

The reemergence of our core cities as more active and vibrant communities brings pressure and challenges to those who design buildings and their systems. The density of buildings, traffic, the scarcity of land, and a competitive spirit among developers are all factors that work together to push modern buildings higher.

Sometimes, we envision high-rise buildings as towering skyscrapers. While this is the romantic and not always incorrect vision, a “high” rise can be as short as eight to 10 floor levels. The National Fire Protection Association (NFPA) defines a high-rise building as a building with an occupied floor that is 75 feet above the level where the firefighting apparatus would stage firefighting operations. That low threshold requires several specific features to be designed into buildings to promote life safety and allow for emergency responders to safely and quickly access the higher levels of the building, thereby saving lives and considerable invested resources. With that fairly simple definition, all high-rise design challenges should be the same, right? Perhaps some additional discussion is warranted before we make that determination!

PRESSURE PROBLEMS

High-rise design and construction present more than a few special challenges, especially regarding the design of plumbing systems. Some of the biggest challenges to high-rise plumbing design relate to controlling pressure. Pressure is both friend and foe in plumbing systems. Plumbing engineers learn early that as you lift water above a datum, you lose 1 pound per square inch for every 2.3 feet of elevation. While this may seem a reasonable incremental loss, it can be a significant penalty when the water is raised 75 feet; then, a requirement is added to maintain a high minimum pressure at the top of the column. Many designers answer this challenge daily.

It’s all the same, right?

For instance, a common condition in a water riser serving a toilet group in an office building supplied with flush valve fixtures requires 25 psi at the most remote fixture. You add a pressure boost system to meet that demand on the top floor. A common complication begins when you stack floors. The combined head pressure may cause the total pressure at the bottom to exceed the allowable safe level as limited by code and materials. This too is a fairly routine condition that often is solved by either placing pressure-reducing valves on each level where pressure exceeds the code maximum or branching from the higher pressure riser to make a pressure zone. This pressure zone uses a central pressure-reducing valve and sub-riser to meet the minimum pressure required at the highest level and the maximum pressure allowed at the lowest level. This particular method has been used successfully in many high-rise building designs.

Supplying adequate water pressure at all levels of the building is critical for building occupants, although economics, basic building functions, and overall heights have significant impact on methods of water supply distribution. Numerous intermediate-height and even very tall high-rise buildings use various pumping schemes. One early method used elevated storage tanks at the top of the building with fill pumps at the bottom of the building, a classic gravity downfeed arrangement. This method evolved into direct pumping systems using multiple pump packages with constant-speed, constant-pressure controls. Both of these methods proved to be reliable

HIGH-RISE PLUMBING DESIGN

by Dennis M. Connelly, CPD



Photo by David Ropinski

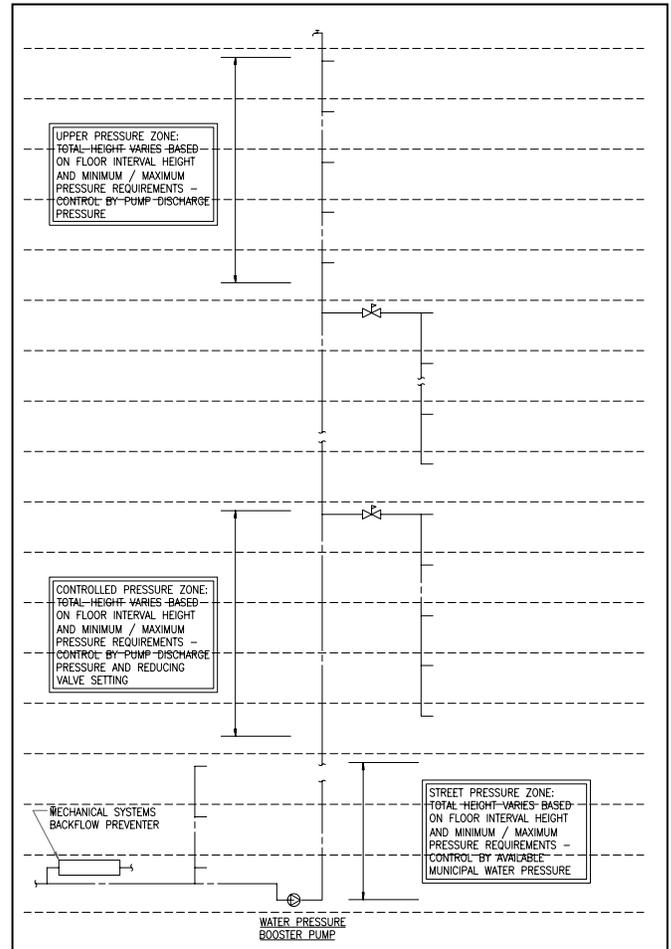
and affordable through the years, and many such designs are still active today or still are used in current design practices. Continuing improvements and development of variable-frequency electric drives and an ever-increasing emphasis on reducing energy consumption and costs make the variable-speed, direct-pumped package a modern workhorse of the industry.

