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A Forensic Engineering Approach to Documenting and Analyzing Domestic Plumbing Failures

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Abstract

Forensic engineering analysis of residential plumbing components can be a daunting task, particularly due to the manner in which they may be handled from the onset of a failure event. Usually, a water loss is discovered by a homeowner or tenant of a building where the source of the leak is easily determined. Remediation of a plumbing loss is likely to begin quickly and often compromises the investigation (i.e., the condition of the failed component changes, connections to the plumbing system are removed, etc.). Under most circumstances, the evidence is handled and collected by people without forensic training, such as the occupant or plumber, making spoliation a significant concern. This paper will discuss the scientific processes and evidence handling techniques utilized by forensic engineers to determine whether a product defect, installation defect, environmental condition, maintenance, or wear and tear were contributory factors to a plumbing loss.

Keywords

Plumbing, product failure, causation, spoliation, nondestructive, destructive, pressure testing, evidence collection, leaking, regulations, subrogation, product defect, design defect, installation, environment, corrosion, dezincification, freezing, insulation, piping, support, mechanical damage, chain of custody, forensic engineering

Introduction

The smallest of plumbing components can cause large monetary claims by damaging properties, displacing occupants, and causing loss of income. Plumbing losses are often the result of a defect in manufacturing or installation in which an insurance company could make a claim against the manufacturer or installer of the failed plumbing component, a process known as subrogation. Additionally, the cause of some losses may be attributed to the product's environment, maintenance, or wear-and-tear — factors that could potentially change what entity has liability for the plumbing loss. Therefore, it becomes important early on in an investigation to evaluate and consider all relevant factors of a plumbing loss to determine why a plumbing component failed and who is ultimately responsible for the loss.

Documentation of Evidence

Unlike most forensic investigations, remediation of plumbing-related losses is almost always immediate with a significant potential for the scene to be altered — and the evidence mishandled by the occupants, claim responders, or restoration companies. The origin of the plumbing failure will be obvious to initial responders to the property, and the failed product will likely be handled or manipulated in an effort to stop water leakage or even removed to restore the integrity of the plumbing system, potentially changing the state of the failed product. The people most likely to unintentionally change or alter evidence once the plumbing failure is discovered include, but are not limited to:

- Occupants of the property.
- Property maintenance personnel.
- Insurance representatives.
- Plumbers.
- Remediation and restoration personnel.

Once the insurance claim process begins, the individuals best suited for controlling the evidence and documenting the loss should be considered. Under ideal

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circumstances, all parties interested in investigating and evaluating the cause of the loss should be contacted and put on notice before removing or altering plumbing components. Such parties can include insurance representatives (insurance adjuster, forensic engineer) as well as the installer and manufacturer of the failed plumbing component. Each involved party is expected to have a slightly different protocol/agenda when it comes to collecting evidence from the property for his or her representative's benefit.

Many times, relevant parties are not available to attend the inspection and collection of evidence. However, such parties may request that certain protocols are followed in an effort to preserve evidence. Professionals that would be expected to be qualified for preserving evidence and documenting the scene include, but are not limited to:

- Trained investigators or forensic engineers on behalf of the insured(s) or their insurance carrier(s).
- Trained investigators or forensic engineers on behalf of the original installer and manufacturer.
- Representatives from the manufacturer and/or distributor.

In most plumbing failure cases, it is expected that the scene documentation and evidence handling will not be initially conducted by trained and experienced professionals as recommended above. Therefore, it is necessary to research the background and establish important facts regarding the loss. A few key questions that help in establishing the basis of an initial investigation are:

- Who installed the failed part and when?
- Was the plumbing system recently modified?
- Was there adequate heat maintained to the property?
- Was the property water pressure regulated?
- What was the water pressure at the loss location and at the time of the loss?
- Were there any environmental issues such as the presence of corrosive chemicals or lack of insulation in the area of the failed part?
- When was the loss discovered, and when was the last time the plumbing component was observed without a failure prior to the loss?

