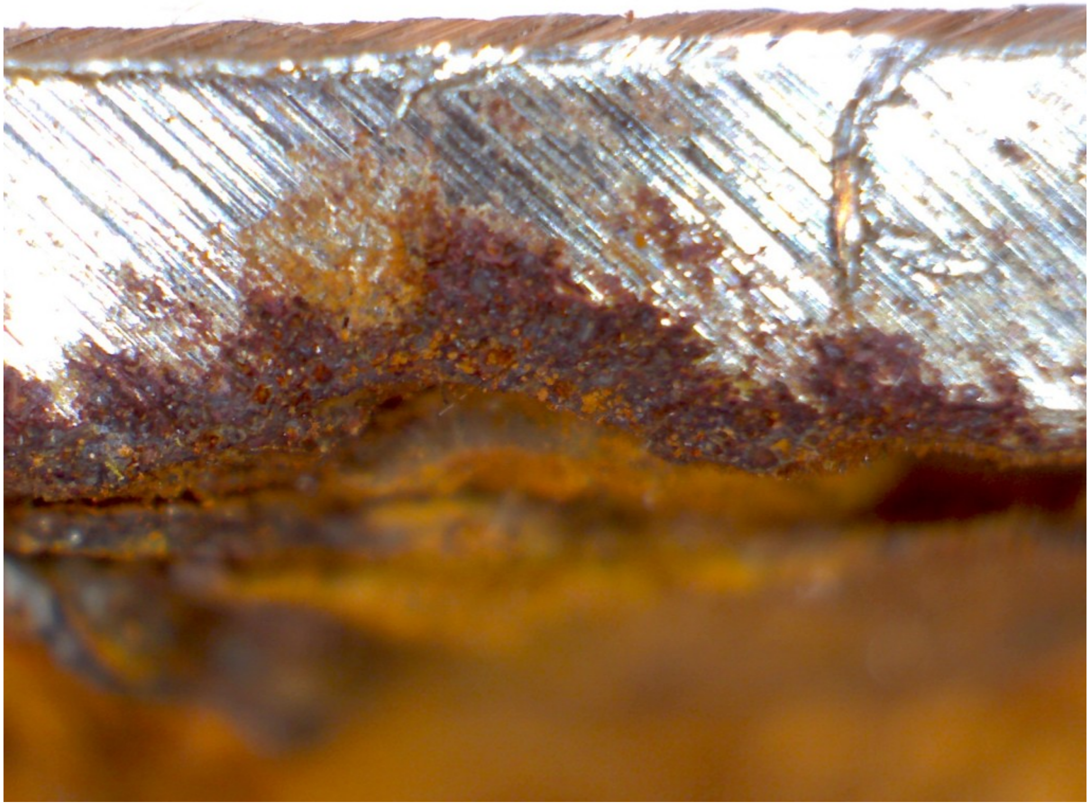

Figure 4b: *This wall section of 2 inch pipe demonstrates less than 1mm of remaining material.*