The critical need to provide adequate flow and pressure gives the high-rise plumbing engineer ample opportunity to practice their craft. A thorough understanding of pumping basics is critical to start with, and one of the most widely recognized sources is the Fluid Handling Training and Education Department of ITT Industries, better known as Bell and Gossett's Little Red Schoolhouse. From this fundamental training, more advanced texts could include the *Pumps and Pumping Systems Handbook*, published by ASPE, as well as training brochures published by all reputable pump manufacturers and system packagers. Even the seasoned professional can benefit from occasional review of these texts to refresh some of the basics and rediscover some of the subtleties of pressure booster systems.

DRAINAGE

Pressure control on the drainage side presents other challenges. True, water is essentially the same in either system; however, drainage theory holds that considerable air travels downward with the water flow. This theory asserts that water flowing in a vertical pipe tends to adhere to the pipe's walls, acting very much like a sleeve of water with a hollow core of air, all sliding down the pipe's walls until it reaches a ratio of approximately 6/24 full of the pipe cross-sectional area. This watery sleeve travels at almost 15 feet per second (fps), propelled by gravity but restricted by friction. When the piping remains vertical, the entrained air is relatively simple to control, but when piping offsets from the vertical, the fluid flow velocity drops considerably, filling the entire pipe diameter. Horizontal, sloped drainage piping should flow in the 4-8 fps range, so it is easy to see that a large slug of water can quickly develop. This can lead to compressing air in the path of the fluid and/or lowering air pressure on the leaving side of the fluid flow. The impact of these fluid and air fluctuations can be controlled by effective use of yoke vents, relief vents, and vent connections at the bases of stacks. Here again, the solutions are largely not unique and have been used successfully on many intermediate-height and even extremely tall high-rise buildings. (For those who are just beginning in this type of plumbing design, a recommended reference is *High-rise Plumbing Design*, by Dr. Alfred Steele.)

A related concern is the impact of the hydraulic jump on the piping itself. The mass of water and the rapid change of velocity from vertical to horizontal cause this jump. While the pressure associated with this jump is significant, it does not destroy the fitting at the base of the stack. Rather, the movement of the pipe stresses the frictional forces that hold the joint to the pipe, leading to eventual coupling failure. Good design must compensate for the strong thrust that occurs at this change of direction. Successful methods include increasing the horizontal drain size and/or slope, using thrust blocks, or using restraining joints with threaded rod or similar arrangements that mechanically anchor the fitting to the entering and leaving piping.