The investigator should not take shortcuts to the origin and cause of the loss. The origin of the plumbing loss should be examined from the outside of the property in, documenting all pertinent information that could be a factor to the loss while working toward the origin of the loss. Following is a list of factors that should be in the investigator's mind when assessing the cause of a plumbing loss:

1) *Occupied*: It is not uncommon for plumbing failures to occur while a property is unoccupied. While the lack of occupancy may not be a direct causal factor, it can often explain the extent of damages sustained to a property following a loss, as well as potentially explain environmental factors that could be attributed to a loss. For example, if a property is unoccupied for an extended period, several factors can lead to a situation that could cause freeze failures.

A common occurrence with unoccupied properties is the failure to maintain heat during freezing weather conditions. Freeze failures would be expected to occur because the occupant failed to set the thermostat properly or because the property's source of fuel/electricity that allows the furnace/heat registers to function properly has been compromised. In addition, stagnant and empty refrigerators have been known to freeze internally mounted filter canisters during extended periods where they are not in use. Therefore, knowledge of the property's occupancy should be established and considered during a plumbing investigation.

2) *Weather*: When evaluating plumbing failures, it is important to investigate the weather conditions preceding a loss for an extended period. Plumbing system losses due to freezing often coincide with a large drop in temperature recorded at nearby weather stations. **Figure 1** demonstrates the weather data for a loss that occurred on December 10, 2012 (red dot). Here it was noted that the loss occurred on a date with -3°F weather conditions.

When outside temperatures drop significantly, any flaw in the property's ability to maintain heat can cause freezing or over pressurization of the plumbing system. When this occurs, the weak link in the plumbing system is often the first to decouple or fracture due to excessive stress. In some circumstances, freeze failures will not be discovered until ambient temperatures have returned to

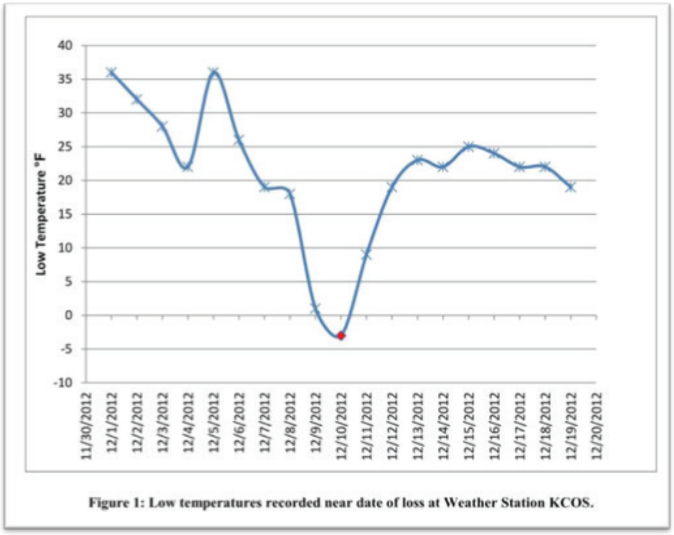

Figure 1
Freezing weather conditions corresponding to reported date of loss.

above freezing — and thawing of the plumbing components has occurred, allowing water to leak out and the plumbing failure to be discovered.

Upon first discovery of a failed plumbing component, it may appear that it failed due to a defect in the product or its installation; however, the weather conditions that were present close to the date of loss need to be evaluated in order to understand whether environmental conditions may have contributed to the loss due to freezing and over pressurization of the system.

When water freezes (changes its physical state from liquid to solid ice), it expands in volume by approximately 9%, according to the International Association for the Properties of Water and Steam. Therefore, any closed plumbing system that experiences freezing conditions will see significant increases in water pressure due to volumetric expansion created by the ice formation. The expansion of water to ice can rupture a plumbing component simply due to the change in volume increasing water pressure. A classic example of over-pressurization and failure due to excessive hoop stress is the copper pipe as shown in **Figure 2**. (Note: Hoop stress is the stress exerted circumferentially to the pipe cross section due to internal pressurization.)

3) *Water Main (domestic or well)*: Plumbing components are typically part of a plumbing system that begins at the water main. Therefore, the source of the water supply should be evaluated if it is suspected that any external factors may have contributed to a failed plumbing component. Interviewing the insured and neighboring properties can help to establish if any variance to the water pressure was observed prior to the loss event. If the building water supply lacks a water pressure reducing valve (WPRV), or other pressure regulation device, simple testing using a portable water pressure test gauge may be conducted to directly determine if the supply pressure is within the operating limits of the failed plumbing component.

