High-Rise DWV and Storm Systems

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One of the oldest and most persistent myths in the plumbing profession is the belief that extremely high velocities develop in the stacks of high-rise buildings. The plumbing engineer is invariably asked how he is going to provide for these velocities at the base of the stack. How is he going to prevent the base fitting from being blown out or broken? No special provisions are required for tremendous velocities, and no special precautions are required to protect the base fitting. Excessive velocities just do not occur!

Terminal Velocity

Depending upon the rate of flow from the branch drain into the stack, the type of stack fitting, the diameter of the stack, and the flow down the stack from upper levels, the discharge from the branch may or may not entirely fill the cross-section of the stack at the point of entry. As soon as the water enters the stack it is immediately accelerated at the rate of 82.2 feet/second/second by the force of gravity, and in a very short distance forms a sheet around the inner wall of the pipe. It can be simply described as a hollow cylinder of water. This sheet of water with a core of air in the center continues to accelerate until the frictional force exerted by the pipe wall on the falling sheet of water equals the gravitational force. The frictional force varies as the square of the velocity, and thus resistance to flow is very rapidly increased. From the point where frictional force equals gravitational force, the sheet of water will continue to fall at a velocity which remains practically unchanged. This ultimate vertical velocity is called "terminal velocity," and the distance in which this maximum velocity is achieved is called the "terminal length."

F.M. Dawson and A.A. Kalinske in "Report on Hydraulics and Pneumatics of Plumbing Drainage Systems" (State University of Iowa, Studies in Engineering Bulletin 10, 1987) and R.S. Wyly and H.N. Eaton in "Capacities of Plumbing Stacks in Buildings" (National Bureau of Standards Building Materials and Structures Report BM 132, 1952) have investigated terminal velocity and derived a workable formula by treating the sheet of water as a solid hollow cylinder sliding down the inside wall of the pipe. The formulas developed for terminal velocity and terminal length, without going through the complicated calculus involved, are

$$V_t = 3.0\ (q/d)^{2/5}$$

$$L_t = 0.052\ V^2_t$$

where: V_t = terminal velocity in stack, fps
L_t = terminal length below point of flow entry, ft
q = quantity rate of flow, gpm
d = diameter of stack, in.

Applying the formulas for various size stacks, it is found that terminal velocity is achieved at approximately 10 to 15 fps and this velocity is achieved within 10 to 15 feet of fall from point of entry. The importance of this research is that it conclusively destroys the myth that water falling in a stack from a great height will destroy the fitting at the base of the stack. The velocity at the base of a 100-story stack is only slightly and insignificantly greater than the velocity at the base of a three-story stack! There is no scientific reason for limiting the height of a soil or waste stack of any size and the stacks can be run straight down, without offsets, for 1000 feet or more with the utmost confidence. So-called "velocity breaks" are absolutely unwarranted and, in fact, could cause excessive pneumatic pressure fluctuations in the stack.

Stack Offsets

Most engineers are aware of the problem which exists whenever a stack offsets at an angle greater than 45 degrees. At the point of offset, flow enters the horizontal drain at a relatively high velocity when compared to the velocity of flow in a horizontal drain under uniform flow conditions at full or half-full flow. When the water reaches the bend at the offset it is turned at right angles to its original flow, and for a few pipe diameters downstream it will continue to flow at relatively high velocity along the lower part of the horizontal pipe.

Since the slope of the horizontal piping is not adequate to maintain the velocity of flow that existed when the water reached the offset, the velocity of flow in the horizontal drain slowly decreases with a corresponding increase in the depth of flow until a critical point is reached where the depth of flow suddenly and sharply increases. This increase in depth is often great enough to completely fill the cross sectional area of the pipe. This sudden rise in depth is called the "hydraulic jump" (**Figure 1**). The critical distance at which the hydraulic jump may occur varies. It is dependent upon the entrance velocity, depth of water which may already exist in the horizontal drain when the new flow is introduced, roughness of the pipe, diameter of the pipe and the slope. The distance varies from immediately at the stack fitting up to ten times the diameter of stack downstream: Less jump occurs if the horizontal drain is larger in size than the stack. Increasing the slope of the horizontal drain will also minimize the jump. After the hydraulic jump occurs and fills the drain, the pipe tends to

