FIRE
—AND—
EXPLOSION
PROTECTION SYSTEMS

A Design Professional's Introduction

Second Edition

Michael R. Lindeburg, PE

The Power to Pass
www.ppi2pass.com

Professional Publications, Inc. • Belmont, California

PART 4: Design of Water Sprinkler Systems

41. Schedule- vs. Hydraulically-Designed Sprinkler Systems

Pipes used in sprinkler systems can be sized in one of two ways. Before calculators and computers made sizing calculations simpler, the traditional manner was to use a *pipe schedule*—a table (such as Table 11) dictating the maximum number of fire sprinklers that can be served by any size of pipe. Different occupancy hazards call for different schedules. This method of design has been in use for more than a century.

With a few exceptions, schedule design is permitted only on new construction when less than 5000 ft^2 (465 m^2) is to be protected and when existing schedule-designed systems are expanded (NFPA 13, Secs. 5-2.2.1 and 6-5).[9] Furthermore, schedule designs are permitted only with sprinklers that have the standard 0.5-inch (1.3-cm) diameter orifices and with listed ferrous and copper piping materials (NFPA 13, Sec. 6-5.1).

Most contemporary sprinkler system designs (and all designs for deluge and water spray systems) are based on hydraulic calculations. This method of design is covered in Secs. 75–78. The total water supply requirements for hydraulically-designed systems are lower than for schedule-designed systems. Also, pipe sizes can be reduced (down the run) in hydraulically-designed systems. For these two reasons, hydraulically-designed systems are generally more economical to install.

42. Sprinkler vs. Water Spray Systems

Water spray sprinkler systems can be thought of as spot protection and are similar to deluge systems in concept and operation. The discharge can be triggered manually or by sensor. The nature of the protection (i.e., the volume, type of spray, and area covered) depends on the type of hazard being protected against.[10]

Water spray systems are not substitutes for sprinkler systems. Sprinkler systems protect the building and structure. Spray systems protect specific hazards such as tanks of flammable liquids and gases, electrical transformers, and rotating electrical machinery.

43. Conventional vs. Residential Sprinklers

Conventional (i.e., commercial and industrial) sprinkler systems are usually unsightly, expensive, and require too much ceiling space to be used in residences. Also, conventional sprinklers achieve their best coverage with ceiling heights higher than the normal residence. Finally, conventional sprinklers react too slowly for residential fires, where heat and toxic gas levels would reach lethal levels before the sprinklers opened. Therefore, conventional sprinkler systems are seldom installed in residences.

Since the late 1970s, new developments have made residential sprinkler systems more attractive (i.e., less expensive).[11] These developments include low-cost piping and quick-response sprinklers with modified spray patterns. Unless they are specifically intended for dry operation, residential sprinklers should only be used in wet systems (NFPA 13, Sec. 4-3.6.2).

---

[9] The 5000 ft^2 (465 m^2) limitation does not apply when sufficient flow (as defined in Table 7) is available with a residual pressure of 50 psi (345 kPa; 3.45 bars) at the highest sprinkler (NFPA 13, Sec. 5-2.2.1).

[10] Design of water spray systems is covered in *Water Spray Fixed Systems* (NFPA 15).

[11] Design of residential sprinkler systems is covered in *Standard for the Installation of Sprinkler Systems in One- and Two-Family Dwellings and Mobile Homes* (NFPA 13D) and *Standard for the Installation of Sprinkler Systems in Residential Occupancies up to and Including Four Stories in Height* (NFPA 13R).

44. Tree vs. Loop Sprinkler Systems

Pipe networks can be designed as tree, gridded, or loop systems. With common *tree systems*, the first sprinkler to operate discharges at a greater-than-design rate due to the nature of the flow's declining pressure. *Loop and gridded systems* cannot eliminate the flow-related friction loss, but by providing multiple (parallel) paths to an open sprinkler, the friction loss can be reduced or minimized. Therefore, sprinkler pipe sizes can be smaller (or sprinkler spacing can be larger) with loop systems than with tree systems.

Although loop and gridded designs enjoy a slight economic benefit from needing fewer sprinklers or smaller piping, they require more piping and more complex design calculations. The cost of materials may be slightly greater for loop systems than for tree systems. With modern computer design methods, design costs are probably not an important factor.