4) *Water Pressure Reducing Valve*: The first plumbing component off the water main and into the property is typically a WPRV. The presence of a WPRV is an indication that the plumbing system is within a municipality providing water pressure above 80 pounds per square inch gauge (psig). A WPRV is typically required by the Authority Having Jurisdiction (AHJ) when the watermain pressure exceeds 80 psig, as it cannot be ruled out that elevated pressure will have damaging effects to plumbing system.

When investigating a property with a WPRV installed, the inlet and outlet pressures of the WPRV should be checked to ensure it is regulating the water supply pressure. In addition, when conducting pressure testing, the residence should be allowed to "dwell" for a period of time to determine if the WPRV allows the residence's pressure to slowly rise. A test that results in an immediate pressure reading of 60 psig may show pressures exceeding 80 psig after a sufficient amount of time has elapsed. In some instance, the property's WPRV may not be adjusted properly or possibly defeated by over-tightening of the adjustment screw on the WPRV. If the WPRV is malfunctioning, disassembly and examination of the valve's internal components for damage, wear, and contamination should be performed.

5) *Expansion Tanks*: Thermal expansion tanks are required in systems having a check valve or backflow preventor to regulate thermal expansion. Expansion tanks are equipped with a pressurized air bladder that allows room for thermal expansion of the water within the plumbing

Figure 2
Failed copper pipe "fish mouth."

system and prevents the water pressure from increasing when the water is heated. These devices are becoming more common as AHJs adopt more recent versions of the Uniform Plumbing Code[1]. Thermal expansion tanks are typically mounted on the cold (inlet) side of boilers and water heaters If a thermal expansion tank bladder loses its air pre-charge, the tank may become water solid and cease to perform its function of protecting against thermal expansion. This allows the water pressure in the residence to spike when heated, and could cause the weak link in the plumbing system to decouple or fracture due to excessive stress.

6) *Exterior Construction (thermal barrier)*: The exterior of the property should be checked for integrity, especially if freezing is suspected as a potential cause of the loss. A thermal imaging camera or infrared thermometer can aid in finding deficiencies in property insulation and/or construction and will also help identify structures that are affected by moisture from the water loss. Often when failed plumbing components are contained within walls and not readily visible, a thermal imaging camera can pinpoint the origin of the outdoor air infiltration intrusion while identifying the cause of the water loss.

7) *Identifying and Documenting the Origin of the Water Loss*: As mentioned above, the origin of the plumbing failure in many cases will be obvious to the initial responder(s), as leaking/spraying water is often easy to detect and trace to the failed component of the plumbing system. If you are not the initial responder (and the origin of the failed plumbing components has not been determined), the system can be cycled back on for detection of the water leak (with proper authorization). As an alternative, pressurized air can be substituted into the plumbing system for leak detection as a method to minimize additional water loss to the property. Once the origin of the water loss has been determined, many factors should be considered to fully document the operating environment of the failed component, such as:

- Documentation of the installation to ensure that it meets the AHJ's code requirements. Code compliance will depend on the adopted code that was in place at the time of the installation.

- Documentation of the service environment for factors that could be causal to the loss. Nearby stored chemicals and harsh working environments can accelerate the failure of many plumbing components.

8) *Preservation of Evidence*: Every effort should be taken to minimize alteration of the evidence. If undocumented evidence is altered, the integrity of the investigation is compromised. For example, a residence's WPRV is to be removed because of concern about over pressurization of a plumbing system, ensuring the position of the adjustment screw as unaltered is critical. Therefore, photographs, measurements, and indexing the head of the adjustment screw with a marker would ensure that the evidence has not been altered from its original position. Guidance for preservation of evidence is provided in many industry guides and standards. Below is a partial list of references that offers guidance on the collection and preservation of evidence:

a. National Fire Protection Association (NFPA) 921, "A Guide to Fire and Explosion Investigations[2]."

b. American Society for Testing and Materials (ASTM) E 1492, "Receiving, Documenting, Storing, and Retrieving Evidence in a Forensic Science Laboratory[3]."

c. ASTM E 860 "Standard Practice for Examining and Preparing Items That Are or May Become Involved in Criminal or Civil Litigation[4]."

d. ASTM E 1188, "Collection and Preservation of Information and Physical Items by a Technical Investigator[5]."

e. ASTM E 1459, "Standard Guide for Physical Evidence Labeling[6]."