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Figure 1. Hydraulic Jump at Offset

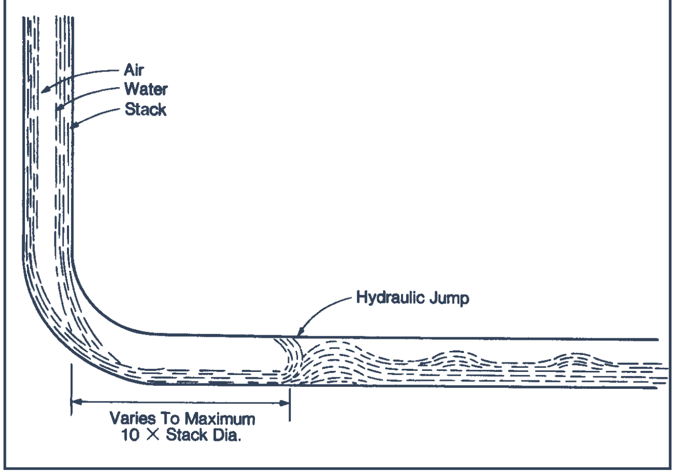
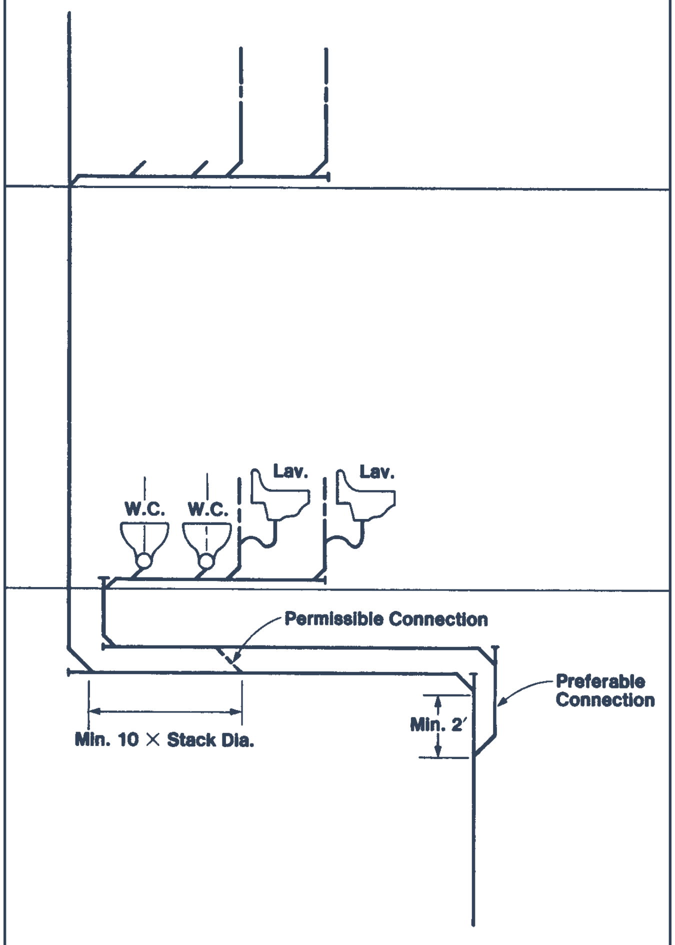


Figure 2. Piping for Fixtures Directly Above Offset



flow full, with large bubbles of air moving along the top of the pipe with the water. Surging flow conditions will exist until the frictional resistance of the pipe retards the velocity to that of uniform flow conditions. Any offset of the stack, at any floor of the building, greater than 45 degrees can cause hydraulic jump.

When the hydraulic jump occurs, and proper venting has not been provided, tremendous pneumatic pressures are built up in the area behind the jump. There have been cases where this excess pressure (greater than a one-inch column of water) has extended 40 feet up the stack. It must be stressed that this excess pressure occurs only when adequate venting has not been provided. Under no circumstances should the fixtures on the floor directly above an offset connect to the stack before the offset. These fixtures should be piped and connected to the horizontal offset more than ten stack diameters downstream or preferably connected to the vertical at least two feet below the horizontal offset (**Figure 2**).