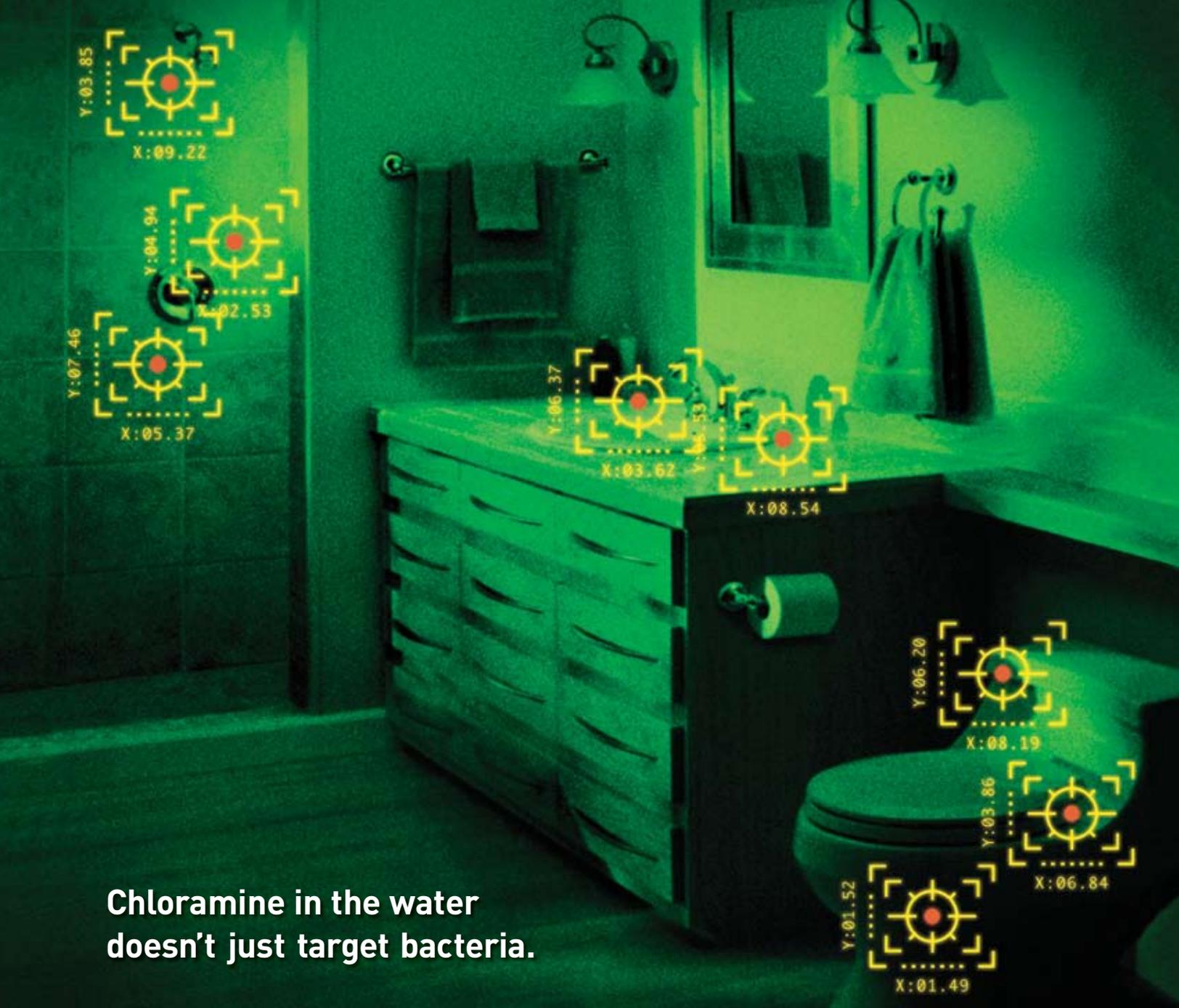


Common high-rise water supply schematic

VENTING

Once the water is raised and used, it is discharged to a drainage system that includes an attendant venting system, which is responsible for the flow of air in the drainage piping network. Air is critical to the drainage process because drainage flow is caused by sloping pipes, and the motive force is gravity. Absent air, the drainage would range from erratic to nonexistent. When the water in a pipe flows to a lower area, air must be added to replace the water, or a negative pressure zone will occur. If this zone is near a fixture, air will be drawn into the drainage system through the fixture trap with an easily identified gulping sound and very slow drain performance. This condition leads to poor performance throughout the drainage system and trap seal loss due to siphoning or blowout.