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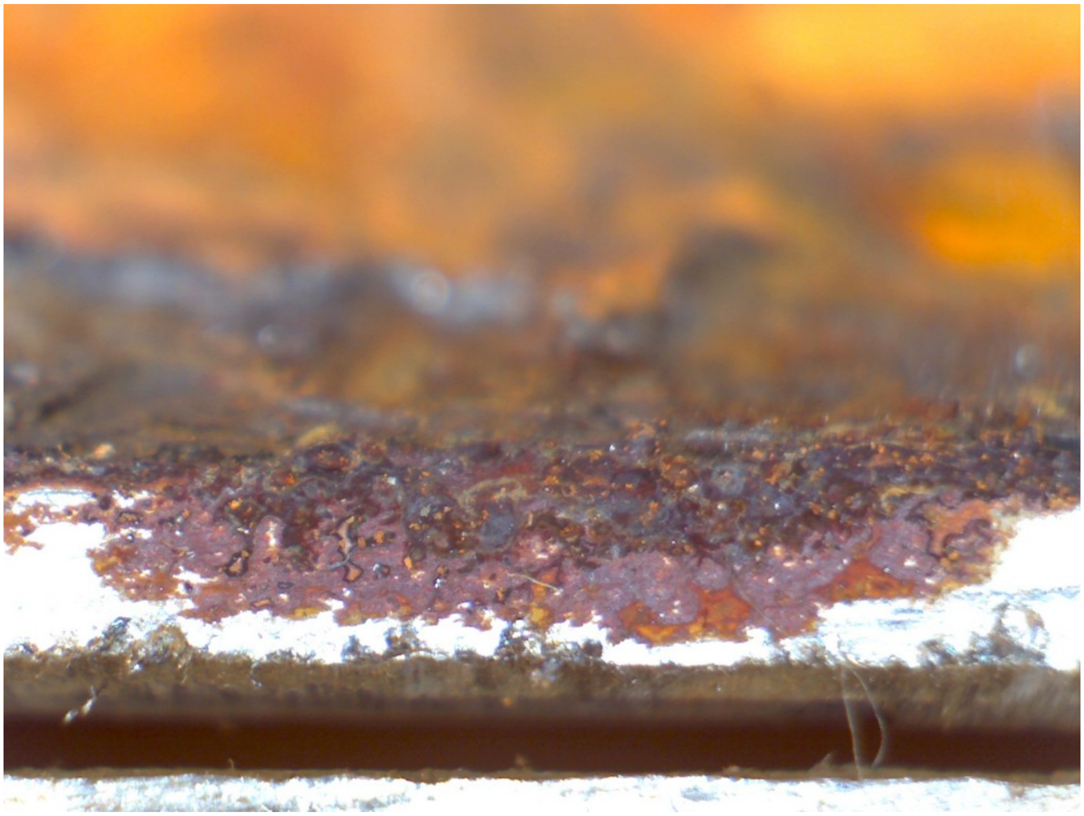

Figure 4c: *This 3/4 Diameter pipe with extremely thin wall section, reference figure 3a. Having found a single section this thin in a random sample suggests the possibility that some leakages currently exist or are imminent. Less than 25% of original material remains.*

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Pipe Threads:

Pipe threads are cut on a tapered end and are designed to interfere with each other as they are tightened - this is not the same as one would find on a nut and bolt for example. The pipe thread creates a tight seal and resists loosening because the threads bind against each other.