Sometimes, it is not possible to maintain the site or preserve evidence as it may become inherently altered through the actions of collecting it. Therefore, it is important to put all potential liable parties on notice and obtain an agreement among parties on a protocol for evidence collection.

An investigator faced with this situation must use thorough and careful documentation of the configuration, position, and installation condition of the evidence to allow for accurate reconstruction and testing at an external facility. Methods can be implemented to document the as-found condition for use in later reconstruction. One example would be the use of "witness marks." For example, a paint pen or other marking device may be used to document cut locations on piping or to document thread engagement on a threaded connection. Tape measures, rulers, and other measuring devices may also be used in photographs and/or video to document conditions such as thread engagement, spacing between components, gaps, component sizes, handle positions, etc.

Thoughtful collection of the evidence is also a key factor. If the evidence is to be later tested, consideration must be given to the requirements of the testing. Often, evidence is collected in a manner that provides insufficient material to connect exemplar components for testing. In this case, the engineer or technician performing the testing may be unable to test the component or may face spoliation concerns as a result of further alteration to adapt the component to the testing environment.

A common example is pipe length — when a component is removed from a plumbing system, enough pipe must be available on either side of the subject component and adjacent fittings (approximately 4 to 6 in.) to allow joining of the evidence to the test environment without disturbing the existing connections that may be related to the loss. ASTM E1492: "Receiving, Documenting, Storing and Retrieving Evidence in a Forensic Science Laboratory" provides valuable guidance for preservation and collection of evidence.

Testing

It is common to test plumbing components to determine specific information related to the mode of failure. Testing the component can be done in the field or in a lab environment and may help to determine where a leak is occurring and at what volume for a given water pressure. Testing can also assist in determining whether the mode of the failure was related to a product defect, installation defect, environmental condition, maintenance, or wear and tear. Testing falls into two main categories: non-destructive and destructive.

1. *Non-Destructive Testing*: When a component suspected of causing a plumbing loss is collected, the immediate cause of the component failure may not be obvious. Non-destructive testing is conducted to help identify the point of failure and assist in determining the mode of failure. Investigators must be careful to maintain non-destructive practices during their work.

ASTM E 860-07, "Standard Practice for Examining and Preparing Items That Are or May Become Involved In Criminal or Civil Litigation" established guidelines for examination and testing of items that "are or may be reasonably expected to be the subject of civil or criminal litigation." As discussed in the standard, the individual conducting the examination should document "the nature, state, and condition of the evidence by descriptive, photographic, or other suitable methods…" This work may utilize methods that do not require physical manipulation of the evidence, such as taking notes, drawing diagrams, taking photographs, etc. With tablet computers becoming increasingly common, it is often possible to take photographs and annotate them directly during the initial inspection.

If destructive testing, which is discussed in the subsequent section, were to take place without the appropriate parties being notified and having a chance to witness said testing, spoliation of the evidence may be considered to have taken place — and the investigation may be compromised. As defined in ASTM E 860, spoliation of evidence is "the loss, destruction, or material alteration of an object or document that is evidence or potential evidence in a legal proceeding by one who has the responsibility for its preservation. Spoliation of evidence may occur when the movement, change, or destruction of evidence or alteration of the scene significantly impairs the opportunity of other interested parties to obtain the same evidentiary value from the evidence as did any prior investigator."

2. *Destructive Testing*: Non-destructive examination and testing of evidence may result in undetermined conclusions as to the cause of the plumbing failure. If the cause of the failure cannot be determined through non-destructive means, it may be necessary to progress to destructive testing. As discussed in ASTM E 860, if destructive testing is determined to be necessary, the investigator should notify the client, recommend the client of notification of other interested parties, and recommend to the client that other interested parties be given the opportunity to participate in the testing.