A *circulating closed-loop system*, which is a permitted application, is a wet pipe-looped sprinkler system in which the pipes have a second purpose—usually to carry heating or cooling water. Such systems are also known as *automatic sprinkler systems with nonfire protection connections*. Water is only circulated through the system; it is not used or removed from the system (NFPA 13, Sec 3-6).

Gridded systems are commonly used when the protected area is large and roughly rectangular.

45. Responsibility for Design

Designing sprinkler systems should be left to knowledgeable specialists. Although any engineer will be familiar with the hydraulic design concepts necessary to design a sprinkler system, many different codes and regulations need to be followed. Designs will vary depending on the facility to be protected. For example, commercial buildings, aircraft hangers, and rubber tire storage facilities are treated differently. For most residential and commercial buildings, *Standard for the Installation of Sprinkler Systems* (NFPA 13) should be consulted.

The current state of the art is that the sprinkler system is a design-built feature of a building. Sprinkler system layouts are not normally included in the contract drawings. The architect and design engineer do not specify all of the details of the system. While certain elements (e.g., sources of water and power) must be provided in the design by the architect or engineer, others are not.

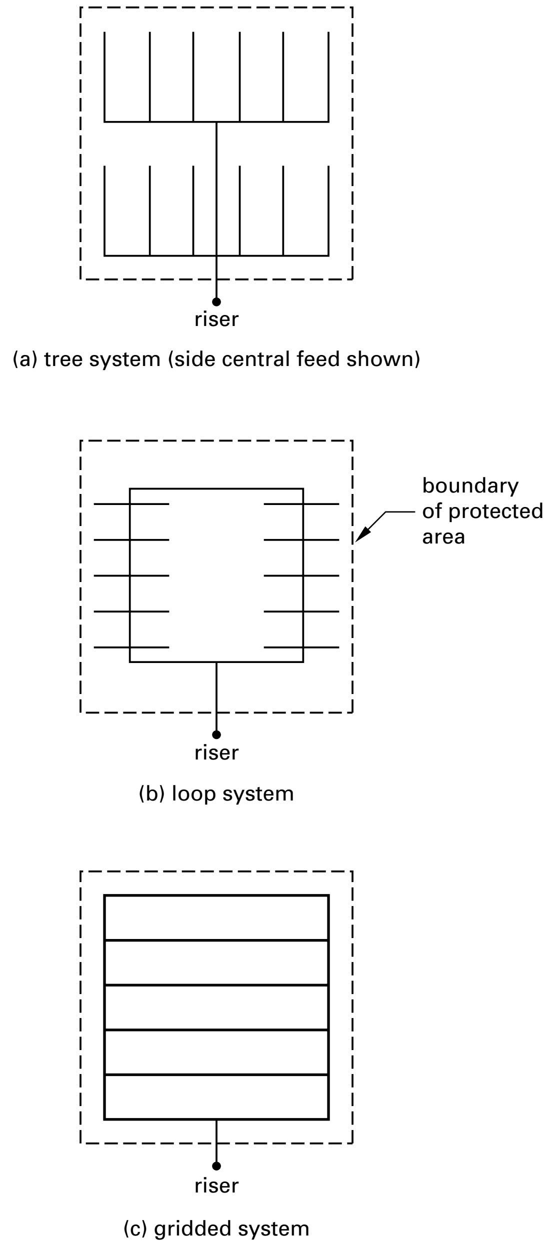


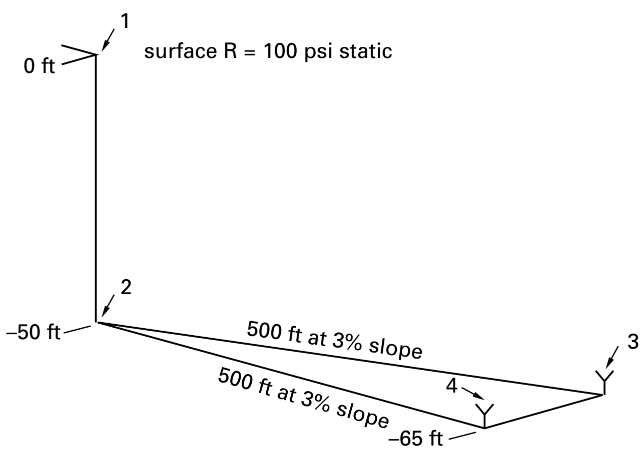
Figure 1 Tree, Loop, and Gridded Pipe Systems

