PDHonline Course M256 (12 PDH)

Siphonic Roof Drainage

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Course Content

1. Introduction

1.1. General: This course is intended to provide enough information on the background, operation and design of siphonic roof drainage systems. The material contained is covered in more detail in the American Society of Plumbing Engineers (ASPE) Technical Standard 100 "Siphonic Roof Drainage." Although you do not require a copy to study this course and take the final test, obtaining your own copy from ASPE is highly recommended. This course is longer than most and is designed for you to earn 12 PDH's. You can expect to spend at least a week of self paced study to cover the material and be ready for the final test.

1.2. Background

1.2.1. Inventor

1.2.1.1. The concept of siphonic or "full-bore" drainage was originally conceived in the 1960's by an engineer from Finland named Olavi Ebeling. He had experience in the flow testing of pipes, fittings and other piping components for their energy loss coefficients with an apparatus utilizing a suction from a water reservoir that incorporated vaned baffle plates to avoid vortexing of the water at the suction entrance.

1.2.1.2. At the time, building regulations in Finland required that all roof drainage piping in buildings be copper. Today, the price of copper continues to skyrocket but even back then it was still a relatively expensive material. Any means of reducing the required pipe diameters while still draining a roof surface adequately meant significant savings.

1.2.1.3. Mr. Ebeling, having realized such a need, applied his knowledge in pipe suctions and hydraulics and realized that the drain-pipe-discharge sequence of a roof drainage system could be made to operate at full bore and applied well know principles of Bernoulli and others to evaluate possible pipe sizing methods and achieve a target flow.

1.2.1.4. After several iterations, Mr. Ebeling found an adequate drain design and patented the device in 1968. Along with the drain, he devised a method of pipe sizing and determined that the systems work best when horizontal runs of pipe are laid flat.

1.2.2. Patents and Intellectual Property

1.2.2.1. General: Mr. Ebeling originally patented his ideas on siphonic roof drainage in 1968. However there are several patents filed with the United States patent and Trademark Office under the names Mr. Olavi Ebeling and Mr. Risto Lunden both of Helsinki, Finland dating from 1978 to 1987. United States utility patents have a lifespan of 17 years. It is therefore safe to say that the general concept of siphonic roof drainage is within the public domain. However, this does not prevent other inventors from obtaining patents for improvements to the concept or to roof drain devices.

1.2.2.2. In addition to utility patents, designers may also obtain what are called design patents. Design patents protect the "ornamental design" of a physical object. Normally, such patents are used to protect objects like statues, furniture designs, automobile interiors and similar works. However this protection can be extended to other objects otherwise not intended to be "ornamental" in function but have a physical geometry that can be interpreted as ornamental and therefore qualified for patent protection. Such patent protection prevents others from making "carbon copies" of a designer's work without approval from the designer.

1.2.2.3. Proprietary Information: Many purveyors of siphonic roof drains and related design software make claims that they possess certain "proprietary information" or "know-how." However, siphonic roof drainage design is based on well known principles of hydraulics that are common with all fields of mechanical engineering. There is no reason for engineers to sign special "non-disclosure agreements" with siphonic roof drainage software providers. Doing so introduces many unnecessary legal entanglements and severely compromises an engineer's obligation to specify systems on a non-proprietary basis. In many cases, companies sell both roof drains and software and tell the user of the software that only their drain can be used in the resultant design. However, as will be discussed further on, there is no technical reason why drains can not be substituted. This is only a marketing ploy.

1.2.3. Pipe Size Reduction

1.2.3.1. The major benefit of siphonic roof drainage (and the original inspiration for its invention) is the reduction in pipe diameter to achieve the same volumetric flow of water off of a roof. This is achieved by exploiting the kinds of flow patterns and behaviors of the flow of water through pipes that result in pressure fluctuations and priming to a full bore condition. These behaviors are systematically avoided and prevented in the design of traditional sanitary drainage and roof drainage systems.

1.2.3.2. The traditional design methods of sanitary waste and roof drainage piping systems limit the level of water in piping to leave a volume of air at atmospheric pressure to exist in every part of the system. For horizontal pipe runs, this level is about 50 percent water and 50 percent air. Roof drainage may go as far as 67 percent water to 33 percent air. Sanitary waste system design includes a set of rules for venting to ensure an atmospheric condition throughout with a variation of about 1 inch of water column in either positive or negative to avoid siphoning of trap seals or expulsion of sewer gasses through drains.

1.2.3.3. Since a traditional sanitary waste or roof drainage system is intended to be at atmospheric pressure throughout, there is no static differential pressure generated in these systems to induce flow. Therefore, these systems include a physical gradient or pitch in horizontal sections to induce flow at reasonable solid-carrying velocities that also maintain smooth flow conditions at the water-to-air ratios mentioned above. Resultant velocities at specified pipe diameters, slopes and internal roughness values are predicted by Manning's Formula, a well known relationship used in the civil engineering field and the basis for the sizing tables found in model plumbing codes.

1.2.4. Pipe Set Level

1.2.4.1. Many engineers who first hear about the fact that siphonic roof drainage piping is installed flat and level are skeptical. What if the pipe is only part full and siphonic action has not occurred? If one considers Manning's Formula (Equation 1.1) it seems that if the slope or pitch (S) is equal to zero, then the velocity in the pipe would then be zero. Therefore, how can water flow through a flat pipe with no pressure differential?

$$V = \frac{1.486}{n} R^{2/3} S^{1/2}$$

Equation 1.1: "Manning's Formula"

1.2.4.2. Manning's Formula does not recognize the reality that even a very long pipe has to eventually drop into a vertical stack in roof drainage. After all, any roof drainage configuration begins with roof drains at one elevation and a point of discharge at a lower elevation.

1.2.4.3. One way to visualize flow in the flat piping sections is by the analogy of a flat table and a pitcher of water. If one were to take the pitcher of water and pour it on a flat and level table, water will not simply "stand up" on the table due to a lack of pitch. It will spread out seeking a form with zero shear stress (i.e. "seek its own level" or assume the form of its container) and consequently run out toward the table's edge and spill over the side.

1.2.4.4. Instead of a flat table, consider a length of pipe oriented perfectly level. At one end is a funnel pointing up. If one were to take the pitcher of water and pour it slowly into the funnel, the water is guaranteed to pour out the other end of the pipe. The degree to which the pipe fills is a function the rate at which the water is poured into the funnel. Other flow patterns of the water surface in the pipe form namely wavy flow and plug flow. These patterns are specifically avoided in sanitary waste drainage systems because they produce pressure fluctuations. Pipe pitch in sanitary waste systems ensures steady flow at atmospheric pressure. Siphonic systems exploit these flow patterns to reach a full bore mode of flow.

1.2.4.5. Another way of thinking of flow through a flat pipe is to consider water as marbles. Each marble represents a scaled up version of a water molecule. Water molecule shape and surface-tension affects set aside, water can be though of as a bunch of marbles rolling over each other. If one were to pour a supply of marbles into the funnel of a flat pipe, they also would eventually pour out the other end. Of course, as marbles are poured in faster they pile up on each other and the pipe fills up. However, once the pipe becomes full, water ceases to behave as a pile of loose marbles.

1.2.4.6. As an incompressible substance without any "free surface" with air, water behaves more as a flexible chain inside the pipe. If one were to drape such a chain on a flat table and drape one end over the edge, the weight of the dangling chain will pull on the length on the table and it will snake down under the influence of gravity. When water fully primes a pipe bore, it acts exactly like the chain. Therefore, pipe pitch is not necessary in any mode of flow in a siphonic roof drainage system.

1.2.5. Design Flexibility

1.2.5.1. The flexibility in siphonic roof drainage system design exists on several facets. Independence of pitch allows for the design of horizontal runs above ceilings and other spaces with overhead limitations. The placement of stacks within a building is much more flexible as a result. While the physical properties of pipe design enable the plumbing engineer to achieve more effective designs, there is also the fact that significant changes can be made to a siphonic system during construction without dire consequences.

1.2.5.2. The review of the hydraulic equations in this training program could lead one to believe that the calculations are “critical” and inordinately rigid. It is true that accuracy is a vital part of the engineering practice. An engineer must use the most reliable and most accepted methods and exercise the highest standard of care. This applies to any mechanical system and siphonic roof drainage is no different. On the other hand, the practice of siphonic roof drainage design does not press an engineer into a higher and unreasonable standard.

1.2.5.3. As mentioned previously, siphonic roof drainage technology was conceived in the mid-1960’s well before the introduction of the personal computer. Although the use of computer software is the current standard of practice in siphonic roof drainage design, there was a period when these systems were designed with hand calculations using charts and tables much like how automatic sprinkler systems were once calculated by hand before sizing software became available. Although automatic sprinkler systems and siphonic systems designed by hand could be shown today to have errors and inaccuracies when reevaluated by computer software, they still worked adequately. In other words, the best level of accuracy is any designer’s goal, but small errors are possible if in fact they occur.

1.2.5.4. In any construction project, many changes can occur. Such changes can result in conflicts that necessitate design alterations. Contractors sometimes regard siphonic roof drainage as too rigid a system because it is engineered. Traditional roof drainage can be altered by a contractor without the designer’s approval as long as the prescribed methods of the plumbing code are followed.

1.3. Myths and Misconceptions

1.3.1. Myth 1: Siphonic systems drain water off of the roof “faster” than traditional piping.
Reality: Although higher operating velocities are achieved, the drainage capacity is a function of pipe size. They can drain as quickly or slowly as desired. <u>Siphonic roof drainage is very good for controlled flow requirements</u>.

1.3.2. Myth 2: Siphonic systems have to be engineered by the manufacturer or supplier of the pipe and drains.
Reality: All siphonic systems installed in the U.S. have been engineered by independent consulting engineers. Some companies advertise that “specialized”

design and installation is required, but this has been demonstrated to be untrue and unnecessary.

1.3.3. Myth 3: The pipe and fittings are available only from foreign proprietary sources. Reality: Pipe and fittings used for siphonic roof drainage systems in the United States are the same as those used for traditional plumbing systems. There are no special manufacturers, materials or installers needed for siphonic roof drainage systems.

1.3.4. Myth 4: There is standing water on the roof at all times in order to maintain a siphonic operation, even while not raining (i.e., the pipe is always full). Reality: When it is not raining, the roof and piping are dry. When it rains, a layer of water develops on the roof, but in the same way as with traditional atmospheric systems. Actually, this layer of water is typically less for siphonic systems.

1.3.5. Myth 5: Water builds up on the roof until a critical level is reached and then the drains "open up" to siphon the water off. Reality: Water build-up on a flat roof or in gutters is not any different than traditional systems. Transition from partly full to full bore is a smooth transition. This property is a tested parameter for siphonic drains (15 second rule). Also, the drains are fixed and without moveable parts.

1.3.6. Myth 6: Only the software offered by a roof drain manufacturer can be used with their roof drain product. No substitutions are allowed by an installer. Reality: Siphonic roof drains in the North America have to be tested for their performance in accordance with ANSI/ASME A112.6.9 "Siphonic Roof Drains" and have the prescribed product markings specified in this standard. Any drain product that successfully completes the tests can be considered an equal product. The properties of different drain products vary slightly. For example, differing geometry of the drain results in differing resistance coefficients. However, a resistance coefficient results in only one minor energy loss among a whole series of major and minor losses. As long as the designer updates the design calculations with the substituted drain to verify proper performance, drain substitutions can be allowed.

1.3.7. Myth 7: There must be valves, utility connections or mechanical controls to make the siphon work. Reality: There are no valves, controls, regulators or moving parts of any kind. The system consists only of drains and piping. Siphonic systems prime due to natural hydraulic action.