Sizing Offset Stacks

Many high rise buildings decrease the floor areas at certain specified heights. To accommodate the decreased areas, fixture layouts are changed and stacks must be offset to new locations. There is an acceptable method of sizing offset stacks which can result in substantial economies. **Figure 3** illustrates a typical offset stack. The procedure for sizing is as follows:

1. Size the portion above the offset as for a regular stack based upon the total number of fixture units above the offset.
2. Size the horizontal offset as for a building drain.
3. The portion of the stack below the offset shall be at least the size of the offset or based upon the total number of fixture units on the entire stack (both above and below the offset), whichever is the larger.

Expansion and Contraction

Expansion and contraction of stacks is another question always brought up for consideration. There has not been an actual documented instance of stack failure due to expansion or contraction of a stack caused by a variation in temperature. The flow of water is not constant enough to keep it in contact with the pipe long enough for the transfer of necessary heat to affect the pipe. Of far greater importance and danger in a high-rise building, and it is a problem which is often overlooked, is the shrinkage in height of the lower stories of the building. As the gross weight of the upper structure is added, foreshortening at the lower floors has been noted to be as much as two inches in a sixty story building. Soluble gaskets installed in the caulked joints have obviated this problem. The structural engineer should always be consulted to determine the extent of foreshortening to be expected.

Suds Pressure

The prevalent use of high-sudsing detergents in washing machines, dishwashers, laundry trays and kitchen sinks has created serious problems in all residential buildings and especially in high-rise buildings. Until manufacturers are forced to market only detergents without sudsing characteristics the plumbing engineer must understand and cope with the dangers created in the sanitary system by the presence of suds. (An interesting sidelight: suds, in and of themselves, do not enhance the cleaning ability of soaps or detergents in any way).

Figure 3. Sizing of Stack with an Offset

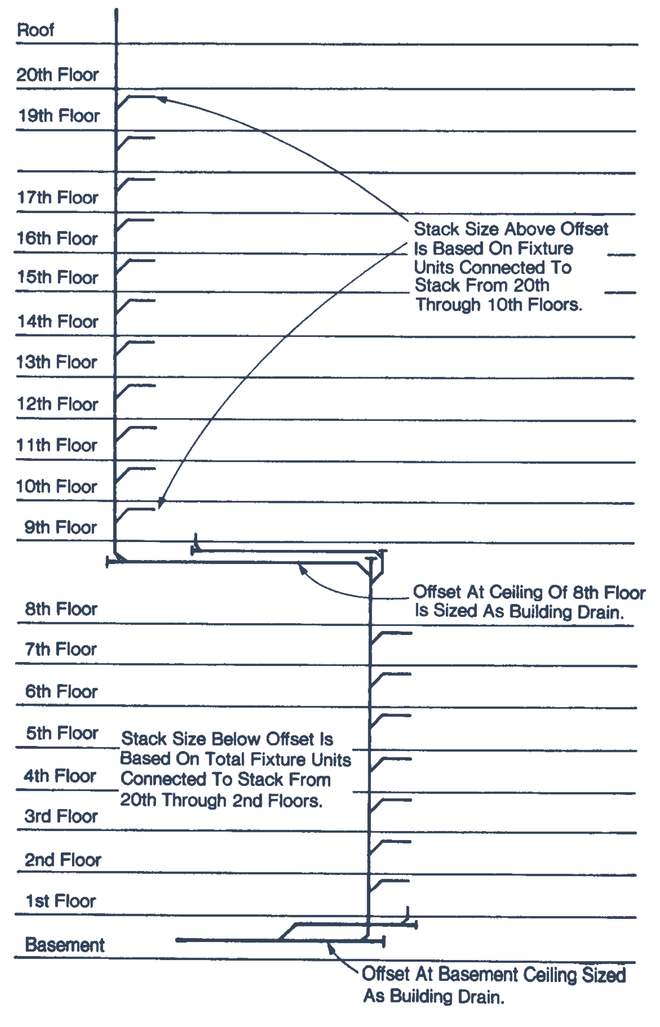
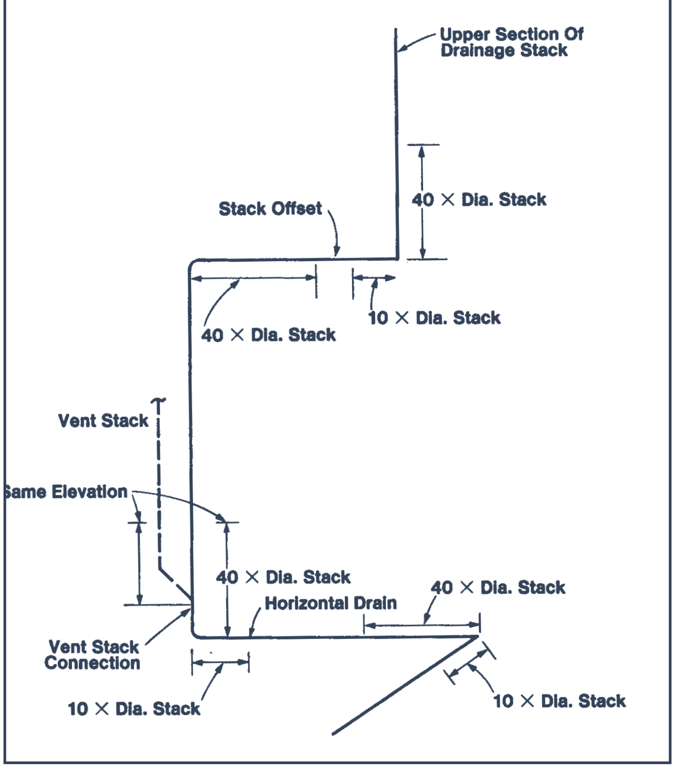