The remedy for this condition is venting. At the individual fixture level, this consists of a fixture vent. As the number of fixtures increases, venting needs do as well, and a venting system evolves, with branch, circuit, and loop vents at the appropriate locations. When dealing with high-rise drainage stacks, a vent stack should be attendant, allowing for pressure equalization and relief along the height and breadth of the system. Aside from relieving pressure in the drainage system, the vent system allows air to circulate in both directions in response to the fluctuating flow in the drainage system. In many high-rise vent designs, where stacks need to offset horizontally on a given floor, a relief vent is required. Although not often highlighted, the building venting system also serves to supplement the vent for the municipal sewer, relieving



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Ferrous Hydroxide
Ferrous Sulfate
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Formic Acid, up to 25%
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Glucose
Glycerine
Green Liquor
Hydrochloric Acid
Hydrochloric Acid, 36% (conc.)
Hydrofluoric Acid, 3%
Hydrofluosilicic Acid, 30%
Hydrogen Peroxide, 50%
Hydrogen Sulfide, Aqueous
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Ammonium Sulfate
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Cadmium Acetate
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Calcium Acetate
Calcium Bisulfide
Calcium Bisulfite
Calcium Carbonate
Calcium Chlorate
Calcium Chloride

Caustic Soda
Chloric Acid
Chlorinated water, (hypochlorite)
Chlorine, trace in air
Chlorine dioxide, aqueous, sat'd
Chlorine water, sat'd
Chromic Acid, 40% (conc.)
Chromium Nitrate
Citric Acid
Copper Acetate
Copper Carbonate
Copper Chloride
Copper Cyanide
Copper Fluoride
Copper Nitrate
Copper Sulfate
Corn Syrup
Cupric Fluoride

Lubricating Oil, ASTM 1, 2, 3	Potassium Bicarbonate	Silver Sulfate	Sodium Tripolyphosphate
Magnesium Carbonate	Potassium Bichromate	Soaps	Stannic Chloride
Magnesium Chloride	Potassium Bisulfate	Sodium Acetate	Stannous Chloride
Magnesium Citrate	Potassium Borate	Sodium Aluminate	Stannous Sulfate
Magnesium Fluoride	Potassium Bromate	Sodium Arsenate	Starch
Magnesium Hydroxide	Potassium Bromide	Sodium Benzoate	Stearic Acid
Magnesium Salts, inorganic	Potassium Carbonate	Sodium Bicarbonate	Strontium Chloride
Magnesium Nitrate	Potassium Chlorate	Sodium Bichromate	Sugar
Magnesium Oxide	Potassium Chloride	Sodium Bisulfate	Sulfamic Acid
Magnesium Sulfate	Potassium Chromate	Sodium Bisulfite	Sulfur
Maleic Acid, 50%	Potassium Cyanate	Sodium Borate	Sulfuric Acid, 98%
Manganese Sulfate	Potassium Cyanide	Sodium Bromide	Sulfuric Acid, 85%
Mercuric Chloride	Potassium Dichromate	Sodium Carbonate	Sulfuric Acid, 80%
Mercuric Cyanide	Potassium Ferricyanide	Sodium Chlorate	Sulfuric Acid, 50%
Mercuric Sulfate	Potassium Ferrocyanide	Sodium Chloride	Tannic Acid, 30%
Mercurous Nitrate	Potassium Fluoride	Sodium Chlorite	Tartaric Acid
Mercury	Potassium Hydroxide	Sodium Chromate	Tetrasodiumpyrophosphate
Methane Sulfonic Acid	Potassium Hypochlorite	Sodium Cyanide	Trisodium Phosphate
Methanol, up to 10%	Potassium Iodide	Sodium Dichromate	Urea
Mineral Oil	Potassium Nitrate	Sodium Ferricyanide	Urine
Motor Oil	Potassium Perborate	Sodium Ferrocyanide	Vinegar
Muriatic Acid	Potassium Perchlorate, sat'd	Sodium Fluoride	Water, Deionized
Nickel Acetate	Potassium Permanganate, sat'd	Sodium Formate	Water, Demineralized
Nickel Chloride	Potassium Persulfate, sat'd	Sodium Hydroxide	Water, Distilled
Nickel Nitrate	Potassium Phosphate	Sodium Hypobromite	Water, Salt
Nickel Sulfate	Potassium Sulfate	Sodium Hypochlorite	Water, Swimming Pool
Nitric Acid, up to 25%	Potassium Sulfide	Sodium Iodide	White Liquor
Nitric Acid, 25 - 35%	Potassium Sulfite	Sodium Metaphosphate	Zinc Acetate
Nitric Acid, 70%	Potassium Tripolyphosphate	Sodium Nitrate	Zinc Carbonate
Oxalic Acid, sat'd	Propanol, up to 0.5%	Sodium Nitrite	Zinc Chloride
Oxygen	Propionic Acid, up to 2%	Sodium Perborate	Zinc Nitrate
Ozonized Water	Propylene Glycol, up to 25%	Sodium Perchlorate	Zinc Sulfate
Paraffin	Sea Water	Sodium Phosphate	
Perchloric Acid, 10%	Silicic Acid	Sodium Silicate	
Phosphoric Acid	Silicone Oil	Sodium Sulfate	
Plating Solutions	Silver Chloride	Sodium Sulfide	
Potash	Silver Cyanide	Sodium Sulfite	
Potassium Acetate	Silver Nitrate	Sodium Thiosulfate	