1.4. Codes and Standards

1.4.1. ANSI/ASME A112.6.9 "Siphonic Roof Drains"

1.4.1.1. General: According to the "Scope" section of this standard,

> *This standard establishes minimum requirements and provides guidelines for the proper design, installation, examination, and testing of siphonic roof drains….*
>
> *It is the intent of this standard to provide standardized test procedures to ensure that drain products are evaluated equally.*

1.4.1.2. The most significant section of this standard is Section 3 “Testing.” The purpose of the specified tests is to ensure that the drain can prime itself and the test standpipe quickly (within 15 seconds) at the maximum design flow rate. The tests also determine the maximum flow capacity for the drain and to take depth versus flow data over the drain’s flow range. The tests also measure the actual resistance coefficient of the device. This coefficient is the same as those assigned to pipe fittings and reducers and it is used in the designer’s hydraulic calculations to determine the minor loss of energy through the drain.

1.4.1.3. Finally, this standard establishes minimum requirements for product marking. To be fully compliant with this standard, the drain must be marked with the manufacturer’s name or trademark. Also the baffle plate and drain body must be marked with the baffle plate model number, resistance coefficient and the words “REPLACE MISSING BAFFLE WITH MODEL _____.” The Purpose of marking both the baffle and drain body is to make it possible for a plumber or roof inspector to identify the drain manufacturer and proper replacement part number if a baffle is damaged or missing. The marking of the resistance coefficient makes it possible for an engineer to determine the value if the siphonic roof drainage system is to be modified long after initial installation.

1.4.2. ANSI/ASME A112.6.4 “Roof, Deck and Balcony Drains”

1.4.2.1. An earlier version of this standard was ANSI/ASME A112.21.2M. It is still referenced in model codes as the standard for roof drains. However, in 2003, this standard was replaced with A112.6.4 “Roof, Deck and Balcony Drains.”

1.4.2.2. This standard does not apply specifically to siphonic roof drains. However ANSI/ASME A112.6.9 does reference this standard to keep siphonic roof drains consistent with traditional drain manufacturing with respect to materials of construction, outlet types, accessories and product marking.

1.4.3. ASPE Technical Standard 100 “Siphonic Roof Drainage”

1.4.3.1. Despite the fact that siphonic roof drainage has been in existence for nearly forty years, no comprehensive written standard has been developed or accepted. This is largely due to the fact that the siphonic industry in Europe is very competitive. Experts in the field could not form a consensus on standardization because to do so would severely limit the individual marketing edge. Each company professed a “better” method and insisted that only their drains could be used on systems they designed.

1.4.3.2. The American Society of Plumbing Engineers (ASPE) initiated a work group to draft a standard for the design of siphonic roof drainage systems in 2004. The goal of this work group was to establish what European interests could not achieve. In the United States, the practice of engineering is highly regulated and the manufacture of consumer products is tightly controlled by several standards. ASPE Technical Standard 100 provides guidance to plumbing engineers so that the design methods can be applied uniformly.

1.4.3.3. The purpose of this standard is to establish a consensus on the minimum performance of siphonic roof drainage systems. It is a “standard of practice” that provides engineers with a means of establishing the minimum standard of care in the design of siphonic roof drainage systems.

1.4.4. ASTM F 2021 “Standard Guide for the Design and Installation of Plastic Siphonic Roof Drainage Systems”

1.4.4.1. This ASTM standard guide was originally published in 2000. It was revised significantly and re-issued in 2006.

1.4.4.2. This document is classified as a guide. It provides guidance on certain details particular to plastic piping when used for siphonic roof drainage systems. Information on minimum pipe wall thickness, thermal expansion, fire-stopping, and pipe roughness values is provided.

1.4.4.3. Guidance on pipe layout and pipe sizing is not included in this document.

1.4.5. International Plumbing Code, Section 105 “Approval,” Paragraph 105.4 “Alternative Engineered Design”

1.4.5.1. This section of the IPC recognizes the use of engineering techniques not specifically identified in the body of the code. Such engineered systems must, however, provide “an equivalent level of quality, strength, effectiveness, fire resistance, durability and safety.” Also, manufacturer installation instructions must be followed. In other words, the “intent” of the code with respect to public safety must be met, even if the method differs from the code’s prescribed methods.

1.4.5.2. For a roof drainage system, “equivalency” is met if the system can drain at the prescribed rainfall intensity, prescribed pipe materials and installation methods are used, and fire resistance practices such as fire-stopping are employed.

1.4.5.3. Of course, this section also requires the construction documents to be stamped and signed by a license professional engineer.

1.4.6. Uniform Plumbing Code, Appendix L “Alternate Plumbing Systems”

1.4.6.1. This appendix section of the UPC recognizes the use of engineering techniques not specifically identified in the body of the code. Such engineered systems must, however, provide “an equivalent level of quality, strength, effectiveness, fire resistance, durability and safety.” Also, manufacturer installation instructions must be followed. In other words, the “intent” of the code with respect to public safety must be met, even if the method differs from the code’s prescribed methods.

1.4.6.2. For a roof drainage system, “equivalency” is met if the system can drain at the prescribed rainfall intensity, prescribed pipe materials and installation methods are used, and fire resistance practices such as fire-stopping are employed.

1.4.6.3. Of course, this section also requires the construction documents to be stamped and signed by a license professional engineer.

1.4.7. National Standard Plumbing Code, Appendix E “Special Design Plumbing Systems”

1.4.7.1. This Appendix serves to control the application of engineered systems that “vary in detail from the requirements of this Code.” Such engineered systems must conform to the NSPC “Basic Principles” which essentially means that “equivalency” must be met.

1.4.7.2. For a roof drainage system, “equivalency” is met if the system can drain at the prescribed rainfall intensity, prescribed pipe materials and installation methods are used, and fire resistance practices such as fire-stopping are employed.

1.4.8. National Fire Protection Association, NFPA 5000 “Building Construction and Safety Code, Section 1.5 “Equivalency”

1.4.8.1. This section of the code specifically states that alternative methods may be used in lieu of those prescribed in the body of the code with approval of the authority having jurisdiction.

1.4.9. Engineered Systems and Licensure

1.4.9.1. General: The majority of systems designed by plumbing engineers can be thought of as “pre-engineered” systems. Sanitary waste systems, natural gas systems and even roof drainage systems are subject to prescribed design methods contained in State plumbing codes. In most cases, design of such systems has been reduced to simple sizing tables leaving little for the designer or engineer to evaluate or calculate. Siphonic roof drainage systems can not be reduced to similar sizing tables since many variables come into play. Therefore, engineering analysis by the designer must be performed in much the same way as for HVAC ductwork, hydronic heating systems or automatic sprinkler systems. As a result, State laws require that individuals designing engineered system be licensed. Although this is well known among engineers that any system has to be designed by a licensed engineer, this information is presented as part of this course because some siphonic roof drain manufacturers have offered to perform “free engineering” services for engineers. This is not legal, and the information herein explains why.

1.4.9.2. State Regulations for Licensure

Background: Licensure of engineers and engineering firms is regulated at the State level. Originally, past engineering disasters prompted a few States to adopt laws regulating the practice of engineering. The purpose of such laws is to protect the health, safety and welfare of the public. Licensed engineers are required to abide by a strict code of ethics to ensure adherence to public safety. Violation of these State laws and canons of ethics can result in serious penalties and legal exposure. It is also illegal to even offer to provide engineering services or use the title of “engineer” in the construction industry.

Individuals: Individuals practicing engineering in the construction field must be licensed. Each State has specified rules and requirements to obtain licensure. The scope of this course does not include information on how to obtain licensure. However, engineers, architects and contractors are strongly advised to obtain the licensure credentials from any individual offering to provide engineering services for designing siphonic roof drainage systems.

Professional Firms: In many States, companies that offer engineering services must obtain a “Certificate of Authorization” or similar permit. The purpose of such a certification is to establish that the company complies with State regulations for professional licensure. Specifically, the company must employ or be owned by licensed engineers. Companies thinking of engaging in a contract with a firm offering to design siphonic roof drainage systems are also strongly advised to obtain the company’s Certificate of Authorization or equivalent permit. This is particularly important if a roof drain product manufacturer or sales representative offers to design siphonic systems.

1.4.9.3. Responsible Charge

"Responsible charge" of engineering is usually defined as the control an engineer is required to make to maintain engineering decisions made personally or by others over which the engineer exercises supervisory direction and control authority. The degree of control necessary for an engineer to be in responsible charge is such that the engineer, (a) personally makes engineering decisions, or personally reviews and approves proposed decisions prior to their implementation, including consideration of alternatives whenever engineering decisions that could affect the health, safety, and welfare of the public are made. In making said engineering decisions, the engineer shall be physically present or, through the use of communication devices, be available in a reasonable period of time as appropriate and, (b) judges the validity and applicability of recommendations prior to their incorporation into the work, including the qualifications of those making the recommendations.

An engineer who signs and seals engineering documents in responsible charge must be capable of answering questions as to the engineering decisions made during the engineer’s work on the project in sufficient detail as to leave little doubt as to the engineer’s proficiency for the work performed. It is not necessary to defend decisions as in an adversary situation, but only to demonstrate that the engineer in responsible charge made them and possessed sufficient knowledge of the project to make them. Examples of questions to be answered by the engineer could relate to criteria for design, methods of analysis, selection of materials and systems, economics of alternate solutions, and environmental considerations. The individual should be able to clearly define the degree of control and how it was exercised and be able to demonstrate that the engineer was answerable within said degree of control necessary for the engineering work done.

1.4.9.4. Liability of Engineer of Record: The purpose of covering issues related to liability to the practicing engineer or their employer, is to guide engineers and designers who may be approached by non-qualified entities who offer to provide engineering services without proper licensure and (where required) corporate Certificates of Authorization. A sole proprietor or corporation that enters into a contract with an Owner becomes the responsible party held liable for errors and omissions (i.e. the Engineer of Record). Anyone providing “free engineering” can not legally offer indemnity to the Engineer of Record because they themselves are not legally qualified to perform engineering services. Any such contract that violates State law can not be upheld and the Engineer of Record will be held as the responsible party and perhaps incur further exposure for having accepted unlicensed engineering services. Such acceptance of so-called “free engineering” is also described as unethical according to the National Society of Professional Engineers Code of Ethics.

1.5. Installations in North America

1.5.1. General: As of December 2006, there are eighteen installations of siphonic roof drainage in the United States. There are a few in Canada as well. There are nine or so additional projects with authority approval either under construction or on the drawing board.

1.5.2. Current List: Below is a list of the various projects:

SIPHONIC ROOF DRAINAGE SYSTEMS
IN THE UNITED STATES

More than 650 million square feet worldwide.
Nearly 7 million square feet in the U.S.

Installations (18):

Boston Convention and Exhibition Center, Boston, MA
IKEA Home Furnishings, Paramus, NJ
IKEA Home Furnishings, New Haven, CT
IKEA Home Furnishings, Bloomington, MN
IKEA Home Furnishings, Atlanta, GA
IKEA Home Furnishings, Canton, MI
IKEA Home Furnishings, Bolingbrook, IL
IKEA Home Furnishings, Brooklyn, NY
IKEA Home Furnishings, Stoughton, MA
Western Virginia Regional Jail Authority, Roanoke, VA
IKEA Home Furnishings, Richfield, MN
Claude Moore Education Center, Roanoke, VA
Barney's New York, Dallas, TX
US Census Bureau, Suitland, MD
General Motors, Lansing, MI
General Motors, Flint, MI
General Motors, Fort Wayne, IN
Target, Central, TX

Approvals (9):

Boston Museum of Fine Arts, Boston, MA
General Motors, Toledo, OH
JFK Airport Warehouse, NYC
Bronx Terminal Market, Bronx, NY
IKEA Home Furnishings, West Chester, OH
Salmon Bay Offices, Seattle, WA
TCP/Disney, Pasadena, CA
Yale University, New Haven, CT
Santa Ana, CA

Figure 1.1

1.6. References and Resources

1.6.1. Engineers can benefit from studying the following references. The references in blue text are included as additional study materials at the end of the course content.