In buildings with simple configurations and low hazards, details such as the locations of sprinkler pipe and sprinklers, types of sprinklers and hangers, and other methods of installation are left to a sprinkler contractor (i.e., the sprinkler installer). In more complex buildings or where hazards are high, a fire protection engineer will contribute to the design. Shop drawings are submitted by the sprinkler system designer for approval by the contract administrator and local authorities.

In many situations (and when permitted by law), the local building and fire officials will have the ultimate

PART 6: Practice Problems

1. A standpipe is being designed for a twin-bore tunnel subway, 50 feet underground. The slope of the tunnel is downward at 3%. The standpipe will be 500 feet long in each bore. Water will be supplied from a city water main at 100 psi on the surface. Assume a pipe friction factor of $f = 0.016$. Use NFPA 14.



(a) What is the minimum flow required in the system?

(b) What are the minimum pipe sizes that can be used?

Answer

(a) Minimum flows are determined from NFPA 14, Sec. 2-1.2: 500 gpm in standpipe 3 and 250 gpm in standpipe 4. Thus, the total in the main is 750 gpm.

(b) The pipe sizing design criteria is based on having a 65 psi residual pressure at the hose valves 3 and 4 (NFPA 14, Sec. 2-1.1). Since the line is 500 feet long, the schedule pipe size from NFPA 14 is 6 inches. However, it is necessary to determine if the elevation drop can compensate for the pressure loss in the 500-foot line.

The cross-sectional areas of pipe are

$$A_{4''} = 0.088\ \text{ft}^2$$
$$A_{6''} = 0.20\ \text{ft}^2$$
$$A_{8''} = 0.35\ \text{ft}^2$$

The flow rates are

$$Q_{1\text{-}2} = \frac{750\ \frac{\text{gal}}{\text{min}}}{\left(7.45\ \frac{\text{gal}}{\text{ft}^3}\right)\left(60\ \frac{\text{sec}}{\text{min}}\right)} = 1.68\ \text{ft}^3/\text{sec}$$

$$Q_{2\text{-}3} = \frac{500\ \frac{\text{gal}}{\text{min}}}{\left(7.45\ \frac{\text{gal}}{\text{ft}^3}\right)\left(60\ \frac{\text{sec}}{\text{min}}\right)} = 1.12\ \text{ft}^3/\text{sec}$$

$$Q_{2\text{-}4} = \frac{250\ \frac{\text{gal}}{\text{min}}}{\left(7.45\ \frac{\text{gal}}{\text{ft}^3}\right)\left(60\ \frac{\text{sec}}{\text{min}}\right)} = 0.56\ \text{ft}^3/\text{sec}$$

Assume that the city water main is of sufficiently large capacity that the static and flowing water pressure at the source are the same.

Since a diameter of 6 inches is allowed by schedule, determine whether a 4-inch pipe will provide the minimum residual pressure at the specified flow.

From point 1 to point 2,

$$\frac{p_1}{\gamma} + \frac{v_1^2}{2g} + z_1 = \frac{p_2}{\gamma} + \frac{v_2^2}{2g} + z_2 + \frac{fLv_2^2}{2dg}$$

$$v_1 = 0 \quad \left[\begin{array}{c}\text{because static and flowing}\\ \text{pressure are the same}\end{array}\right]$$

$$z_1 = 0 \quad [\text{datum}]$$

$$v_2 = \frac{Q_{1\text{-}2}}{A_{4''}} = \frac{1.68\ \frac{\text{ft}^3}{\text{sec}}}{0.088\ \text{ft}^2} = 19.1\ \text{ft/sec}$$