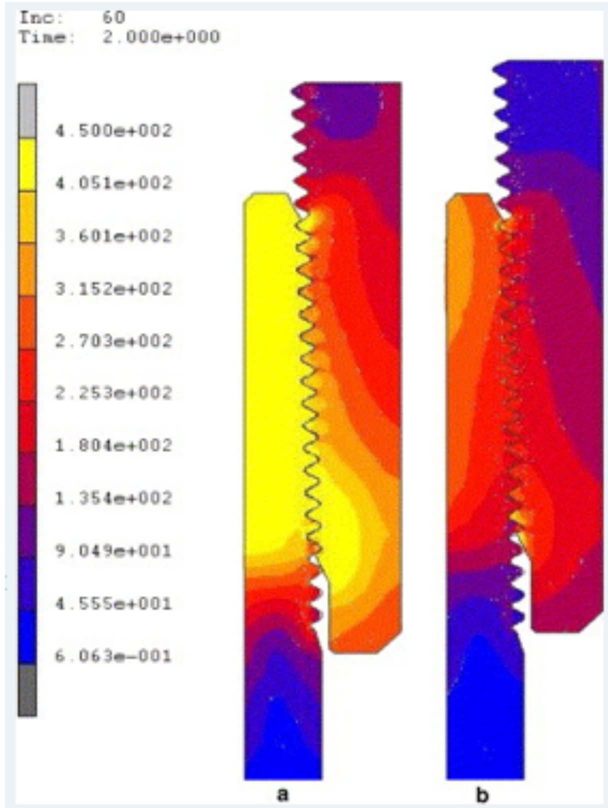
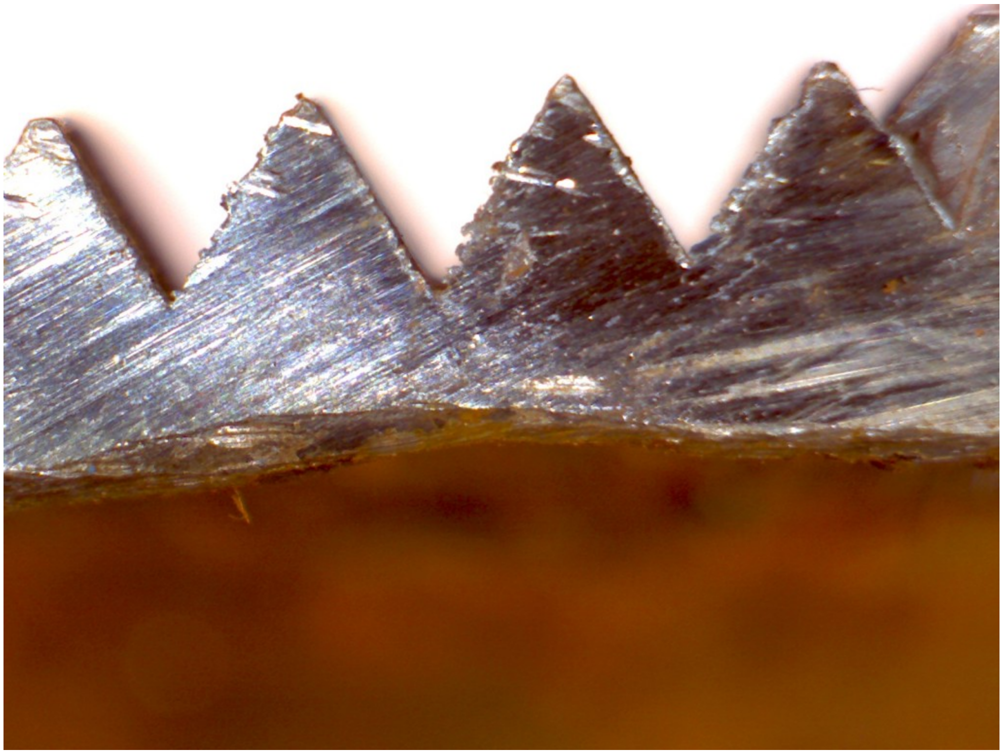


Figure 6a *shows a typical (not actual) stress accumulation in pipe threads as torque is applied to the adjoining pipes (yellow is highest stress, blue is lowest). These stresses remain in the steel as stored energy - like a spring can store energy when compressed. When corrosion approaches the thread root a crack may rupture and propagate around the circumference of the pipe compromising the structural integrity.*

Baseline threaded sections: Threaded sections are particularly vulnerable to failure because they are already under a highly stressed interference fit condition, a failure would likely propagate around the circumference of the pipe or provide a path for leakage.