Arthur, S, Wright, G. and Swaffield, J., *Operational Performance of Siphonic Roof Drainage Systems*, Building and Environment, No. 40, August 2004.

Arthur, S., Swaffield, J.A. and May, RWP, *Priming of a Siphonic Rainwater Drainage System*, CIB-W62-1998 International Symposium on Water Supply and Drainage for Buildings, Rotterdam, The Netherlands, 1998.

Arthur, S., *The Principles of Siphonic Roof Drainage*, PM Engineer Magazine, Business News Publishing, Troy, Michigan, July 2003, Vol. 9, No. 7, pp. 42-48.

Arthur, S., & Swaffield, J.A., *Siphonic Roof Drainage: Current Understanding*, Urban Water, Vol. 3, No. 1, pp. 43-52(10), 2001.

Arthur, S., & Swaffield, J.A., *Siphonic Roof Drainage : The State of the Art*, Urban Water, Vol. 3, No. 1, pp. 43-52(10), 2001.

Arthur, S., & Swaffield, J.A., *Siphonic Roof Drainage System Analysis Utilizing Unsteady Flow Theory*, Building & Environment – Vol. 36, No. 8, pp. 939-948(10), 2001.

Arthur, S., & Swaffield, J.A., *Numerical Modeling of the Priming of a Siphonic Rainwater Drainage System*, The Proceedings of CIBSE: Building Services Engineering Research and Technology, Vol. 20, No. 2, 1999.

Arthur, S. & Swaffield, J.A., *Understanding Siphonic Rainwater Drainage Systems*, CIB-W62-1999 International Symposium on Water Supply and Drainage for Buildings, Heriot-Watt University, Edinburgh, Scotland, 1999.

Bowler, R., and Arthur, S., *Siphonic Roof Rainwater Drainage – Design Considerations*, CIB-W62-1999 International Symposium on Water Supply and Drainage for Buildings, Heriot-Watt University, Edinburgh, Scotland, 1999.

Bramhall, M.A. and Saul, A.J., *Examination of the Performance of Syphonic Rainwater Outlets*, CIB-W62-1998 International Symposium on Water Supply and Drainage for Buildings, ISSO, Rotterdam, The Netherlands, 1998.

Bramhall, M.A. and Saul, A.J., *Performance of Syphonic Rainwater Outlets*, Eighth International Conference on Urban Storm Drainage, Sydney, Australia, 1999.

Bramhall, M.A. and Slater, J.A., *A Study of the Implementation of Analytical Design Software within a Civil Engineering Environment*, Third Association of European Civil Engineering Faculties, International Symposium on Civil Engineering Learning Technology, Cardiff, Wales, 1999.

Bramhall, M.A., and Saul, A.J., *The Hydraulic Performance of Syphonic Rainwater Outlets Relative to their Location within a Gutter*, CIB-W62-1999 International Symposium on Water Supply and Drainage for Buildings, Heriot-Watt University, Edinburgh, Scotland, 1999.

British Standard BS EN 12056-3:2000, Gravity Drainage Systems Inside Buildings, Part 3: Roof Drainage, Layout and Calculation, ISBN 0-580-36486-0, BSI 09-2000.

Ebeling, Olavi, *et al*., United States Patent No. 4,107,929, "Rain Water Roof Outlet or Similar for a Building," (August 22, 1978).

Ebeling, Olavi, *et al*., United States Patent No. 4,112,691, "Rain Water Roof Outlet or Similar for a Building," (September 12, 1978).

Ebeling, Olavi & Lunden, Risto, United States Patent No. 4,492,491, "Rain Water Roof Outlet or Similar for a Building," (January 8, 1985).

Ebeling, Olavi, United States Patent No. 4,652,365, “Waste Screen (for Roof Drainage Outlets),” (March 24, 1987).

Ebeling, Olavi & Lunden, Risto, United States Patent No. 4,683,685, “Draining Arrangement for Roof,” (August 4, 1987).

Fried, Erwin & Idel’chik, I.E., Flow Resistance: A Design Guide for Engineers, Taylor & Francis Ltd, Philadelphia, PA, 1989.

Hanslin, R., *Siphonic Rain Water Drainage System*, Geberit, AG, CH-8645, Jona, Switzerland.

Heald, C.C., Cameron Hydraulic Data Book, 17th Edition, Ingersoll-Rand, Woodcliff Lake, NJ, 1992.

Jöhri, H., *New Knowledge from the Geberit-Pluvia Roof Drainage Department*, Geberit, AG.

Lockhart, R.W., and Martinelli, R.C., *Proposed Correlation of Data for Isothermal Two-Phase, Two Component Flow in Pipes*, Chemical Engineering Progress, Vol. 45, No. 1, 1949.

May, RWP, Escarameia, M., *Performance of Siphonic Drainage Systems for Roof Gutters*, Report SR 463, HR Wallingford, 1996.

Rattenbury, J.M., *Fundamentals of Siphonic Roof Drainage*, PM Engineer Magazine, Business News Publishing, Troy, Michigan, March 2001, Vol. 7, No. 3, pp. 52-58.

Rattenbury, J.M., *Hydraulic Head: The Missing Link in Roof Drainage*, Plumbing Systems & Design Magazine, Chicago, Illinois, Vol. 2, No. 3, May/June 2003, pp. 8-12.

Rattenbury, J.M., *et al.*, ANSI/ASME A112.6.9-2005, “Siphonic Roof Drains,” American Society of Mechanical Engineers, New York, NY, 2004.

Roche, A.O., *et al.*, ANSI/ASME A112.6.4-2003, “Roof, Deck and Balcony Drains,” American Society of Mechanical Engineers, New York, NY, November 2003.

White, Frank M., Fluid Mechanics, Second Ed., McGraw-Hill Publishing Company, New York, NY, 1986.

Whitworth, P., *et al*., ASPE Data Book, Chapter 2: Storm Drainage Systems, American Society of Plumbing Engineers, Westlake Village, California, 1990.

Wright, G. B., Swaffield, J.A, & Arthur, S., *Investigation into the Performance Characteristics of Multi-Outlet Siphonic Rainwater Systems*, Building Services Engineering Research and Technology, 1 October 2002, vol. 23, no. 3, pp. 127-141(15).

2. Hydraulics of Siphons

2.1. Siphon, Defined

2.1.1. A siphon can be defined as follows: "A siphon is a continuous tube that allows liquid to drain from a reservoir through an intermediate point that is higher than the reservoir, the up-slope flow being driven only by barometric pressure without any need for pumping. It is necessary that the final end of the tube be lower than the water surface in the reservoir."

2.1.2. It is therefore a bit unfortunate that siphonic roof drainage is described as siphonic since the pipe (or continuous tube) is not configured to pass at a point above the roof level. In siphonic roof drainage systems, horizontal runs are installed flat (without pitch). However, siphonic systems can be described as driven by barometric pressure because the vertical drop in the piping system with a final discharge to an atmospheric manhole generates negative pressures within the piping system.

2.1.3. Although the word "siphon" is used to characterize this type of roof drainage system, these systems can and normally do operate as atmospheric systems with both water and air present. It is not actually necessary for the piping system to be fully primed and in a siphon mode to provide positive drainage.

2.2. Energy Equation (Bernoulli Theorem)

2.2.1. The energy equation for fluids is basically an expression of energy conservation. A fluid either in motion or at rest has a total energy that is constant, if we suspend the reality of energy losses due to the viscous effects of flow through pipes. The energy equation is shown as Equation 2.1:

$$\frac{P_1}{\rho g}+\frac{V_1^2}{2g}+Z_1=\frac{P_2}{\rho g}+\frac{V_2^2}{2g}+Z_2$$

Equation 2.1

2.2.2. In this equation form, each term has the units of feet of water column (ft w.c.), which is shorthand for foot-pounds of energy per pound of fluid. This equation describes a fluid as having three basic forms of energy. A fluid can have static pressure energy ($P/\rho g$), which is the energy taken to compress the fluid against the pipe walls. It can also have kinetic energy ($V^2/2g$) which is the energy gained by acceleration to a certain velocity (V). Finally, the fluid can have potential energy due to it's elevation (Z) in a gravity field (in feet). As will be shown further in this program, potential energy (Z) tends to be the most important parameter in siphonic roof drainage. However, the varying conditions of both static head and velocity head are also closely tracked in hydraulic calculations.

2.2.3. The Energy Equation simply demonstrates that in an ideal fluid, total energy (the sum of all three energy forms) is conserved. However, although energy is conserved, energy can be converted from one form to another. For example, anyone who has dived to the bottom of a pool or has gone snorkeling knows that as one increases their depth (i.e. goes down in elevation, Z), the static pressure (P) increases and it is felt at the ear drums. Air flowing over an airplane wing has to flow faster over the top surface than over the bottom. This difference in velocity (i.e. kinetic energy) creates a pressure differential and lift is created.

2.2.4. However, the energy equation is only an idealized construct used to describe the conservation and transfer of energy in fluids. In real life, the flow of any fluid results in irreversible losses of energy. Such loss is usually referred to as friction and comes in the forms of “Major” losses and “Minor” losses. So Bernoulli’s Theorem can be more completely represented in Equation 2.2:

$$\frac{P_i}{\rho g}+\frac{V_i^2}{2g}+Z_i=\frac{P_e}{\rho g}+\frac{V_e^2}{2g}+Z_e+\sum_{j=1}^{m}\left(h_f\right)_j+\sum_{k=1}^{n}\left(h_t\right)_k$$

Equation 2.2

2.2.5. This equation is a more complete form for the conservation of energy in a real fluid. Two additional terms appear on the right hand side. On the left hand side are the three energy forms of a fluid at the inlet of a pipe or fitting (shown by the subscript i). On the right hand side are the three resulting energy forms at the exit (indicated by subscript e). However, as the fluid passes through the pipe or fitting, energy is lost so the Total Energy described by Bernoulli on the exit side is not equal to the energy possessed at the inlet. So in order to estimate what the resulting static pressure (P) is, we have to estimate the energy lost. There are major losses through straight lengths of pipe (indicated by the summation of all losses h_f) and there are minor losses through fittings (indicated by the summation of all losses h_t). These terms are consistent with the annotations of ASPE Technical Standard 100.

2.3. Major Losses (H_f)

2.3.1. General: Major losses of energy are those created by flow of fluid through a conduit or pipe. In the context of siphonic roof drainage, major losses are those caused by flow through striaght sections of pipe. The energy loss of fluids due to flow through pipes is typically quantified by the Darcy (or Darcy-Weisbach) equation.

2.3.2. The Nature of Accepted Equations: The capability to precisely predict energy loss in water flowing through pipes (especially if it has some small percentage of entrained air) is not possible by any known means (at least means accessible to the practicing engineer). Hydraulic energy loss calculations are estimates at best, but they are good enough tools for engineers to predict to a fairly close certainty the behavior of a fluid system. Exotic numerical methods are not necessary. However, there is always room for improvement and research and testing specific to siphonic roof drainage continues in order to refine certain parameters like pipe roughness and resistance coefficients.