Figure 4. Suds Pressure Zones



When the flow of wastes from upper floors contains detergents, the suds-producing ingredients are vigorously mixed with the water and air in the stack as the waste flows down the stack and further mixing action occurs as other branch waste discharges meet this flow. These suds flow down the stack and settle in the lower sections of the drainage system and at any offsets greater than 45 degrees in the stack. Investigation has shown that where sudsing wastes are present the sanitary and vent stacks are laden with suds, and this condition was found to exist for extended periods of time.

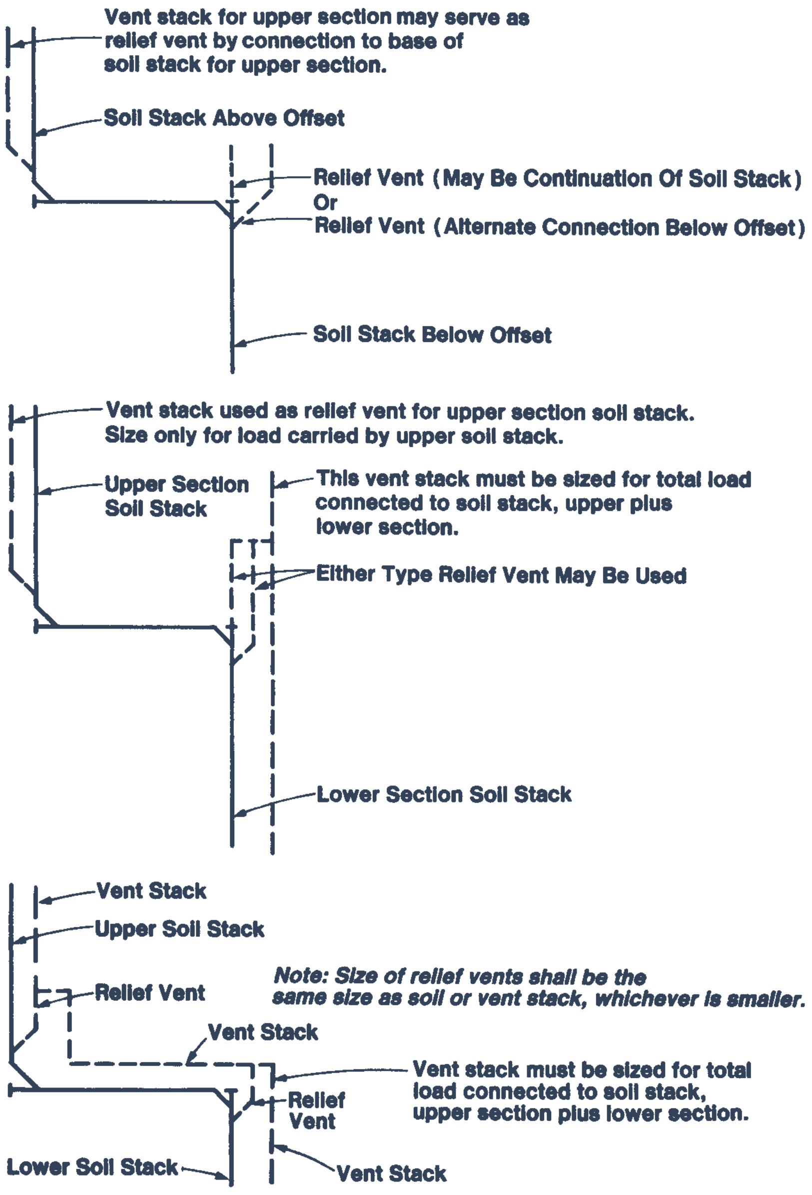
Liquid wastes are heavier than suds and easily flow through the suds-loaded drainage piping without carrying the suds along with the flow. Everyone is aware of the difficulty of flushing the suds out of a sink. The water simply flows through the suds and out the drain, leaving the major portion of the suds behind. The same action occurs in the lower sections of the drainage system except for one important difference: air, as well as water, is now flowing in the piping. This air, which is carried down with the waste discharge, compresses the suds and forces them to move through any available path of relief. The relief path may be the building drain, any branches connected to the building drain, the vent stack, branch vents, individual vents or combinations of any of the foregoing. A path of relief may not always be available, or could be cut off or restricted by the hydraulic jump, or a path may just be inadequate due to location or size. If one or more of these conditions exist, excessively high suds pressure can develop and blow the seals of traps with the accompanying appearance of suds in fixtures.

High suds pressure zones occur at every change in direction, vertically or horizontally, which is greater than 45 degrees. Where vent stack base connections, relief vents, branch vents or individual vents serve as the relief path for the high suds pressure, they are usually found to be inadequate in size with resultant suds conditions appearing at the