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noxious or even hazardous gases and allowing the sewer to drain without pressure limitation.

VERTICAL PIPING

Plumbing engineers must consider the impact of plumbing systems on general construction practices. Most experienced engineers and contractors agree that vertical piping systems are generally more effective than horizontal piping systems in multilevel projects. Vertical piping uses fewer supports, hangers, and inserts and requires less horizontal space in ceiling plenums for sloping to achieve drainage.

Altogether, vertical piping is a pretty good bargain; however, it is not without penalty. The penalty of vertical piping is multiple penetrations through structural slabs. Each of these penetrations must be sealed or protected to prevent vertical migration of fire and smoke (i.e., turning the tall building into a tall chimney). Not only is the sealing of penetrations an issue, but the sheer number of penetrations also can be equally difficult. The location of these multiple penetrations is critical to the integrity of the structure and the function of the fixtures even more than the aesthetics of the built environment. Tall buildings require more robust structures, further limiting the allowable space for penetrations. Other structural practices, such as post-tensioned beams and slabs, which serve to lighten the overall building structure, can limit even further the available locations for slab penetrations.

One method that sometimes helps with pipe size can be to place “wet” columns at various locations on the floor plate. This sometimes reduces the main stack and supply riser sizes, can potentially minimize conflicts with the horizontal branch in ceiling plenums, and certainly can help make the plumbing system more accessible for subsequent tenant connections. Successful high-rise design requires the entire design team to take extra effort to read, understand, and interpret the impact of building systems on one another, as well as be open to discuss, coordinate, and adjust each individual system to suit the needs of the building. A well-executed high-rise design is an integrated and complex assembly, and each component should be treated as a part of that integrated whole.