2.3.3. Major Losses and the Darcy-Weisbach Equation: The Darcy-Weisbach equation is an important and widely used equation in hydraulics. The equation estimates the head loss from friction over a given length of pipe at a given diameter. The equation was initially a variant on the “Prony Equation” as expressed by Henry Darcy of France. It was further refined into the form used today by Julius Weisbach in 1845. Darcy-Weisbach is shown here as equation 2.3:

$$h_f=f\left(\frac{L}{D}\right)\frac{V^2}{2g}$$

Equation 2.3

2.3.4. In this equation, the term f is a friction factor specific to the fluids Reynold's Number and the pipe inner diameter and surface roughness. The term L is the pipe length and D is the pipe inner diameter. The final term, of course, is the fluid's kinetic energy.

2.3.5. Colebrook White Equation: This equation is used to solve in a numerical fashion the friction factor (f) appearing in the Darcy Equation. This equation is a function if the fluid Reynolds Number, kinematic viscosity and absolute roughness. This equation is shown here as equation 2.4:

$$\frac{1}{\sqrt{f}} = -2\log_{10}\left[\frac{2.51}{\mathrm{Re}\sqrt{f}} + \frac{\varepsilon}{3.71D}\right]$$

Equation 2.4

2.3.6. The absolute roughness value (ε) for a given pipe material should be attained by accepted references or pipe manufacturer data.

2.3.7. As mentioned above in 2.3.5, this equation has to be solved with numerical techniques. The term f appears on both sides of the equation. On the left side it is part of a square root function, which is ordinarily not difficult to work with. However, on the right side it appears inside the Logarithmic function. This makes it impossible to solve directly for f. Therefore, today's method for solving for the value of f involves computer analysis.

2.4. Minor Losses (H_t)

2.4.1. General: Minor energy losses are those caused by changes in direction, changes in velocity, mergers of flow streams, entrance into roof drains and dispersal of water from a high velocity to an atmospheric chamber.

2.4.2. Resistance Coefficients: The resistance coefficient of any minor loss can be defined as shown in Equation 2.5:

$$h_t = K_i\left(\frac{V^2}{2g}\right)$$

Equation 2.5

2.4.3. In this equation, the ratio of the overall minor loss of energy (h_t) and the kinetic energy of the fluid passing through the loss source is the resistance coefficient (K_i). Resistance coefficients are dimensionless values and are a unique characteristic of fittings, roof drains, and flow mergers. Turbulent flow conditions in pipes and fittings preclude the ability to successfully evaluate resistance coefficients mathematically. The resistance coefficients for elbows, increasers, reducers and other devices have been extensively studied and can be found in many engineering references such as Crane Technical Paper 410.

2.4.4. Entrance losses through roof drains are highly dependent on the geometry of the roof drain. Since such geometry varies significantly from manufacturer to manufacturer, each drain design must be tested in accordance with ANSI/ASME A112.6.9 to establish the resistance coefficient under controlled conditions. However, although geometry may vary significantly, the actual resistance coefficients do not vary to the point where different drain manufacturer models are incompatible.

2.4.5. Resistance coefficients for flow mergers, while also extensively studied, can not be expressed as a single number for a given fitting geometry. These coefficients are also dependent on the ratio of flows into the merger leg and branch and therefore have to be evaluated for the specific flow conditions encountered. Interestingly, it is common for either a leg or branch of a flow merger to have a negative resistance coefficient which at first may suggest that a flow stream gains energy. This is actually the case, but the energy is gained from the other merging flow stream as momentum is exchanged between the two flow streams.

2.4.6. Velocity Head Loss at Exit: As the flow streams from several drains merge together into a single pipe and proceed down the stack and out the point of discharge, a certain amount of kinetic energy is gained by the water on the way down. This energy is ultimately dispersed into the storm drainage system and can not be recovered and is therefore considered one of the several minor losses experienced by the system with a resistance coefficient of 1.0. This energy loss is always accounted for in hydraulic calculations.

2.5. The Siphonic Equation

2.5.1. The “Siphonic Equation” summarizes the main purpose of the hydraulic calculations involved in sizing siphonic roof drainage piping. In traditional design, pipe size is based only on the quantity of water to be drained, the pipe pitch and the pipe roughness. In siphonic roof drainage, pipe pitch is not a factor, but pressure loss (i.e. pressure differential) becomes a new parameter. Sizing a siphonic roof drainage system is less like sizing drainage pipe and more like designing a chilled water loop or a domestic water distribution system.

2.5.2. To understand the similarity better, we return to Equation 2.2:

$$\frac{P_i}{\rho g}+\frac{V_i^2}{2g}+Z_i=\frac{P_e}{\rho g}+\frac{V_e^2}{2g}+Z_e+\sum_{j=1}^{m}\left(h_f\right)_j+\sum_{k=1}^{n}\left(h_t\right)_k$$

2.5.3. If we consider a typical system consisting of drains on a roof and a point of discharge, we can designate the inlet (i) at the drains and the exit (e) at the point of discharge. At both the inlet and exit, the pressure is atmospheric. Therefore, the static pressure terms can be dropped from both sides of the equation. Also, the velocity of water ahead of the drains (inlet) is assumed to be small in comparison to the other terms so it can be dropped. Finally, the velocity at the exit (e) is quite significant. This is the remainder of the kinetic energy gained by the water on its way down from the roof. Since this kinetic energy is ultimately dispersed into the storm drainage system, it is considered a loss. It is therefore placed within the summation of Minor Losses with a resistance coefficient (K) of 1.0.

2.5.4. When we rewrite the remaining terms, the resulting equation becomes:

$$Z_i - Z_e = \sum_{j=1}^{m} \left(h_f\right)_j + \sum_{k=1}^{n+1} \left(h_t\right)_k$$

Equation 2.6

2.5.5. This equation tells us that the energy available to the system is the difference in height between the roof drains and the point of discharge ($Z_i – Z_e$). This energy is in the form of potential energy and is referred to as the "Disposable Head." The energy required to overcome the irreversible energy lost at a given flow is represented by the sum of all of the major and minor losses as shown on the right side of Equation 2.7. The sum of the major and minor losses in any piping system is commonly referred to as a "System Curve."

2.6. System Curves

2.6.1. General: A system curve is a characteristic of a piping system. It represents the energy required to achieve a particular flow through the piping system over a range of flow. Because the Darcy-Weisbach Equation (Equation 2.4) is a function of the square of the velocity (V), system curves are approximately parabolic in shape. For a siphonic roof drainage system the system curve is the sum of all of the major and minor losses from the roof drain inlet to the point of discharge. For a system with multiple drains manifolded together to one point of discharge, system curves for each drain path need to be analyzed. Figure 2.1 below shows a representative system curve:

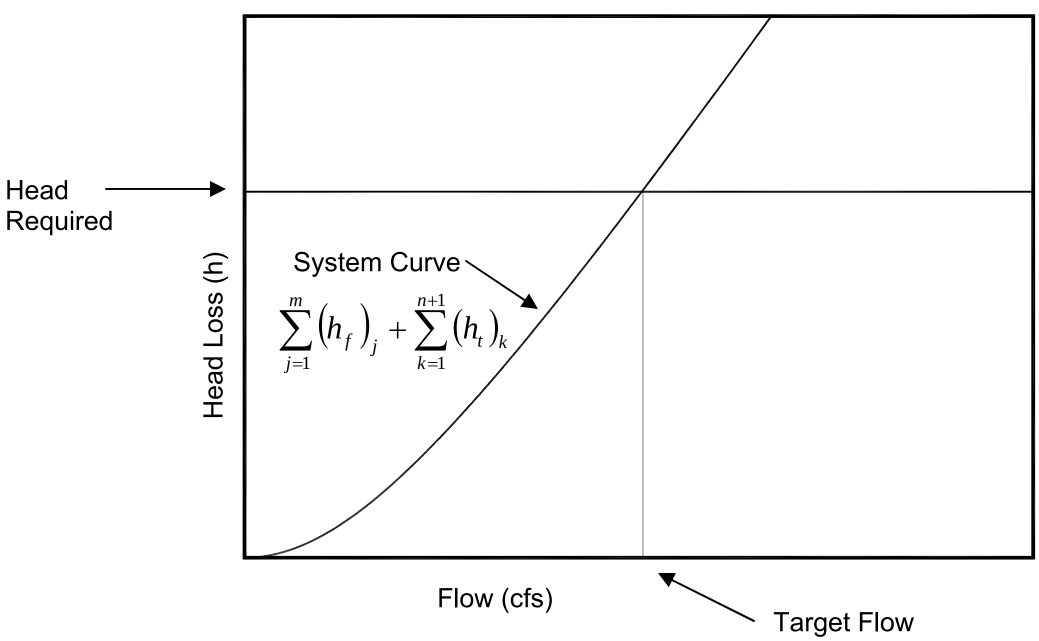

Figure 2.1: "Representative System Curve"

2.6.2. As mentioned, the system curve is approximately parabolic because head loss is proportional to the square of the flow (or velocity). It is not exactly parabolic because it is also proportional to Reynold's Number (Re) which also varies with velocity. Wherever the target flow intersects the curve, the head loss is determined on the vertical scale (Y-axis). This is the amount of energy needed to induce that flow to overcome the irreversible energy lost.

2.7. Disposable Head:

2.7.1. In a siphonic roof drainage system, the energy available is the difference in height between the roof drains and the point of discharge. This is typically referred to as the "Theoretical Disposable Head." It is considered theoretical because it is the maximum amount of potential energy available However, in practice, the storm sewer into which a roof drain system connects to can become surcharged. Usually, civil engineers design storm drainage system for lower intensities because there is a great deal less "hydraulic risk" entailed because "local ponding" can make up for storm drainage capacity.

2.7.2. This, however, is not the practice with roof drainage, so a system designed for a higher rainfall intensity (draining the roof) may frequently tie into a piping system catering to an overall lower capacity. Therefore, it is prudent to coordinate the discharge capacity of the roof drainage system with the civil engineer. If the storm drainage system can become surcharged by the roof drainage load, the manhole or catch basin water level will submerge the discharge pipe and the atmospheric pressure assumption made in Section 2.5.3 is no longer applicable. Therefore, the actual Disposable Head would be the difference in height between the roof drains and the rim elevation of the catch basin or manhole to which the system connects.

2.7.3. The actual Disposable Head used to design a system will determine the minimum flow capacity of a fully primed system discharging into a surcharged storm system. However, it may be possible for the storm system to be not charged or fully charged. This <u>increases</u> the disposable head to the theoretical disposable head thereby increasing the drainage capacity and operating velocities. For reasons that will be discussed further on, it is important to evaluate the operating velocities and the static pressure through the system at this increased capacity to ensure that cavitation will not occur or maximum drain capacities are not exceeded.