fixtures. The vent pipe sizing tables in practically every code are calculated on the basis of air flow capacity and do not in any way provide for the more demanding flow of suds. Sizes which are based on these code tables are inadequate to accommodate suds flow and thus are incapable of providing adequate suds pressure relief.

Suds are much heavier than air and consequently do not flow with the same ease. They produce a much greater friction head loss for the same rate of flow. The density of old or regenerated suds varies from 2 pounds per cubic foot to a high of 19 pounds per cubic foot, dependent upon the detergent used. For equal rates of flow and pressure loss, the vent pipe diameter for suds relief flow must be from 20 to 80 per cent greater than for air flow.

Whenever a soil or waste stack receives wastes from washing machines, dishwashers, laundry trays, kitchen

Figure 5. Venting at Stack Offsets



sinks or other fixtures where sudsing detergents are used, the drainage and vent piping for the lower floor fixtures or for the fixtures above offsets must be arranged to avoid connection to any zone where suds pressure exists.

Suds pressure zones exist in the following areas:

1. At a soil or waste stack offset greater than 45 degrees: 40 stack diameters upward and 10 stack diameters horizontally from the base fitting for the upper stack section. A pressure zone also exists 40 stack diameters. upstream from the top fitting of the lower stack section.
2. At the base of a soil or waste stack: The suds pressure zone extends 40 stack diameters upward from the base fitting.
3. In the horizontal drain from the base of a stack: The suds pressure zone extends 10 stack diameters from the base fitting, and where an offset greater than 45 degrees in the horizontal occurs, the pressure zones extend 40 stack diameters upstream and 10 diameters downstream from the offset fitting.
4. In a vent stack connected to a suds pressure zone: The suds pressure zone exists from the vent stack base connection upward to the level of the suds pressure zone in the soil or waste stack. **Figure 4** illustrates all the above zones.

