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Forensic Engineering Investigation of PVC Piping Failure in a Multistory Condominium Building

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Abstract

Polyvinyl chloride (PVC) piping systems in larger commercial buildings are subjected to greater stresses due to normal building movement when segment length, diameter, and schedule are increased in comparison to smaller residential installations. The likelihood for increased stresses in these system installations must be recognized and accommodated for in the initial piping system design. Performance aspects, such as thermal expansion and building settling, must be considered as well as piping configurations and hanger support placement. This paper addresses the investigation methodology used to identify the causes of chronic building construction defects that resulted in water and mold damage to a recently renovated multistory condominium building.

Keywords

Plumbing, piping thermal expansion, PVC, hanger, framing, shrinkage

Background

The property discussed is a four-story wood frame condominium building containing 30 luxury residences of approximately 1,600 to 2,200 square feet. Construction of the building (**Figure 1**) began in 2005 and was completed in the summer of 2008. The property was occupied continuously since that time. The building site was a former marble/granite quarry site with minimal soils in need of removal with the initial construction on a solid granite base. The building was also built on property with a downward slope at the back of the building, resulting in a partial below-grade driveway and parking garage with the building's foundation on top of and fastened to bedrock.

Figure 1
Property as seen.

Above the partially below grade-level parking garage were four floors of wood frame construction as well as a wood-framed roof truss system. Since the building was in northern New England, it was outfitted with a metal roof, which is popular in areas of heavy snow accumulations. The 18,000-square-foot building was configured with two main buildings abutting each other, with a footprint of approximately 9,000 square feet each.

Leaks, Mold, and Suspected Causes

In the fall/winter of 2013-2014, seven years after construction was completed, four pairs of horizontally adjacent and vertically aligned (see **Figure 2**) condominium units were found to be damaged by long-term exposure to moisture and subsequent mold growth.

As seen in **Figure 3**, water leakage was initially thought to be caused by a leaking roof boot seal around vent piping, due to the manner in which the boot was damaged. The boot was damaged in a manner consistent with heavy snow load deflecting the roof sheathing and distorting the rubber seal and aluminum flange. It was later determined that this was not possible, however, due to the steel roof construction and strength of the roof truss system. Another explanation was sought.

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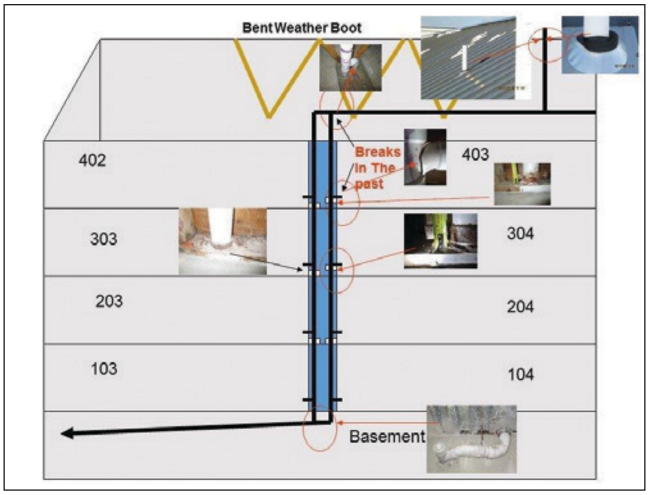

Figure 2
Diagram of building piping system.

Figure 3
Damaged roof vent boot.

Figure 4
Vent piping entering attic space.

Below the attic, as seen in **Figure 4**, the two piping waste stacks serving both buildings passed vertically through a common wall between both building units and intersected in the attic space.

Origin of Water Leakage Identified

After the initially suspected origin of leakage from the roof boot seal of the vent piping was discounted, further investigation identified that water was found in a common piping chase way behind the abutting condominium units' kitchen cabinets. At the time of the author's involvement in this investigation, four of the condominium units were sealed off and undergoing restoration for water and mold damage (**Figure 5**).

Piping Fastening System Description

The waste stack vent piping system functioned as a discharge system for sewage, gray and wastewater; it also vented through the attic and roof. The system piping was configured within the building to extend vertically from the basement/garage level sewage connection to the roof vent through a commonly shared chase way as seen in **Figure 5**. The system was supported at each floor penetration with standard riser clamps within the common piping chase way space (**Figure 6**). No provision for expansion or contraction was incorporated into the design or construction of the system — by either the engineer who designed the system or the mechanical contractors who built it.

Figure 5
Kitchen walls removed, exposing piping.

Kitchen wastewater was connected to the 4-inch main drain waste line by way of horizontal 2-inch PVC piping sections that passed through (and were restrained within) holes in framing members, significantly limiting vertical movement. (**Figure 7**).