When conducting destructive examination, a written protocol should be established beforehand that clearly lays out the steps to be performed and how they are to be performed. A clear, detailed protocol removes ambiguity and provides all interested parties with a clear understanding of what to expect at the time of the examination.

The protocol should include all steps anticipated to be conducted, including photographing of the evidence and chain of custody forms, dimensional measurements, functional testing such as pressurization (and what pressures will be used), etc. The protocol should be circulated to all interested parties in advance of the testing to allow for careful consideration and potential alteration of the protocol (if mutually agreed upon). During destructive testing, deviation from the proposed protocol may be necessary, depending on the progression of the testing.

If deviation from the protocol is identified, all parties should be involved in discussing and documenting the change in protocol. All dissenting opinions — and the reason for the dissention — should be documented and given careful consideration. It may be necessary to cease the destructive examination and reconvene at a later date for continuation if a deviation or alteration is not agreed upon or if additional equipment is determined to be necessary. Additionally, the destructive exam may be ceased if it is determined that another potentially interested party, such as a subcomponent part manufacturer, is identified during the initial examination. Exclusion of an involved party is likely to raise spoliation issues during a destructive examination if the involved parties are not allowed the opportunity to participate in the exam.

Engineering Analysis

Once the investigation is complete and all testing and examination has reached its conclusion, it is time to determine the cause of the loss as it relates to the product failure. It is important to remember that just because the “why” of the product failure has been determined, the “who” may not be determined. It is not enough to determine the physical reason for the failure; the investigator must also determine what actions (or lack of actions) led to the failure. The causes of a product failure may be attributed to:

1. *Product Defect*: A plumbing component may be defective in many ways but can generally be categorized as either a “design defect” or “manufacturing defect.”

a. A design defect is a defect within the design of the component that resulted in the product failure. For example, dezincification is a well-known and well-understood phenomenon where a brass plumbing component with high-zinc content may fail due to the zinc being preferentially leached from the brass. The leaching of the zinc results in voids and brittleness where the zinc is now absent. If the design of the component was to use high-zinc brass alloy, the product defect would be attributable to a design defect because it is well known that high-zinc brass alloys may undergo dezincification. Plumbing components manufactured in large quantities with a “design defect” should experience systemic failures with multiple instances of failure occurring throughout the product’s distribution.

In some cases, the design defect may be related to lack of critical warnings that would help prevent misuse or improper installation of a product. Toilet supply lines with polymer ballcock nuts are an example of a product design that evolved over the years from having no warnings, to having a “Hand Tight Only” warning imprinted on the face of the nut as shown in **Figure 3**. Due to the low strength of the polymer nut, over-tightening can cause the ballcock nut to fail over time at the last thread root. Even with the warning “Hand Tighten Only,” it is not uncommon to see tool markings on the exterior of the polymer nut, indicating an improper installation (i.e., an “installation defect” discussed later) where the nut was potentially overtightened. Witness marks indicating that a tool was used on the polymer ballcock nut is also shown in **Figure 3**.

b. A manufacturing defect is simply an imperfection within the component that was the result of the manufacturing process. For example, if the design of the brass product discussed above specified a low-zinc brass alloy but high-zinc alloy was utilized during manufacturing, then the product defect is considered to be a “manufacturing defect” because the part was not manufactured to its design specification.

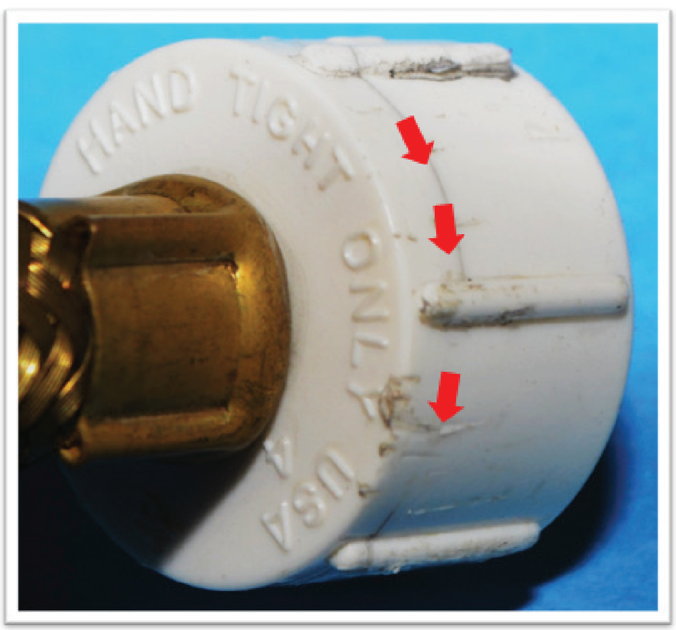

Figure 3
Failed ballcock nut. Warning: “Hand Tight Only.”