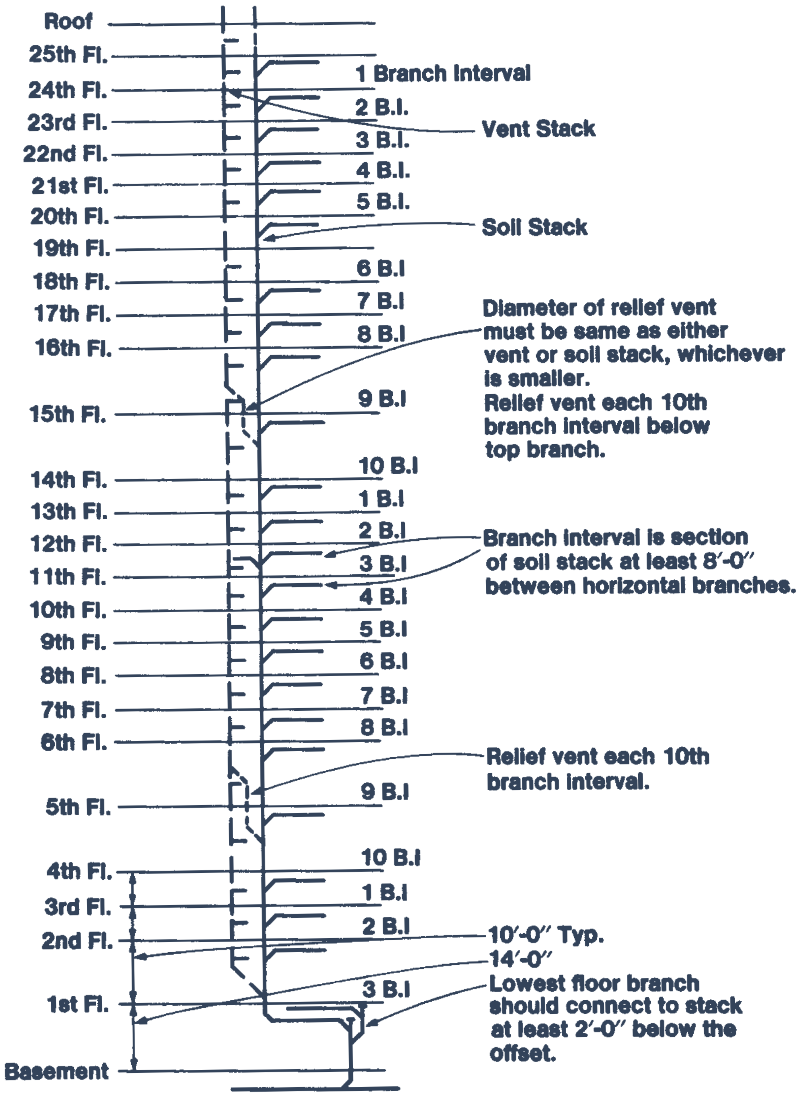
Vent System

The design of vent stacks for high-rise buildings conforms to the design criteria established for any building with slight additional precautions. It is important to understand that the sole purpose of a vent stack is to relieve excessive pressure fluctuations in the soil or waste stack it serves. Just as the flow of water obeys all the laws of hydraulics so does the flow of air obey all the gas laws. The length of run and size of pipe should be designed to maintain pressure fluctuations in the sanitary system within limits to maintain a maximum pressure variation of plus or minus one-inch column of water at fixture traps.

When water is flowing in the sanitary system, pressures in the drainage and vent stacks of a multi-story building are constantly fluctuating. The vent stack connection at the base of the drainage stack and the branch vent connections to the branch drains cannot always eliminate these fluctuations. For reasons which have not as yet been determined, excessive pressure fluctuations occur in stacks which have more than ten branch intervals. It then becomes extremely important to balance pressures throughout the drainage stack by means of relief vents located at various intervals. Drainage stacks in buildings having more than ten branch intervals should be provided with a relief vent at each tenth interval, counting from the topmost branch downward. The lower end of the relief vent should connect to the soil or waste stack below the drainage branch connection and the upper end should connect to the vent stack at least three feet above floor level. **Figure 5** illustrates methods of providing relief vents at stack offsets and **Figure 6** illustrates relief vents for stacks having more than 10 branch intervals.