2.8. Analogy to Pump Selection

2.8.1. With terms such as "System Curve" and "Disposable Head" defined, it is useful to compare siphonic roof drainage design to a more common and familiar engineering task: selecting a centrifugal pump. Refer to Figure 2.2:

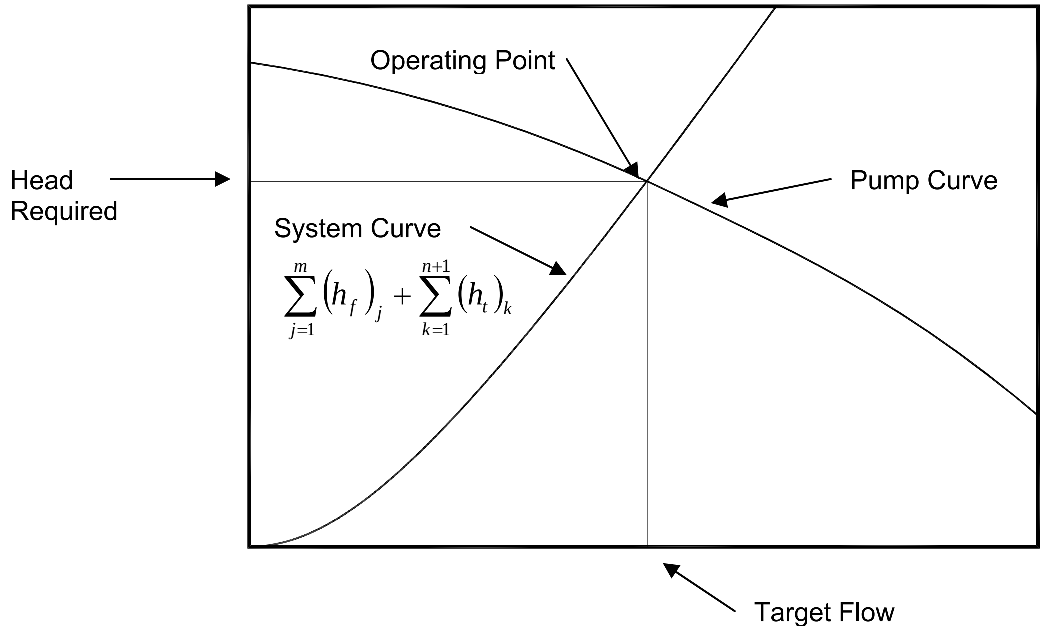

Figure 2.2: "Determining the Operating Point"

2.8.2. In the figure above, there is a representative system curve for a piping system. At the target flow, there is a certain head required to attain that flow to overcome the irreversible energy losses caused by friction and turbulence. This point on the graph is referred to as the "Operating Point." In mechanical systems a pump would be required to provide the required head to achieve flow at the desired Operating Point. Normally the engineer would refer to pump manufacturer pump curves to select an appropriate size pump that has a performance curve that passes through or just above the Operating Point. Usually, this is done by finding the appropriate pump casing size and then selecting from several impeller diameters. In other cases, the pump could be operated by a variable speed drive to vary the position of the performance curve up or down to maintain the desired Operating Point. Some systems, depending on their function, can vary the System Curve itself by modulating valves to increase or decrease flow resistance.

2.8.3. In siphonic roof drainage design, the design process is very similar. But instead of selecting a mechanical pump to cater to a particular system curve, the engineer manipulates the piping system to achieve the necessary Operating Point. First, refer to Figure 2.3:

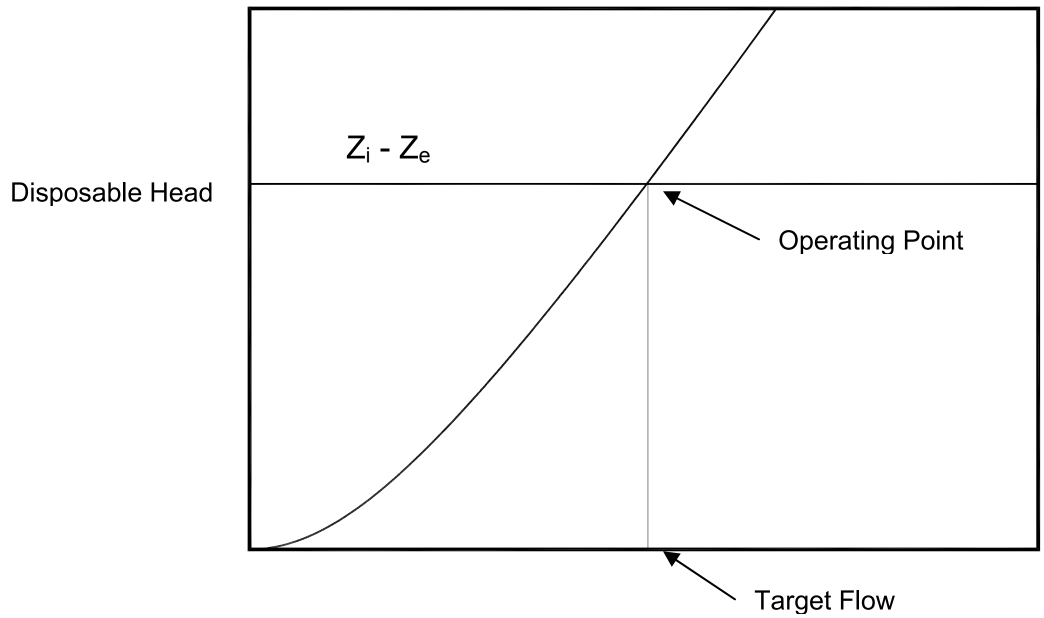

Figure 2.3: Siphonic Roof Drainage Operating Point

2.8.4. In Figure 2.3, the System Curve is represented as in Figures 2.1 and 2.2. The target flow is the sum of all the flows into each connected roof drain as determined by the Rational Method. It is the minimum flow required to drain a roof of a fixed area at the selected rainfall intensity. Instead of a pump curve as shown in Figure 2.2, the energy available is represented by the horizontal line. This is the Disposable Head as described above. It is a fixed value, because the height of the building is fixed and this potential energy is available to the system regardless of the flow rate. The goal of the engineer is to create a system curve that intersects the operating point or gets as close as possible. This is where hydraulic calculations come into play.

2.8.5. Ideally, a designer would be able to quickly arrive at the precise arrangement of pipe sizes, reducers, drains, etc. to achieve the required Operating Point. In practice, however, this is not quite possible without spending an inordinate amount of time testing out the nearly infinite number of possible pipe configurations. Therefore, the design process is an iterative one whereby the engineer arrives at a solution that is "good enough." The designer comes up with the "good enough" solution by evaluating certain error parameters and trying to stay within error limits. Refer to Figure 2.4:

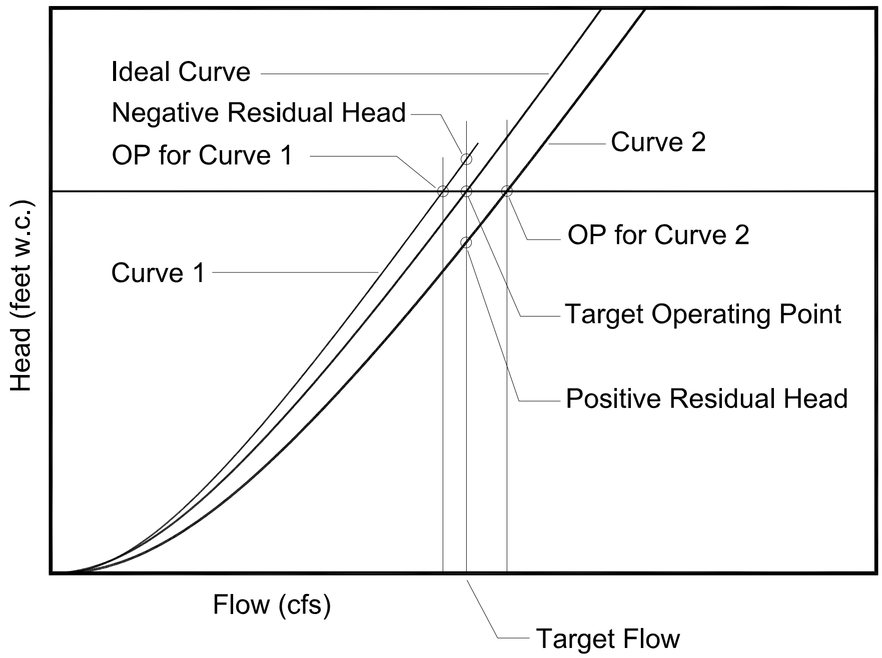

Figure 2.4: Residual Head

2.8.6. In the Figure above, the "ideal" curve passes through the Target Operating Point. This represents the Target Flow for the system and the available Disposable Head to the system. Curve 1 represents a system that is sized such that the actual Operating Point falls short of the Target. This system is undersized because more energy is required to achieve the Target Flow than there is available. This system is said to have a "Negative Residual Head" which is the difference between the energy available and the energy required.

2.8.7. Curve 2 represents a slightly different system which results in an Operating Point that exceeds the Target Flow. This is not a problem unless the resultant capacity requires a rainfall intensity that occurs extremely infrequently. Also, if the system does achieve this flow, the designer must ensure that minimum static pressures in the system do not result in cavitation. Curve 2 represents a system with a "Positive Residual Head" because the Target flow can be achieved with less energy than is available.

2.8.8. Ideally, a system should have a slightly positive residual head, about less than three feet of water column. The curves above represent the flow path from a single drain to the discharge point. For a system with multiple drains, this analysis must be repeated for each drain to achieve what is referred to as "Balance."

2.8.9. Figure 2.5 below shows an example of a system with three drains A, B and C:

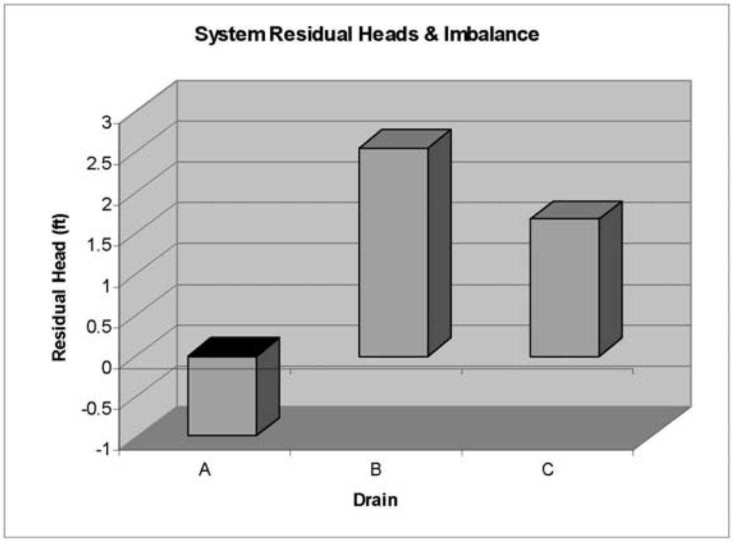

Figure 2.5: Residual Heads & Imbalance

2.8.10. Drain A has a negative residual head of about 1 foot. Drain B has a positive residual head of 2.4 feet and C has a positive residual head of 1.5 feet. "Imbalance" of a system is the difference between the maximum and minimum residual heads. In this case it is 2.4 feet + (-1.0 feet) or 3.4 feet. This system has both a negative residual head and a higher than acceptable imbalance so it would have to be resized to achieve better results. Refer to Figure 2.6 below:

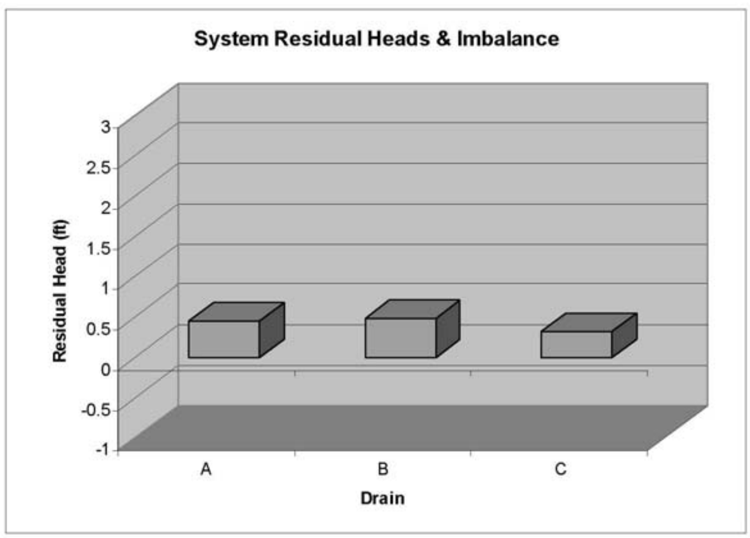

Figure 2.6: Balanced System

2.8.11. This is an evenly balanced system with all slightly positive residual heads. The accepted rule of thumb for imbalance is 10% of the Disposable Head or 3 feet, whichever value is less. A building 40 feet high would have an imbalance limit of 3 feet. A one story building of 15 feet would have an imbalance limit of 1.5 feet.