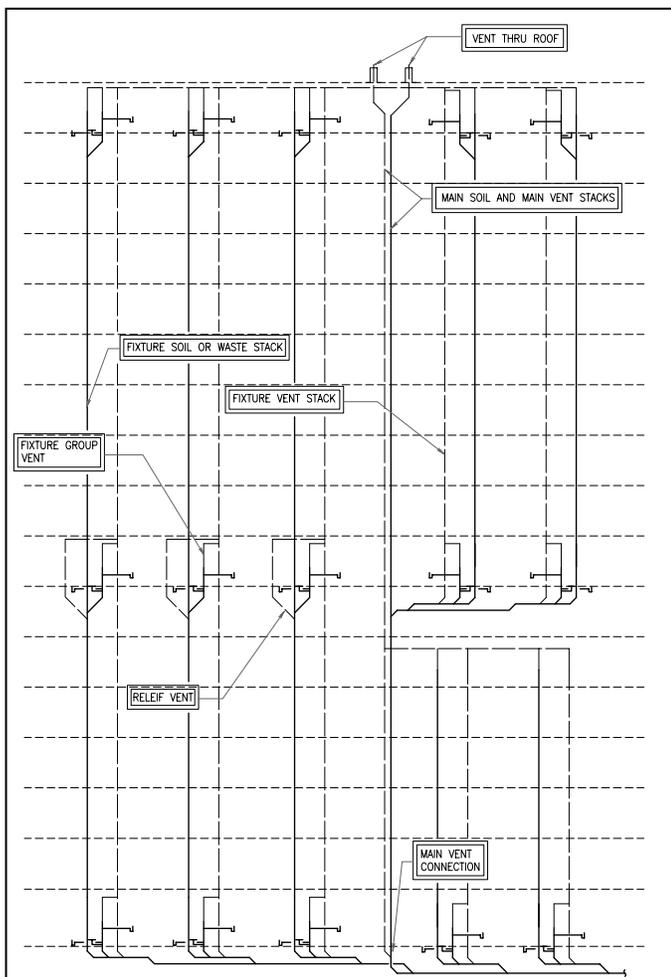
FIRE PROTECTION

One area that should not be overlooked in any high-rise design is the fire protection systems. As a minimum, all high-rise buildings should have sprinkler systems on each floor and standpipe systems in each stairwell. These systems have proven themselves throughout the years to significantly save both life and property. The specific type, coverage density, and outlet placement all vary based on the building type, height, and location and local fire authorities. All high-rise buildings containing fire protection systems have large, dedicated fire pumps to provide the flows and pressures required for the individual system. While not always tasked with these system designs, plumbing engineers need to know that these systems are an integral part of the building and must account for their presence regarding equipment space, riser locations, and ceiling cavities.

MATERIALS

For most high-rise designs, piping systems can be specified and installed using very standard piping and fittings. Sanitary and vent piping and storm water piping within these buildings are mostly hubless cast iron, selected primarily for availability and quiet operation. Underground sanitary and rainwater piping is hub and spigot cast iron with gasket joints. In some instances, particularly horizontal, large-diameter drainage piping below grade, the piping is ductile iron with mechanical-type joints. This type of piping system is used widely because of its suitability to flow and pressure, availability, and quiet operation, and because it is typically made of post-consumer product, so it is very “green” in application.

Water systems for high-rise buildings are typically Type L copper. Tubing sizes 2 inches and smaller are typically assembled using 95-5 solder; for larger diameter tubing, we usually leave the contractor the choice to braze or use mechanical joints with roll groove fittings. Medical gas distribution is typically Type L copper with brazed joints as outlined by NFPA. Except for extremely tall buildings, these materials generally give good service over a wide pressure range and are within maximum pressure limits by significant amounts. As buildings get taller, many water systems can exert pressures that exceed the safe working pressure of copper tubing. In some areas, stainless steel light wall pipe (Schedule 10) or standard pipe (Schedule 40) is a reasonable alternative to increase safe working pressures. Both of these materials can be joined using roll groove mechanical joints.