The vent-sizing tables in many existing codes do not list the size of pipe required for the exceptionally long lengths of run encountered in high-rise construction. Utilization of the following formula will result in the maximum permissible length.

Figure 6. Venting for Stacks Having More Than 10 Branch Intervals



$$L = 2226d^5/fq^2$$

where: L = length of vent piping, ft.
d = pipe diameter, inches
f = coefficient of friction of pipe
q = quantity rate of flow, gpm

Wet Columns

It is a rare occurrence indeed if all space is rented in a high-rise office building during the design phase of the project. The type of tenant or his plumbing requirements are not known at the time of design. If provisions were not made to accommodate these future requirements, costs would be prohibitive to install the necessary services when they became known. This problem is solved by the installation of “wet stacks” or, as they are sometimes called, “wet columns,” at the same time the rest of the plumbing systems are installed.

The wet stacks provided for tenants and future fixtures or equipment should consist of soil and vent stacks with plugged outlets at every floor, and cold, hot and hot water circulating risers with valved outlets at every floor. (See **Figure 7**).

The following guidelines have proven satisfactory for establishing the location and size of stacks, risers and outlets:

1. Wet stacks should be located approximately 150 feet apart or within 72 to 80 feet of horizontal run of the sanitary line to the furthest point of probable future or tenant fixture connection.
2. One wet stack should be sized to accommodate a restaurant.
3. Hot water valved outlets should be located and arranged so branch piping does not exceed 50 feet from a riser or main. If this is impossible provision should be made for Circulation of the branch piping.
4. Pressure-reducing valves should be provided on the hot and cold water valved outlets where the static pressure exceeds 70 psi.

Table 1 for assigning anticipated fixture unit values for wet stack outlets has proven to give satisfactory results.

The wet stacks are sized as though the future loads are already connected to the stacks and risers. The entire plumbing system is sized on the assumption that wet stacks will contribute the estimated loading.

Storm Water

There are some aspects of storm water design for high rise buildings which require special attention. Because many high rises have setbacks as they proceed skyward, roof drains are provided on lower roofs as well as the high roof. This can cause trouble for the unwary designer. The flow in the downspout from the high roof can affect the flow from a lower roof if the downspout offsets at the level where the discharge from the lower roof connects to the downspout. Air entrapped in the horizontal offset, because of the hydraulic jump, is compressed and any connection from the low roof drain to this high pressure area will cause a fountain of water to spurt out of the drain. This same phenomenon can occur at connections of high pressure in the storm water building drain. To eliminate the problem of a lower drain acting as a relief for a high pressure area, any low roof or area drain should always be connected to the vertical downspout a minimum of two feet below an offset.

In many installations, cooling towers for air conditioning systems or gravity tanks are located on or above the roof. The roof drains are utilized to receive the discharge from the drains for this equipment. Under these conditions the roof drain and downspout should be sized to accommodate these flow rates.