$$z_2 = -50\ \text{ft}$$

$$f = 0.016$$

$$L = 50\ \text{ft}$$

$$d = \frac{4\ \text{in}}{12\ \frac{\text{in}}{\text{ft}}} = 0.33\ \text{ft}$$

$$p_1 = 100\ \text{lbf/in}^2$$

$$\gamma = 62.4\ \text{lbf/ft}^3$$

$$\left(\frac{100\ \frac{\text{lbf}}{\text{in}^2}}{62.4\ \frac{\text{lbf}}{\text{ft}^3}}\right)\left(144\ \frac{\text{in}^2}{\text{ft}^2}\right) + 0 + 0 = \left(\frac{p_2\ \frac{\text{lbf}}{\text{in}^2}}{62.4\ \frac{\text{lbf}}{\text{ft}^3}}\right)\left(144\ \frac{\text{in}^2}{\text{ft}^2}\right) + \left[\frac{\left(19.1\ \frac{\text{ft}}{\text{sec}}\right)^2}{(2)\left(32.2\ \frac{\text{ft}}{\text{sec}^2}\right)}\right] + (-50\ \text{ft}) + \left[\frac{(0.016)(50\ \text{ft})}{0.33\ \text{ft}}\right]\left[\frac{\left(19.1\ \frac{\text{ft}}{\text{sec}}\right)^2}{(2)\left(32.2\ \frac{\text{ft}}{\text{sec}^2}\right)}\right]$$

$$p_2(2.3\ \text{ft}) = 230.8\ \text{ft} - 5.7\ \text{ft} + 50\ \text{ft} - 13.7\ \text{ft} = 261.4\ \text{ft}$$

$$p_2 = 113.7\ \text{lbf/in}^2$$

From point 2 to point 3,

$$\frac{p_2}{\gamma} + \frac{v_2^2}{2g} + z_2 = \frac{p_3}{\gamma} + \frac{v_3^2}{2g} + z_3 + \frac{fLv_3^2}{2dg}$$

From the previous calculation,

$$\frac{p_2}{\gamma} = p_2(2.3\ \text{ft}) = 261.4\ \text{ft}$$

$$\frac{v_2^2}{2g} = 5.7\ \text{ft}$$

$$z_2 = -50\ \text{ft}$$

$$v_3 = \frac{Q_3}{A_4} = \frac{1.12\ \frac{\text{ft}^3}{\text{sec}}}{0.088\ \text{ft}^2} = 12.7\ \text{ft/sec}$$

$$z_3 = -50\ \text{ft} + (500\ \text{ft})\left(-0.03\ \frac{\text{ft}}{\text{ft}}\right) = -65\ \text{ft}$$

$$L = 500\ \text{ft}$$

$$f = 0.016$$

$$d = 0.33\ \text{ft}$$

$$261.4\ \text{ft} + 5.7\ \text{ft} + (-50\ \text{ft}) = \left(\frac{p_3\ \frac{\text{lbf}}{\text{in}^2}}{62.4\ \frac{\text{lbf}}{\text{ft}^3}}\right)\left(144\ \frac{\text{in}^2}{\text{ft}^2}\right) + \left[\frac{\left(12.7\ \frac{\text{ft}}{\text{sec}}\right)^2}{(2)(32.2)\frac{\text{ft}}{\text{sec}^2}}\right] + (-65\ \text{ft}) + \left[\frac{(0.016)(500\ \text{ft})}{0.33\ \text{ft}}\right]\left[\frac{\left(12.7\ \frac{\text{ft}}{\text{sec}}\right)^2}{(2)(32.2)\ \frac{\text{ft}}{\text{sec}^2}}\right]$$

$$261.4\ \text{ft} + 5.7\ \text{ft} - 50\ \text{ft} = p_3(2.3\ \text{ft}) + 2.5\ \text{ft} - 65\ \text{ft} + 60.7\ \text{ft}$$

$$p_3(2.3\ \text{ft}) = 261.4\ \text{ft} + 5.7\ \text{ft} - 50\ \text{ft} - 2.5\ \text{ft} + 65\ \text{ft} - 60.7\ \text{ft} = 218.9\ \text{ft}$$

$$p_3 = 95.2\ \text{lbf/in}^2$$

This is greater than 65 psi, so a 4-inch line is ok.