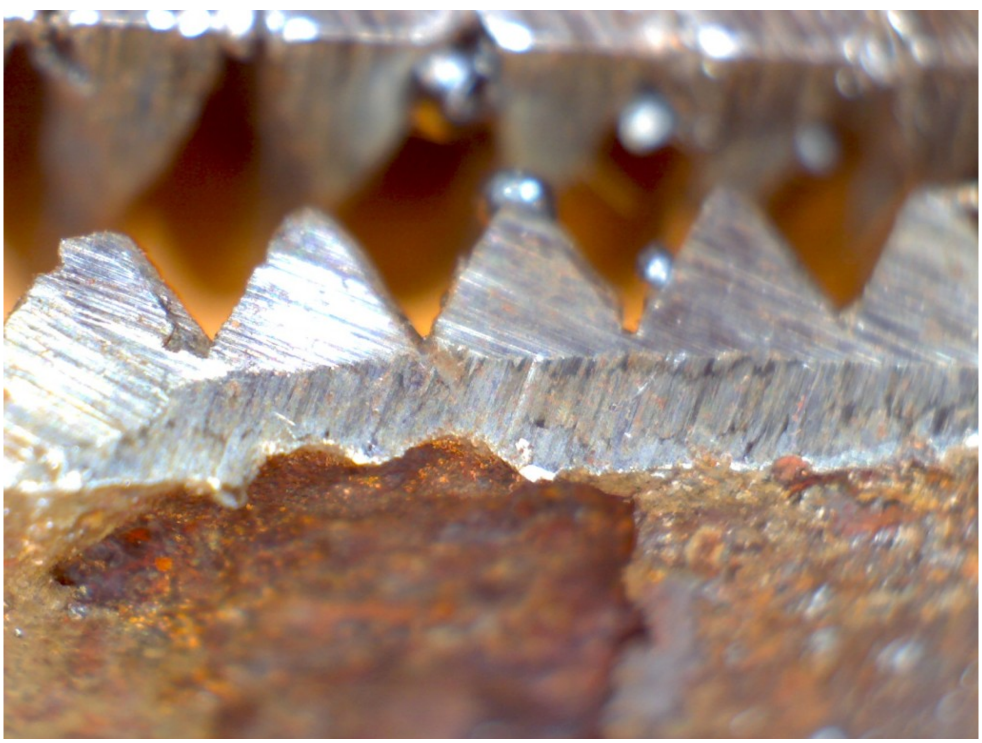


Figure 6b and Figure 6c: *Threaded section demonstrating active corrosion near thread root. Less than 1 mm of material remains.*

Baseline Serviceability:

Valves are useful for isolating segments of the potable water system so that repairs to the plumbing or upgrades to fixtures (and appliances) can be performed without disruption to other residential units. Further, in the event of a leak, small sections of the system can be isolated for repair and mitigation. In the event that a valve fails to open or close, the next larger valves in the system must then be used to isolate the line.

This not only impacts more residents, it also subjects the larger valve to possible failure - larger valves are generally exercised less often and may be more likely to get stuck especially after many decades without use. This makes the whole system less serviceable until eventually, frequent and full-building shut downs may need to be performed to fix minor system problems.

Figure 7a: *This valve failed at Unit 1D. The valve was used to isolate the unit even though the whole building was shut down. This was done because the mechanical contractors wanted to open the line pressure gradually upon re-energizing the water system ahead of the repair.*

Figure 7b: *Only a nub remains. Blue dust is typical of active corrosion in brass. Notable pitting at flange is remnant. This valve was lost long before the mechanic tried to return the system to service. This condition is more likely than not to exist elsewhere in the system.*

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Conclusion

This piping condition assessment is to be used for assessment only. However, the sampling was performed in such a way that analysis could be followed on, if needed. The stratified sampling technique was deployed in conjunction with high definition micro imagery and would allow metallurgists to calculate a probable failure date from this report. However, it is recommended that remediation and system improvement analysis would yield more meaningful results for the community.

This assessment establishes a baseline condition of 1/20 inch (.05 inches or about 1 mm) of remaining material in critical sections of the system. This assessment establishes three likely failure modes that may arise from the baseline condition. These include;

1. Failure by corrosion (pitting leaks / thread failure)

2. Failure by non-serviceability (due to persistent valve failure)

3. failure by water quality degradation (rust in pipes, clogging, elevated metals)

The potable water system at this structure is currently stable, but fragile. Failures by any of the identified modes may be experienced in the relatively near future and it is recommended that remediation is concluded within the next 5 years [6]. Remediation technologies under consideration include pipe liner, copper repipe, and flexible materials such as PEX. It is apparent from this assessment that some technologies may be better suited for different sections of the system taking into consideration cost vs performance. Repair and improvement analysis should be pursued in earnest to discover the most efficient strategy to restoring high reliability and water quality to the HOA Community.

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References:

[1] On-line Piping Diagrams

[2] EPA Water Quality Standards

[3] City Water Quality Report 2012:

[4] Freemont Analytical, LLC water quality report.

[5]. Environmental Protection Agency Report on the Analysis of Corrosion in potable water systems 1982

[6]. "It is recommended that complete remediation is concluded within the next 5 years." Ref: David Coles PE, is an estimate based on extensive professional engineering in piping systems and is not meant to be a predictive analysis of first failure date or an indication of the magnitude of failure.

[7] Wikipedia is an excellent and reputable source for simple answers to complicated technical/engineering subjects. The following string is provided to the reader as a primer in basic pipe corrosion issues.

Galvanized Pipe:

The zinc serves as a sacrificial anode, so that it cathodically protects exposed steel. This means that even if the coating is scratched or abraded, the exposed steel will still be protected from corrosion by the remaining zinc - an advantage absent from paint, enamel, powder coating and other methods.

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