Figure 7. Typical Wet Stack

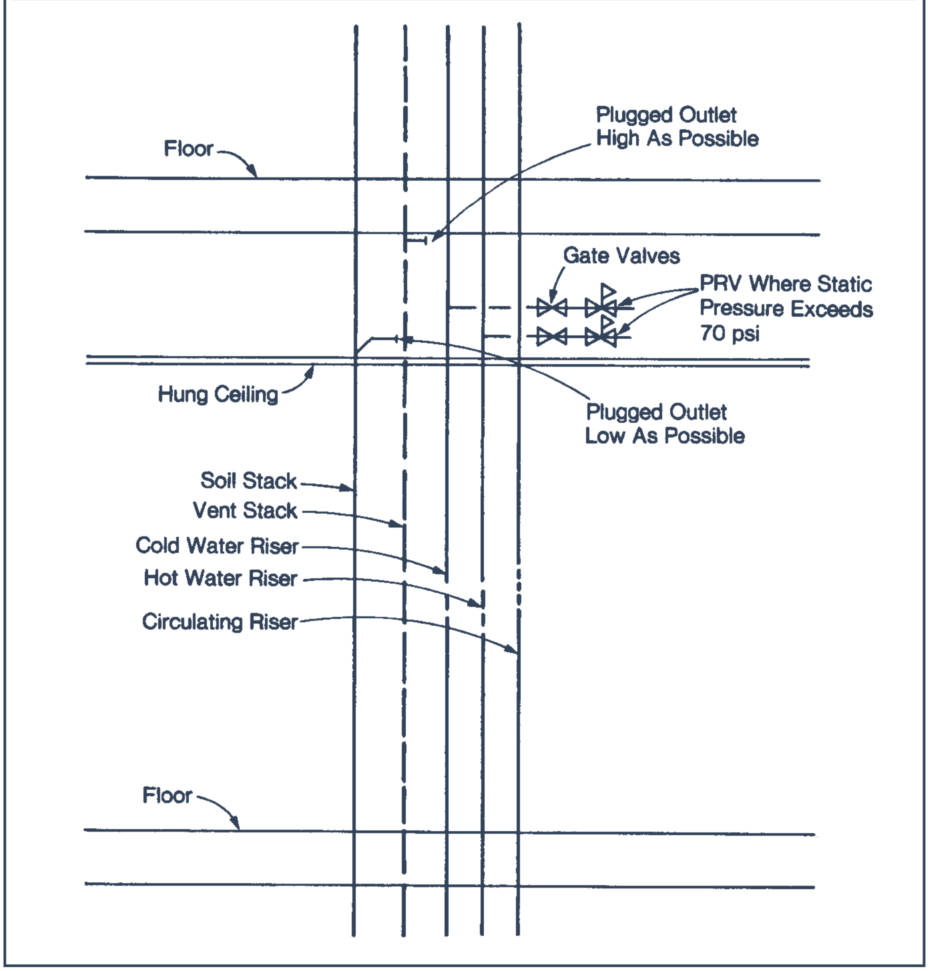


Table 1. Fixture Units for Wet Stacks

Service	Outlets at Each Floor		Outlets at Each Floor Where Restaurants Occur	
	FIXTURE UNITS	OUTLET SIZE	FIXTURE UNITS	OUTLET SIZE
Sanitary	16	4"	60	4"
Vent	16	3"	60	3"
Cold Water	14	1½"	50	2½"
Hot Water	3	1"	40r	2"

An expansion joint or offset should always be provided at the connection to roof drains. This is required to prevent pipe expansion from raising the roof drain and destroying the integrity of the waterproofing of the roof. Storm water piping is probably subjected to the most frequent movement of any plumbing system, but not necessarily the maximum expansion. The movement is due to the frequently changing difference in the outside temperature relative to the inside temperature. In winter, melting snow and ice at low temperatures flow into the drain where the piping is surrounded by an ambient temperature of 70 degrees or higher.

Low temperature liquid flow in the storm water piping will cause condensation to form on the outside of the piping in the building. It is therefore advisable to insulate all storm water offsets to prevent condensation from staining ceilings.

The storm water system for high-rise construction is usually adequately covered by code, but there are many codes which do not cover, and thereby by omission do not permit the installation of controlled-flow roof drainage. It is well worthwhile discussing the use of controlled-flow roof drainage with the authorities if it is not covered by their code. Controlled-flow roof drainage has advantages to recommend it, in lieu of conventional roof drainage, in most applications. It is especially advantageous for high-rise construction. The higher the building, the more economical its use becomes. Economy is of prime importance to the builder, but of even far more importance than the economies realized, controlled-flow roof drainage is one of the best ways to combat water pollution and flooding during heavy rainfalls. It is the author's considered opinion that every municipality should make it mandatory to use controlled-flow roof drainage where combined public sewers are utilized. Here is an ideal and practical method of fighting pollution which does not cost the community one red cent! During heavy storms, sewage treatment plants cannot handle the increased flows and consequently tremendous quantities of untreated raw sewage are dumped into the nation's streams, lakes or oceans. Where separate public storm and sanitary sewers are available, it is still desirable to use controlled-flow as a means of alleviating flooding. By limiting the quantity of flow into the storm sewers during heavy storms, the sewers are better able to handle the runoff from other areas.