2. *Installation Defect*: Installation defects are common and relatively self-explanatory. An installation defect is a defect in the installation of the component that directly leads to the loss. For example, toilet supply lines often use polymer ballcock nuts that explicitly state that they are to be hand-tightened only and to not utilize tools as a tool may overtighten the fitting. If the fitting is overtightened, initiation cracks may develop that will be affected by creep stress during service and ultimately result in rupture of the ballcock fitting. Tool marks on the ballcock nut may be a good indicator that the nut was tightened more than "hand-tight." If it can be determined that a tool was used, it may support fractography of the fracture surface to investigate the cause of the loss as an installation defect resulting from the installer's failure to follow the manufacturer's published requirements.

3. *Environmental Conditions*: Component failures due to environmental considerations are often referred to as "an act of nature" or "an act of God." An example of a failure due to environmental conditions may be corrosion of a steel or iron fitting due to proximity to the ocean and salt-laden air. However, the investigator must not be too quick to deem a product failure "an act of nature."

If it is foreseeable that component may be used in the subject environment and that component failed because of said environment, then the component failure may be attributed to a "design defect" as previously discussed. For example, polybutylene tubing was the subject of a class-action lawsuit that resulted in the stoppage of all production of polybutylene piping in 1995. Polybutylene was used in many residences in lieu of copper; however, polybutylene became embrittled due to common water treatment chemicals, such as chlorine. Due to the embrittlement, polybutylene began to fracture and resulted in many water losses throughout the country. The failure of polybutylene was considered a design defect because polybutylene was susceptible to chemicals that were known to be present in the environment for which it was intended.

4. *Lack of Maintenance*: Lack of maintenance, or lack of care, indicates the product failed due to the absence of expected and/or routine action. Similar to environmental conditions, an investigator must not be too quick to deem a product failure "an act of nature" or "long-term wear-and-tear" if the loss was due to a lack of expected maintenance activities. A common example of lack of maintenance is water heater failure due to a consumed or depleted anode rod. Anode rods are installed in traditional tank water heaters to provide corrosion protection. The anode rod is typically made of zinc and is preferentially degraded by residential water chemistries. Once an anode rod is depleted, corrosion of the water heater itself may progress at an accelerated rate. Because of this, water heater manufacturers provide maintenance instructions on inspection and replacement of the anode rod.

5. *Long-Term Wear-and-Tear*: Sometimes, a component fails because it has reached the end of its designed useful life. In this situation, the component that failed is considered to not have any defects, did not fail due to environmental conditions, and did not fail due to a lack of maintenance. For example, boilers have a finite life expectancy, even when routinely maintained and kept in good working order. The American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE)[7] lists the average life expectancy of an electric boiler as 15 years. A water loss that takes place with an electric boiler that is 25 years old may have failed as a result of degradation of non-replaceable or non-maintainable components that are beyond their published service life.

Conclusions

The forensic investigation of plumbing failure events involves more than just a visual examination and testing of a failed component. The investigation should go beyond a simplistic analysis and consider the system in which the failed component was installed, the environmental factors that may have affected the failure mode, as well as consideration for the age and maintenance provided to the failed plumbing component.

Failure to perform a complete and thorough analysis will ultimately hinder or prevent a determination of the proper root cause of the loss. Furthermore, the lack of a complete and thorough analysis serves to make this analysis vulnerable to arguments that the appropriate burden of proof has not been properly established. Once all factors of a plumbing failure have been carefully reviewed and analyzed, the forensic investigator should develop appropriate testing protocols based upon scientific principles to properly analyze the subject plumbing component(s) and to arrive at determining the root cause of the loss.

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