Examination of Existing Piping and Repair History

During the investigation, it was revealed that in previous years broken piping fittings were found in the 2-inch piping connection between the stack riser and each unit's kitchen sink drain. The plumbing contractor, who was reportedly the same contractor who installed the system, repaired the damaged fittings and pipe. Further inquiry by forensic engineering investigators found that these reported pipe damages were in three additional condominium units, and a recent pipe break in another unit was found during mold remediation by contractors.

Figure 6
Vent stack pipe resting on riser clamp.

Figure 7
Horizontal piping restrained within framing.

Figure 8
Provided photo of cracked "tee" fitting at riser.

Although photograph documentation was not provided from the earlier pipe breaks from past years, the most recent event's damaged fitting was photographed by the condominium management staff and provided to investigators (**Figure 8**).

As a result of the past repairs to the three units' fractured piping, the manner in which that piping had originally been installed could not be documented.

Although past piping repairs had already been performed, examination of the piping chase way and vent stack piping revealed that the piping was not resting on the riser clamps designed to secure a pipe against vertical downward movement and that the riser clamps were actually suspended off of the sill plates (**Figure 9**).

Figure 9
Riser clamp suspended above sill plate due to framing settling and pipe expansion on third floor of building.

The installation method of this piping being constrained (see **Figure 10**) without accommodation for expansion, contraction, or building movement — combined with reports of where past plumbing repairs were located (and how they failed) — led to the author's opinion that a plumbing system design defect was the cause of the piping failures and building damage.

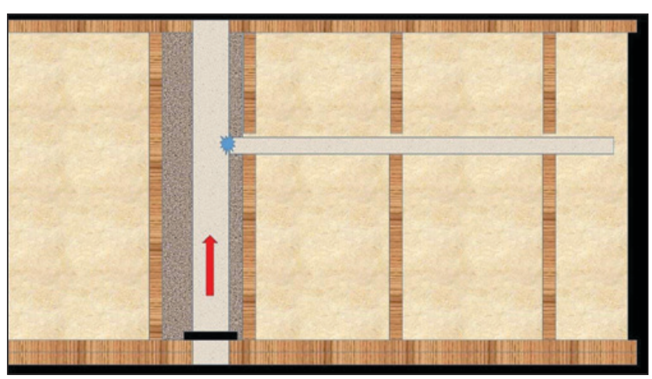

Figure 10
Diagram of piping connection to vent riser.

Conditions Leading to Pipe Failure

Thermal Expansion of PVC and Other Piping Materials

In comparison to other materials used in the manufacturing of piping, PVC (polyvinyl chloride), as well as other plastic piping materials, has a large thermal expansion coefficient, as referenced in the *Mechanical Engineers Reference Manual.*

MATERIAL	EXPANSION COEFFICIENT (10^{-6} in/in °F)
Aluminum	10
Carbon steel	6.5
Cast iron	5.9
Copper	9.3
Stainless steel	9.9
ABS acrylonitrile butadiene styrene	35.0
HDPE high density polyethylene	67.0
PE polyethylene	83.0
CPVC chlorinated polyvinyl chloride	44.0
PVC polyvinyl chloride	28.0

When the piping was initially installed, an estimated ambient temperature of 70 degrees Fahrenheit was assumed. It is possible that due to cooking, dishwasher heating, and hot water consumption activities, discharge temperatures into the waste piping could reach as high as 120 degrees Fahrenheit in accordance with the *International Plumbing Code.* Additionally, the piping in the attic during summer months would also be subjected to higher heat loads. Based upon this, the estimated thermal expansion of the piping is calculated as follows (ref *Mechanical Engineering Reference Manual*):

Dl = Lo α(T1-To)
Dl – Change in length
Lo – Original length
α – Coefficient of linear expansion PVC (.000028 *in/in °F*)
T1 – Final temperature degrees Fahrenheit (heat load applied)
To – Initial temperature degrees Fahrenheit (at installation)

The piping system has an estimated 70 cumulative feet from the main sewage line connection to the midpoint height within the attic space. With a ΔT of 50 degrees Fahrenheit, the expansion of the piping due to elevated temperature is calculated to be 1.18 inches.

Construction Framing Shrinkage

New lumber has higher moisture content than lumber that has been part of the building system over a period of time. As such, dimension reductions due to loss of moisture shrinkage should be expected. According to the American Society of Plumbing Engineers (ASPE) *Plumbing Engineering Design Handbook,* Volume 2:

Protection from Damage/Wood Shrinkage: *Provide slip joints and clearance for pipe when wood shrinks. Approximately ⅝ inch (16 millimeter) per floor is adequate for typical frame constructions, based on 0.4 percent shrinkage perpendicular to wood grain. Shrinkage along the grain usually does not exceed 0.2 percent.*

Based upon the ASPE guidelines regarding the amount of shrinkage of wood framing members, ⅝ of an inch per floor would equate to 2.5 inches of "settling" or shrinkage from the initial vertical height of the building.