Common high-rise drain and vent schematic

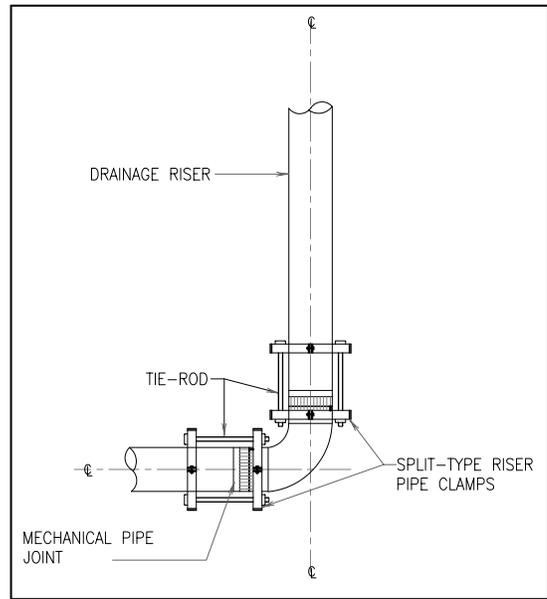
COMPLEX HIGH-RISE STRUCTURES

Moving from the very general discussion about basic concepts of design and system coordination, one must consider pressure piping in the water supply and distribution system, as well as general drainage and venting approaches. Finally, plumbing engineers must recognize the impact of plumbing installation on the building structure. All of these discussions apply, in various degrees, to any type of high-rise building: office, condominium, or hotel. These challenges multiply when plumbing engineers design buildings that are more complex because of function, such as hospitals. Typically, hospitals have a higher density of plumbing fixtures than most other types of buildings, leading to more penetrations to serve them.

Hospitals offer a challenge because they require so many more systems. Aside from the routine rainwater, sanitary drain and vent, and cold water systems, hospitals often have other special piping needs, such as laboratory waste, medical gases, or multiple water temperatures to serve patient care or cleaning and sanitizing purposes.

Many hospitals have laboratories, and some other types of institutional buildings may have drainage systems to serve chemical- or acid-using fixtures or equipment. Where this occurs, it is important to define acceptable piping materials, in both suitability to the medium being piped as well as acceptability to the local authority. High silicon iron, borosilicate glass, polypropylene, and PVDF are all commonly used. Different materials have different strengths and weaknesses. Iron and glass piping are almost universally suitable for use with most acids, bases, and similar chemicals. Both are heavy and require more space for installation, but they are not easily attacked by flame or generate heavy fumes and smoke. Simple penetration protection is adequate in most locations. On the other hand, plastic products can be somewhat troublesome for both chemical drainage systems in general and high-rise buildings in particular. They have a narrower list of chemicals that they resist well, and they are more fragile as well as susceptible to failure by flame exposure. Plastics also may cause smoke-generation issues that must be addressed to protect life safety. Resolution of these installations may vary by location and authority having jurisdiction. Regardless of the material and approval received, chemical, acid, and laboratory drainage and vent systems must be separate from the domestic drain and vent systems used throughout the building.

In one recently completed high-rise laboratory building, biological research labs were on the upper four floor levels. Each of these lab spaces was served by an acid- and chemical-resistant drain and vent system, separate from the domestic drain and vent systems, that extended to connect to a monitoring station at the junction with the building sewer. In this case, glass piping was selected, offering the benefits and longevity of that material. On the highest level, a biosafety containment facility was added for critical research in a fully secure environment. Even though this floor used products and materials identical to the adjacent lower floors, the piping circuits were segregated and protected from potential discharge to the environment until passing through a sterilization facility. Even the vents were filtered to prevent uncontrolled discharge to the environment. This containment facility also housed a small population of research



Drainage stack thrust anchor detail. Thrust anchors shall be installed at all aboveground bases of drainage stack turnouts.

animals, which were appropriately safeguarded and cared for, including cage-washing and autoclave equipment to protect against infection. Drainage from this equipment is a high-temperature waste, which often causes difficulty with leakage when using one of the available plastic products.

Multiple water temperatures required for different operations lead to another increase in piping and penetrations. This is not only for the supply side, such as cold water distribution, but also for the circulating hot water piping. Usually each water temperature must circulate independently, but occasionally multiple risers or multiple-temperature circulating piping can be combined to return to the heater or mixing valve. Finally, there are the medical gases. Code requires distribution for patient uses to be horizontal, on each floor, with zone valve boxes and area alarm panels. These distribution systems must be fed from sources that are usually remote, thus requiring another set of supply risers.