3. Siphonic Roof Drains

3.1. General: Siphonic roof drains are actually very simple devices. They include all of the familiar components common to traditional roof drains, but have one added part to make the connected piping system sustain full-bore flow for as long as possible. Figure 3.1 shows a cut-away of a typical siphonic roof drain with all its required components:

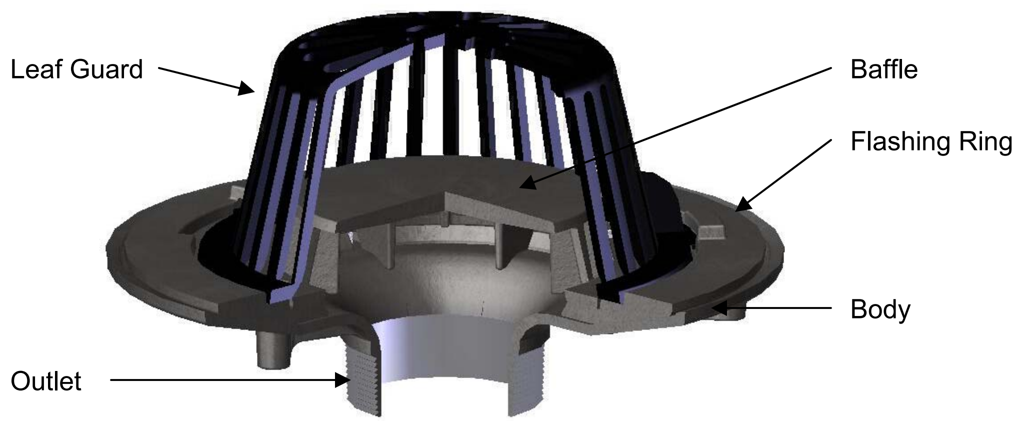

Figure 3.1 (Courtesy of the Jay R. Smith Manufacturing Company)

3.2. Drain Body: The drain body has the same function as any traditional roof drain existing on the market. The purpose is to provide a means of mounting the fixture to a roof deck system with attachment hardware with drilled hardware connections or other mounting accessory located underneath. It also provides a spigot outlet connection for the attachment of drainage pipe below the roof deck surface. The top surface of the outer rim functions as a beveled surface to accept a waterproofing membrane system to be clamped down under pressure using the flashing ring with bolts. These bolts engage the inner rim of the flashing ring and thread into associated threaded holes in the drain body using fastening hardware thereby clamping the roof membrane system and providing a water-proof seal around the drain body and roof penetration. The center of the drain body consists of a spigot outlet protruding downward and beveled at a suitable angle to facilitate the sand casting process used in its manufacture.

3.3. Flashing Ring: The flashing ring has the same function as any traditional roof drain existing on the market. The lower surface has a beveled surface to mate with the outer top surface of the drain body. The inner rim has protrusions to accept fastening hardware as described above. The inner rim has a depression on the upper surface that receives the base of the air baffle.

3.4. Air Baffle: The air baffle consists of a disc shape. Most designs include fins or blades that protrude from the bottom of the disc. They function as straightening vanes similar in form and purpose as those used in anti-vortex plates used in pump suctions and other similar applications.

3.5. Dome Strainer (Leaf Guard): All roof drains are required to include a leaf guard accessory to comply with plumbing codes. This leaf guard has in fact been a standard roof drain accessory for roof drains since the 1940’s. This leaf guard on a siphonic roof drain has the same function as any other roof drain available on the market. The leaf guard functions as a strainer or sieve to trap foreign objects and prevent their ingestion into the drainage pipe system. This leaf guard functions only as a strainer of debris and has no effect on the performance of the drain itself. During performance testing, a roof drain product is required to be tested both with and without the leaf guard to assess the difference in performance (if any) relative to flow rate and resistance coefficient. However, for most drain designs, the leaf guard has an immeasurable effect on drain performance.

3.6. Governing Standard: Siphonic roof drain performance testing is governed by ANSI/ASME A112.6.9. Drains of different manufacture and style that are tested to this standard should be considered as compatible. In other words, there is no need or reason to have to select one proprietary drain to serve as the basis for the piping system design.

4. Operating Description

4.1. General: Siphonic roof drainage systems operate for most of their lives in a part air, part water condition. Basically, a siphonic roof drainage system is simply “holes” on a roof into which water drains, just like any traditional system. Siphonic roof drainage systems do not have to be in siphonic mode to be effective. They operate with some if the cleansing and high-capacity benefits when only part-primed. They tend to operate toward siphonic condition in response to increased rainfall intensity and become part-primed during decreased rainfall intensity. In other words, siphonic roof drainage systems are <u>dynamically stable</u> and offer reliable and robust performance even though established hydraulic analysis is not perfect. Siphonic roof drainage systems tend to approach full-bore flow with increasing rainfall intensity. If rainfall rate or predicted drainage rate falls short, ingested air slows down the overall drainage capacity until the drain baffles are submerged and siphonic drainage takes over again. This process repeats during a rainfall event until the storm event subsides. Even if some drains ingest air while others don’t, the part-primed condition continues and water is drained effectively off of the roof. Air entrainment is a normal part of their operation and it does not suddenly halt drainage. It is simply carried in suspension with the water.

4.2. Zero Rainfall: When not raining, the piping and roof are dry. No significant amount of water is retained in the piping. Of course, no roof surface is perfectly pitched and some standing water may be present, but this is typically evaporated over a 24 to 48 hours. Also, no pipe system is installed perfectly level so some residual water may be present in the piping after a rain event, but air convection up through the piping typically assists in evaporation. The question is frequently asked about the effect of ice and snow. This technology was developed and first applied in Scandinavia. If in your region, it is prudent practice to heat trace roof drains, then the same can be done for siphonic roof drains. In general, however, the warm air from within the piping system tends to rise up and through the roof drains and cause melting in the immediate area around the drain.

4.3. Light Rainfall

4.3.1. Drain Weir Flow: During periods of light rainfall, such as a drizzle, well below the design rainfall intensity, water simply flows toward the drains and into the piping system just as if the drains were traditional. This flow condition is referred to as weir flow where the hydraulic head built up around the drains is the only energy inducing flow into the system. In this condition, the piping system is atmospheric.

4.3.2. Open Channel Flow: Inside the piping, some water builds up along the length of the horizontal piping. Although there is no pitch in the pipe to induce open channel flow, there is always an end to the horizontal pipe where there is an elbow pointing down connecting to a vertical stack. Water simply cascades over the end of this elbow like water over a weir and an open channel flow condition is created with a balance between water entering and water cascading out at the end.

4.4. Moderate Rainfall

4.4.1. General: During moderate rainfall events, intensity is highly variable both temporally and spatially. Water distribution is affected by the velocity and direction of wind and by the position of adjacent vertical surfaces. Empirically derived equations (that are used as part of the accepted standard of care by practicing engineers) are not perfect. Pipe roughness values are close approximations, but still approximations. Water viscosity varies with temperature. Therefore, siphonic roof drainage systems are subject to the same multitude of variables as traditional systems (Manning's Formula is derived by the same type of empirical trial and error and can be subject to variation due to pipe roughness and temperature). But the sizing methods are "good enough" for drainage pipe.

4.4.2. When it rains at an intensity below the design rainfall intensity, siphonic roof drainage systems are in a constant state of flux, changing from one flow pattern to another. The behavior of such systems is to progress toward full-bore capacity as rainfall intensity approaches the design intensity. At about fifty percent of the design rainfall intensity, siphonic systems fluctuate in and out of full bore operation. As intensity increases, the time spent in full-bore flow increases and time spent in part-primed condition diminishes. As such, the depth of water on a roof will fluctuate, but since the observed periods between full-bore operation at a given rainfall intensity is much less than the time of concentration, the depths observed remain below the overflow settings on the roof.

4.4.3. Branch Piping: One interesting feature of siphonic roof drainage systems is that they can act as a set of individual drains acting siphonically or as a complete system with all drains hydraulically connected (i.e. in full bore flow). At moderate rainfall intensities, each drain and the connected branch pipe can fully prime, even if the manifold and stack are only part-primed.

4.4.4. Wavy Flow: Wavy flow occurs primarily due to the discharge of a relatively high velocity stream from branch piping into the manifold. In other words, the flow from a branch goes from a small diameter to a larger pipe diameter and therefore decreases in velocity. The flow from the branch is described as "critical flow" which means the velocity exceeds the velocity of the propagation of a wave over a free surface. It is analogous to "super-sonic" flow of air. The water discharging into the larger manifold slows down to a "sub-critical" velocity. Much like how air makes transition from supersonic to subsonic flow through sudden shock waves, water undergoes this transition by a sudden hydraulic jump. These jumps form at the branch piping connections to the manifold and tend to propagate downstream. When the peaks of these waves do not touch the crown of the pipe, the flow pattern is referred to as wavy flow.

4.4.5. Plug Flow: As the manifold continues to fill in response to increased rainfall intensity, the peaks of wavy flow will eventually touch the crown of the pipe. When this occurs, pockets of air become trapped between two wave peaks and are then dragged along with the wave flow. When this occurs the flow pattern is referred to as plug flow.

4.5. Design Rainfall

4.5.1. General: Design rainfall is the rainfall in inches per hour selected by a designer based on statistical averages for a given region. At this intensity or approximately near this intensity, the piping system is intended to be at full bore flow with some intermittent air entrainment. Although a design rainfall intensity is selected as the basis for adequate pipe sizing for a system, it is extremely rare if not impossible for any given system to be receiving rainfall at exactly the design rainfall intensity. The design rainfall is only a design parameter that establishes a particular probability that a rainfall event near that value will occur during the lifespan of a building.

4.5.2. Bubble Flow: As the rainfall intensity approaches the design rainfall intensity, the plug flow pattern in the piping starts to increase in velocity and any remaining air in the piping tends to mix with the water to create a frothy or bubble flow. The air is carried along with water to the point of discharge and as the water to air ratio increases, the water becomes visually clearer (in clear sections of pipe in testing rigs).

4.5.3. Full Bore Flow: At about a water-to-air ratio of 95 percent, a siphonic roof drainage system is considered to be in full-bore flow. This state lasts only briefly during the lifespan of the system, but it does occur intermittently even at rainfall intensities much less than the design intensity. The actual flow capacity of the system is the greatest during full bore flow.

4.6. High Intensity Peaks

4.6.1. High intensity peaks can occur in severe weather. This is recognized in model plumbing codes. Any roof drain system is required to be accompanied by a secondary drainage system to protect the roof from overloading should there be either a blockage or a sustained period of rainfall above the primary systems design capacity.

4.6.2. For “flat” roofs, high intensity peaks can be tolerated for quite a long period of time, so they are of less concern. This is why 60 minute duration storms are typically used to select design rainfall intensity. Roofs with gutters or other geometries with low residual volume, high intensity peaks are more of a concern. Therefore, storm events with shorter return periods and shorter durations should be selected.