Considering the movement of the piping off of the sill plate due to wood framing shrinking (2.5 inches) in addition to the vertical movement of the piping due to thermal expansion (1.18 inches), the total sum of these distances of 3.68 inches supports a conclusion that the vertical piping stack was not supported by the building framing and was not acting in unison with the building structure as one coordinated "system."

Piping Failure Analysis

Due to thermal expansion of the piping, as well as shrinkage of the four stories of the wood framing of this structure, the vertical riser vent stack was not being supported by the riser clamps fastened to the piping at the sill plate locations at each floor penetration. Wood framing shrinkage also added to the distance between the riser clamps and sill plates.

These conditions, in addition to the constraints on the horizontal kitchen waste lines, caused the weight of the estimated 200+ feet of vertical stack piping (and any internal liquid) to be imparted to these 2-inch horizontal pipes. As seen in **Figure 8**, this condition resulted in cracking of the "T" fittings connecting these 2-inch waste lines to the vertical 4-inch riser within the chase way due to excessive weight and stress overload.

Additionally, the base of the stack systems, which were supported by a steel Milford hanger, was also deflected in a downward direction due to this one pipe support securing a major portion of the weight of the piping system (**Figure 11**).

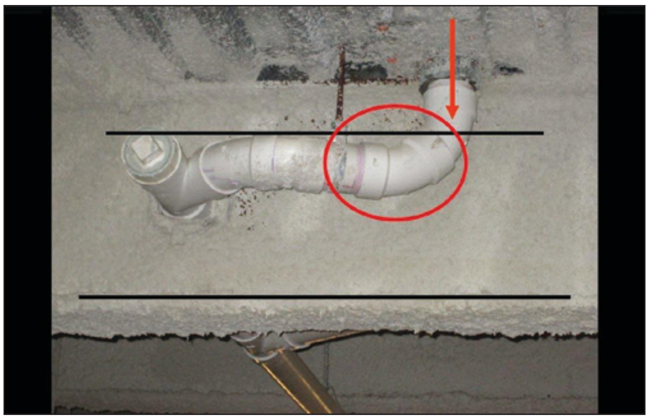

Figure 11
Basement vent stack out of plumb due to excessive weight.

Manufacturer and Code Direction

The following manufacturer and Code guidelines address piping design issues regarding thermal expansion, wood framing shrinkage (in relation to piping support), as well as the need for and installation of expansion joints.

American Society of Plumbing Engineers – *Plumbing Engineering Design Handbook* 2nd Edition Volume 4:

Expansion Joints: *It is recommended that expansion joints be located in an accessible space to allow maintenance or replacement. The guides allow axial movement…An expansion joint should be installed every 30 feet according to the manufacturer's recommendations.*

Drain, Waste and Vent Piping: *Expansion and contraction usually do not present a problem in DWV installations in one- and two-family dwellings due to the short lengths of piping involved. It does create problems in high-rise buildings where long stacks are installed.*

2003 *International Plumbing Code* Section 308.8 – Expansion Joint Fittings:

Expansion joint fittings shall be used only when necessary to provide for expansion and contraction of the pipes. Expansion joint fittings shall be of the typical material suitable for the use with the type of piping of which such fittings are installed.

The manufacturer's pipe design guide (2003 edition) states: "Engineers, designers and installers should use resources such as the *American Society of Plumbing Engineering Design Handbook.*" This design guide also states: "For vertical stacks in multistory applications compensation for expansion, contraction, or building settling is often accommodated by the use of offsets or expansion joints."

Conclusion

In smaller residential structures where pipe sizes and lengths are relatively small, the effects of pipe thermal expansion and building movement are not as severe. In comparison, care must be exercised by piping designers and installers to recognize the characteristics of piping material behavior and building structural movement in larger buildings. The effects of thermal expansion of PVC piping will be greater in the longer piping lengths used in larger commercial building construction and must be accommodated for. The same can be said for stresses imparted into piping in wood frame construction due to wood dimensional shrinkage caused by a loss of moisture over time.

Expansion joints and thermal expansion loops must be incorporated into the initial piping system design with care given as to the placement of these vital components — with forethought into issues such as the accessibility for maintenance and inspection. The configuration of piping must also be considered so as to avoid stresses caused by thermal expansion and building settling.

Engineers, architects, and contractors should communicate and not "operate in a vacuum," allowing issues that extend across engineering disciplines and manufacturers' recommendations to be addressed in the initial stages of the system design, long before construction begins or retroactive repairs and redesign modifications become necessary.

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