AN EXAMPLE

A particular new hospital has a number of additional plumbing design opportunities beyond those associated with high-rise construction. First, this project is an infill project, constructed between two wings of an existing high-rise hospital, one of which is also involved in a vertical expansion and facility upgrade to the ICU floors. A second interesting task was the relocation of several active drainage systems serving the hospital and exiting through this project's site, which include primary and secondary storm drainage, sanitary drainage, relocation of the grease waste drainage from a significant food preparation area, installation of a new passive-type interceptor, relocation of acid-resistant drainage from a major laboratory function, and installation of a new acid neutralization basin. The new interceptor and neutralization basin and outfalls are located in the private perimeter roadway that surrounds the building.

Another area of coordination with the underground systems is the addition of a new branch from the central utilities on campus, designed and installed as a separate contract by

a separate engineering and contracting team. This included high-pressure steam and condensate, chilled water supply and return, emergency power duct bank, primary high-voltage power supply, telephone, and fiber optic. All of these modifications were required to be completed before the first-floor slab was poured.

Even after the underground adventures were covered, the building continued to present creative opportunities to the design team. The slab spacings were determined to copy those in the existing hospital, which were very short intervals. This led to an approach that is commonly used for hotel-type construction, using multiple vertical risers placed in the toilet chases to serve multiple floors. Of course, this approach was required to be modified because of the irregular stacking of like fixture groups from floor to floor and the relatively large floor plates (varying between 22,000 and 24,000 square feet per floor). Additional complexity was provided by the modern HVAC requirements for medical facilities and the impact of ceiling plenums, high-density communication and data systems, and high ceiling elevations for more spacious aesthetics on typical patient care floors. Interspersed throughout the building are specialty areas, such as isolation rooms, patient preparation, patient step-down recovery, and ADA-accessible patient rooms.

The ultimate solution for the project was a combined system using large, centrally spaced main waste and main vent stacks that allowed each smaller fixture riser to extend to the main stacks individually or as a building drain. The riser diagram that resulted has a distinctive fan- or brush-shaped outline where all piping funnels together into the main stack. In the final configuration, this building ended with three main soil, waste, and vent stacks, two main rainwater stacks, one main water supply riser, and one main medical gas riser.

IT'S ALL THE SAME, RIGHT?

As this discussion illustrates, modern high-rise design is often a series of design concepts that must be tested through analysis and coordination and then adjusted during the coordination period to maximize flexibility and constructability. This exercise is critical for all building trades but especially so for plumbing systems, for which piping must be accurately placed or accounted for in the early construction phases, while the fixture mounting and finishing connections are made much later after the piping systems are concealed. It also highlights the

need for designers and engineers to be familiar with the work of their peers in other trades. This allows for a certain amount of anticipation between trades, which should be beneficial to the overall project.

In summary, I have quickly reviewed the process of high-rise plumbing design, particularly focusing on pressure control and the impact of piping systems on the general construction of the building. You can see that although many solutions are routine and similar in application, each approach has trade-offs that must be identified, evaluated, and committed to on each unique project. This understanding supports the notion that good engineering is thoughtful and proactive and that good engineers are open to frank discussion and understanding pertaining to their own trade work, as well as that of other trades that are involved in the building.

In design and construction, all high-rise buildings are significant undertakings for everyone involved. All buildings are unique in form and specific design solutions. It takes a collaborative effort and a determined outlook to achieve success in high-rise design and construction. Good high-rise plumbing design makes even the tallest of structures more comfortable and safer for all building occupants, and good engineering and design practices and experiences turn the most daunting high-rise design into a matter of scale.

In the final analysis, I believe the answer to the question is “yes.” It is all the same—all high-rise buildings are such complex organisms that they require close scrutiny and evaluation to maximize the project’s potential for the owner and to create a design that is robust enough to serve the needs of the building for years to come and still provide for affordable construction. **PSD**

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Photo by David Ropinski