5. Rainfall Intensity

5.1. General: The nature of rainfall on any roof is random, transient and ultimately unpredictable at any given moment in time. Rainfall intensity varies both temporally and spatially over a catchment area during any storm. Therefore, engineers refer to statistical averages collected over time by NOAA and the National Weather Service. Statistical rainfall data is normally expressed in terms of Return Period and Duration. The selection of rainfall intensity is discussed in more detail in Chapter 5 of ASPE Technical Standard 100.

5.2. Rainfall Return Period: The Return Period of a storm is the statistical average (and sometimes extrapolated estimate) at which a storm of a certain total rainfall is expected to occur and is expressed in years. Model plumbing codes include rainfall data for 100-year storms. This means that there is approximately a 1% chance for that storm to occur in a given year during the lifespan of a building. A 2-year storm is likely to occur at about 50% of the time during the lifespan of a building.

5.3. Rainfall Duration: Rainfall data is also characterized by its duration. Sometimes a storm event is described as (for example) 6 inches of water in a two-hour period. This translates to 3 inches per hour. In model codes, the duration is 60 minutes. This means that for a 100 year storm of 60 minute duration having a total rainfall of X inches has an average rainfall of X inches per hour. However, during the 60 minute period, the storm varies in intensity greatly. It may start at some minimal intensity, increase to a peak rate greater then X inches per hour, and then subside, but the total rainfall in that 60 minute duration is X inches. In general, the shorter the duration for a storm of a given return period, the greater the peak intensity.

5.4. Time of Concentration: The definition of time of concentration seems to vary among civil engineering sources. There is one over-simplified version that describes the term as the time (T) it takes a drop of water to flow from the furthest point away from a drain over a drainage surface and enter into the drain. Part of this definition includes the properties of that drainage surface. The more the unevenness, roughness, and porosity of the surface, the greater the time of concentration. The meaningful property that is missed by the above definition is the storage capacity of the surface provides either by physical conditions or the porosity of the surface and the property of the drainage capacity of the drain at the accumulated depth of water ahead of it.

5.5. A more accurate way of defining time of concentration is the time it takes for drops of water to fall on the surface and contribute to an equal quantity of drops to enter the drain. In other words, "time of concentration" can be thought of as "time of saturation." When it starts raining, a certain amount of water flows into the drain immediately. In this case, weir flow into the drain prevails and water depth will slowly grow as the residual volume of the drainage surface starts to fill. This accumulation continues until the flow of water onto the surface (by rainfall) equals the flow into the drain (either by weir flow or siphonic action) and the surface achieves a steady state at some depth ahead of the drain.

5.6. Selection Based on Roof Type: "Flat" roofs (i.e. those with nominal pitch of 2% to 3%) typically have a long time of concentration. Therefore, the model codes are based on long return periods, but also long durations. However, roofs with a good amount of pitch or roofs draining to gutters have a much shorter time of concentration; therefore rainfall events with short return periods and short durations (about 2 to 5 minutes) should be selected for system design. Such short duration storm data is included in Appendix B of ASPE Technical Standard 100.

5.7. The important point to be made here is that the designer's selection of rainfall intensity rests on local rainfall data, roof geometry and discharge limitations (if any) to the site storm sewer system. A siphonic roof drainage piping system does not dictate the rainfall intensity. In fact, it is sized by hydraulic calculations to cater to the selected rainfall intensity. Finally, the selection of rainfall intensity should be factored into roof deck strength (especially if the roof deck is to be used to temporally detain water as a controlled-flow system) and overflow drain/scupper height.

6. Roof Drain Selection and Placement

6.1. Flat Roofs: Drain placement on "flat" roofs is normally dictated by structural and roof design criteria. The pitch of steel or the maximum thickness of tapered insulation usually establishes the maximum spacing between roof drains. These conditions are normally determined by the structural engineer and/or architect prior to the building design being handed over to the plumbing engineer. Siphonic roof drainage systems do not present any other special needs for roof drain placement, so the architect or engineer may simply lay out roof drains as they normally would.

6.2. Gutters: Gutters are not common in roof drainage design in the United States. However, some buildings with certain architectural designs may incorporate them. Continuous gutters provide a good way to reduce the number of drains and stacks that is otherwise not possible for flat, cricketed roofs. On the other hand, gutter systems have very little reserve volume to store water during those short-duration peaks in rainfall intensity. The roof drainage should therefore be sized for statistical rainfall of shorter return periods and duration, which will reduce the roof surface area for each drain thus requiring more drains. This needs to be evaluated by the designer.

7. Pipework Layout and Dimensioning

7.1. General: The layout of piping can be described as part science and part art. There is literally an infinite number of ways to lay out piping for a given set of drains. However, there are good ways to lay out pipe and less than efficient ways. Many times, people ask if it is possible to run pipe uphill (or in other words drop down and then back up to negotiate an obstruction). While in theory this is possible, it requires that the pipe system be full at all times (or be fully primed) to work. However, when it stops raining, the pipe system will drain down, except for the trapped segment of pipe. When it rains again, the trapped section will become a barrier for open channel flow and wavy flow and delay or completely prevent the priming process. Therefore, such a layout has to be avoided. In other words, piping should be laid level or drop downward in the direction of flow (with no pitch necessary for the horizontal sections). Also, pipe systems with two or more drains have to be “balanced” to ensure proper flow into each drain.

7.2. Assigning Flow to Drains

7.2.1. Tributary Area: The tributary area or catchment surface covered by a roof drain is the projected horizontal area calculated about the high points or ridges around a drain low point. The maximum flow to the drain is the catchment area times the design rainfall intensity. This method is referred to as the “Rational Method” and is represented in Equation 7.1

$$q_i = \frac{1}{43200} C I_d A_i$$

Equation 7.1 The “Rational Method”

7.2.2. In this equation, q is flow in cubic feet per second (cfs), C is a dimensionless runoff coefficient (normally C=1.0 for membrane roofs), I is the design rainfall intensity in inches per hour and A is the catchment area in square feet.

7.2.3. Influence of Vertical Surfaces: Quite often, roof surfaces to be drained are adjacent to vertical walls. If rain always fell perfectly vertical, the vertical surface would not need to be included in the catchment area of the roof below. However, wind driven rain will fall against the vertical surface thereby increasing the virtual catchment area. In Figure 7.1 below, Catchment Area A must also include 50% of the vertical surface up to a limit of 30 feet. However, because the direction of rainfall at any given time varies, Catchment Area A is also a variable that differs from that of Area B. Therefore, the drains from Area B <u>should not be connected to the drainage system serving Area A</u>.

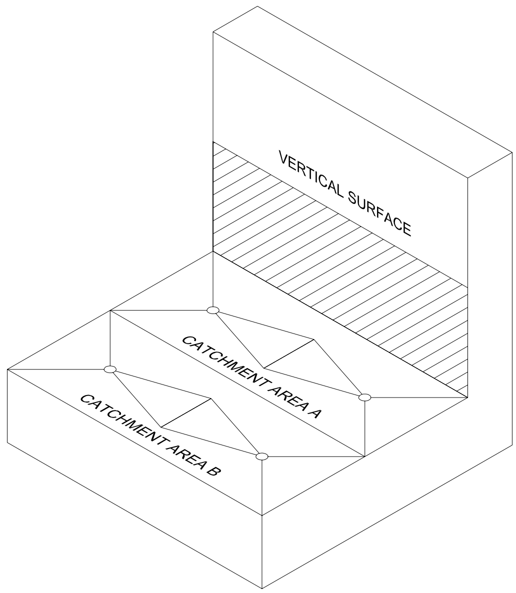

Figure 7.1: Vertical Surfaces

7.2.4. Influence of "Shadowing": In the same manner of vertical surface catchment, the same building configuration can create a shadow effect to the drains below. In Figure 7.2 below, the higher portion of the building can prevent rainfall to reach the drains of Area A while Area B sees the full influence of the rainfall. This also makes the virtual catchment area of Area A variable in a different way than Area B. Therefore, the piping system serving Area B <u>should not be connected to Area A</u>.

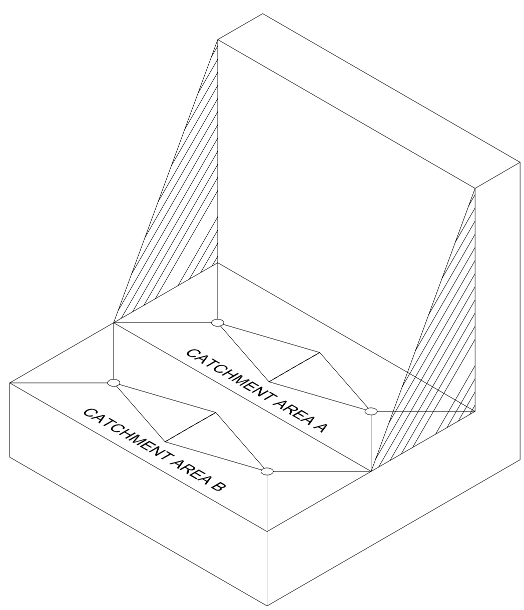

Figure 7.2: Building Shadowing

7.3. Recommended Steps for System Layout

7.3.1. General: As has been mentioned more than once before, there are almost limitless means by which siphonic roof drains can be connected together or run separately to convey the water down and out the building. The general goals of the designer are to:

1. Stay above ceiling spaces provided and above minimum clearances specified by the Architect or Owner,

2. Take the shortest path out the building to minimize piping,

3. Make sure all drains operate as intended by minimizing variability of rainfall between sets of drains (see Sections 7.2.3 and 7.2.4),

4. Make sure the system responds to increased rainfall by approaching full bore flow.

7.3.2. Steps:

1. First study the roof design and identify areas that are at different elevations and look for catchment areas of adjacent drains to see if they will work together manifolded. Avoid connecting drains from different elevations because this is difficult to do with any degree of accuracy in calculations. Determine the low point locations and the corresponding ridges and make the area calculations for each drain. This can be done quickest by using the Area function in AutoCAD or Microstation.

2. Look at the roof layout and see how secondary overflow is to be addressed. If by scuppers, make sure the flow path from the most internal spot is not obstructed by expansion joints, mechanical equipment or other items on the roof. If secondary drains, look at the roof layout for their placement. Note that it is not necessary to pair each primary drain with a secondary overflow drain. Because overflow drains function only to skim water off of the roof when rain water depth has reached a set level, they can be placed further down the roof and closer to the exterior wall.

3. Study the civil drawings to determine where the storm water is intended to go. This will form the basis for your strategy to place the stacks. Where possible, the stacks should be placed nearest the side of the building where the storm drain system leaves the property. There may also be a detention pond. The piping system should run towards that location.

4. Look at the building architectural layout to identify any available shafts or chases where stacks can be placed. Often stacks have to be offset on their way down from floor to floor. This is perfectly appropriate. Hydraulic calculations need to reflect the pipe and elbows.

5. Study the roof framing plan provided by the structural engineer or the architect. It is also a good idea to overlay the mechanical equipment on the roof and (if available) the ductwork layout. Lay out the location and direction of the piping given how you want to manifold together groups of drains, how the roof framing is configured and how you have to work around obstructions. If the piping is to be in a warehouse area with an Early

Suppression Fast Response (ESFR) sprinkler system, be sure to keep the piping at the distances specified in NFPA.

6. With the pipe routing, stack location(s) and points of discharge identified, begin hydraulic calculations by collecting the physical data of the piping system starting from the point of discharge back to the drains. At first, the pipe size has to be "guessed at." As a rule of thumb, the initial size should be about one half the size of an equivalent gravity drain pipe taken from the storm drainage sizing tables of the plumbing code. This results in a close first guess that will be further adjusted by further calculation. Enter in the pipe lengths, the fittings (elbows, reducers, junctions, etc), pipe elevations and height of vertical sections and then finish off each path with the roof drain. Calculate the pressure losses, velocities, static pressures, etc. and adjust the pipe sizing and configuration until satisfactory residual heads and balancing is achieved.

7. Keep in mind that it is best to manifold together drains with similar square footages. It is even better to connect them together in order of increasing square footage (if possible) because the end of the manifold nearest the stack will have the lowest internal pressure making it possible to draw in a larger quantity of water with about the same length and diameter pipe as the upstream drains. It can be problematic to tie a drain with a significantly smaller area at the end of a manifold. It is best to bring it separately to the stack and tie into the vertical stack. Hydraulic calculations will guide you on how far down that connection should be.

8. It is also best to allow for a length of piping running horizontally before connecting into a manifolded system. See Figure 7.3 below. In this example, there is a 4 inch roof drain that connects to a 3 inch branch pipe that then drops down about 30 inches and runs horizontally for nearly 6 feet and increases to a 4 inch branch that runs horizontally for about another 4 feet before angling into the manifold. The 4 inch drain was selected for its flow capacity, but there was a relatively high pressure differential in the manifold that made it necessary to neck down the connected pipe to create resistance and control the system curve to achieve a balanced system. By changing the length of the 3 inch pipe, the system curve was adjusted to get close to the target operating point. Hydraulic calculations verify this. The actual installation is shown in Figure 7.4 below.

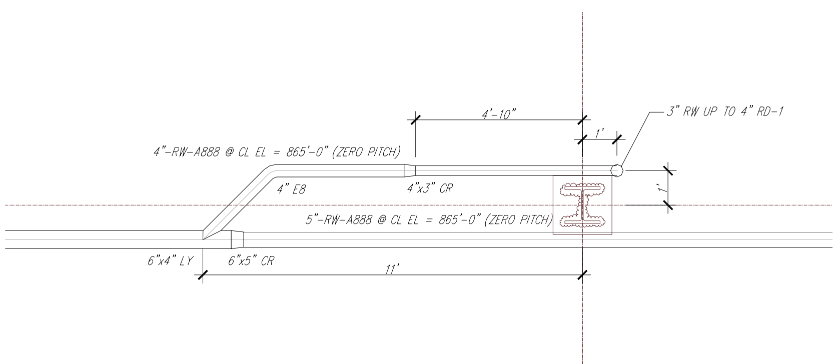

Figure 7.3: Sample Drain Connection to Manifold

Figure 7.4: Actual Installation

9. When designing the vertical stack, it is best to neck down a pipe size from the size of the manifold connecting to it. Testing and past practice has shown that this configuration causes the stack to enter into plug flow more quickly and draw down the internal pressure faster. This accelerates the priming process. In the other extreme, an oversized stack will not be able to prime quickly or be able to prime at all. Testing has shown that stack sizes up to 6 inches should have full-bore flow velocities of 6 to 7 feet per second. As a rule of thumb, stack sizes greater than 6 inch should have velocities one foot per second greater than the pipe diameter. In other words, a ten inch pipe should have a velocity of 11 feet per second. Computer software on the market may also have recommended minimum velocities for stacks. If so, these should be followed. Figure 7.5 below shows a sample stack design. Figure 7.6 shows the actual installation.

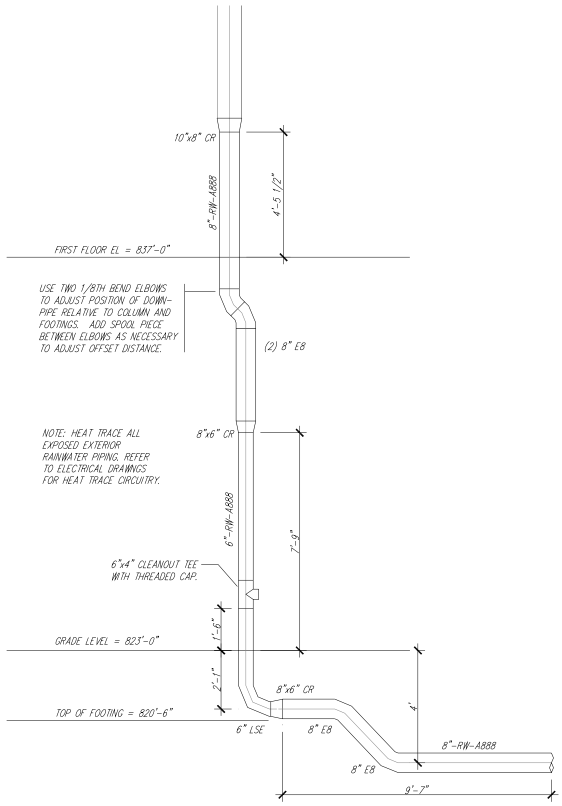

Figure 7.5: Sample Vertical Stack Design

Figure 7.6: Actual Installation

7.4. Residual Head: Residual Head was discussed in Section 2. A properly designed system should have resulting residual heads for each drain less than 3 feet of water column. Sometimes it is quicker to design the system to achieve the proper balancing regardless of the residual heads and then do one of two things (or both): manipulate the stack diameter to add resistance to the entire system and reduce the residual head, or increase the design rainfall intensity. Increasing the design rainfall intensity by just a few percent can knock down the residual heads quite effectively. The result is a system that has a greater drainage capacity by a few percent. CAUTION: If flow is increased, the interior pressure will drop. Always double check the static pressures to ensure cavitation will not result when the system primes. Also double check that the maximum capacity for each drain is not exceeded.

7.5. Balancing and Imbalance: Imbalance was also discussed in Section 2. A properly designed system will have a resulting imbalance of 10 percent of the Disposable Head or 3 feet, whichever is less. Balancing is easiest to achieve by using the method discussed in Step 7 of Section 7.3.2.

7.6. Minimum Pressures: When static pressure drops inside the piping, the pressure can approach the water's vapor pressure. If the vapor pressure is reached, cavitation will result as water flashes into vapor spontaneously. It is also important to note, that the exterior ambient pressure has an effect on how far down static pressure can be drawn for cavitation to occur. In general, though, static pressure should not decrease beyond negative 25 feet of water column.

7.7. Minimum Velocity: In indicator for the ability for a system to prime is the resulting full-bore velocity. Velocities in horizontal pipe sections below 2.5 to 3 feet per second indicate that the segment of pipe will have difficulty achieving plug flow that triggers priming. The velocities for vertical stacks were discussed in Step 8 of 7.3.2.

7.8. Varying Roof Elevations: As has been mentioned earlier, drains at different roof elevations should be piped separately.

7.9. Recommended Discharge Design: A roof drainage system has to eventually tie into the site storm sewer system. The storm sewer system is designed for open channel flow at atmospheric pressure, normally. Heavy rains may fill the system, however. In either case, the siphonic condition needs to terminate before connecting to the storm sewer system. The siphonic action can be terminated at any time simply by increasing the lower horizontal piping out to the equivalent "gravity" pipe size as determined from Manning's Formula or the tables in the plumbing code. This segment of larger pipe will not prime but operate in open channel flow with part water and part air. When this pipe is tied into a manhole or catch basin, the storm sewer sees no difference. The connecting manhole should also be ventilated by some means. This can be accomplished by installing an open grate instead of a sealed manhole, or use a perforated manhole cover. When this is not possible, a vent pipe can be extended from the manhole and terminated above grade. This ventilation will prevent the possibility of pressure fluctuations in the storm sewer system.

8. Pipe, Fittings and Couplings

8.1. Materials Used: Section 2.2 of the ASPE Technical Standard 100 has a list of suitable pipe and fittings. Note that hubless cast iron is listed, however, it should not be used in sections of drainage systems that exceed atmospheric pressure. This however, occurs perhaps only 10 percent of the time and mainly at the base of stacks draining tall buildings. In general, any material currently listed in plumbing codes can be used. If an alternative suitable material needs to be used, approval by the local inspecting authority needs to be obtained.

8.2. Materials to Avoid: First of all, a pipe material that is not specified in the governing plumbing code should not be used unless the local authority having jurisdiction gives consent. Also, any material that uses a joint system that can not withstand positive or negative pressure of any kind should not be used. Finally, pipe materials with wall thicknesses too thin to withstand full vacuum can not be used. In general, all of the normally approved drainage pipe materials can withstand these conditions.

8.3. Expansion Joints: Expansion joints may bee needed for either spanning across building expansion joints to account for building movement or for the thermal expansion or contraction of the piping itself. This is particularly important for long horizontal runs of thermoplastic piping. This is discussed further in ASTM F 2021 "Guide for the Design and Installation of Thermoplastic Piping Systems," which includes coefficients of thermal expansion for common plastics used for drainage pipe. Mechanical expansion joints have to be able to withstand both positive pressure (for pipe integrity testing under pressure) and negative pressure without allowing air infiltration. There are many products available, particularly those rated for use in pump suction applications.

8.4. Pipe Support: Pipe should be supported by traditional means as would be done for any drainage pipe system. Follow local code requirements and the recommendations of the pipe manufacturer.

8.5. Pipe Bracing: Lateral sway bracing is recommended for any drainage pipe suspended by a hanger rod greater than 18 inches. This is specified in the Cast Iron Soil Pipe Institute Specifier's Handbook. During the part-primed condition (i.e. like traditional drainage pipe with part water and part air), piping can sway slightly. Therefore the pipe should be held with a lateral brace about every 30 feet and at changes in direction. A typical method is to use a piece of black steel pipe and clamp it to the pipe and attach the other end to the building structure at a 45 degree angle. This is typical for "seismic bracing" although seismic displacement is not the function of the bracing here.

8.6. Pipe Anchoring: When addressing pipe thermal expansion and contraction, expansion joints need to be placed somewhere along the pipe length. In addition to the expansion joint, however, corresponding anchoring points have to be included to hold one end of the pipe fixed. Anchoring is also recommended for both the top and bottom of a drainage stack with riser clamps.

8.7. Pipe Integrity Testing: The only testing necessary for a siphonic roof drainage system is a simple pressure test to verify that joints are properly installed. Pipe testing criteria is included in ASPE Technical Standard 100. However, any additional testing required by the local inspecting official should also be conducted. More than once, inspectional authorities have asked for full operational testing (i.e. simulating a design rainfall event). However, the quantity of water required to achieve full bore flow as well as the method of properly distributing the water over the roof is so great that it is impractical and presents an unnecessary hazard to people handling hoses and pipes, etc. The ability of the system to work properly is documented through hydraulic calculations, just like hydraulically designed automatic sprinkler systems meeting NFPA 13 requirements.

9. Hydraulic Calculations

9.1. General

9.1.1. Pre-PC Calculation: Siphonic roof drainage technology was conceived in the late 1960's, well before personal computers were available to designers. Sizing methods prior to the early 1980's were by hand calculations. Although hand calculation poses a greater risk of human error, early systems worked successfully. This should demonstrate that a good amount of "wiggle room" is allowed for these systems. However, hand calculations are time-consuming, not to mention more prone to error. The introduction of the desktop computer and software packages capable of performing the many repetitive calculations necessary to design an accurate system has replaced the practice of hand calculation, even with a spreadsheet.

9.1.2. Automatic Sprinkler Analogy: Many years ago, automatic sprinkler systems were sized from hand-calculation. At one time, a "pipe schedule" method was used. However, it was determined that more thorough hydraulic analysis was necessary, but such calculations were performed by hand. But today, design of automatic sprinkler systems is done principally with computer software. It has become the accepted "standard of care" in the industry. This is also true for siphonic roof drainage systems.

9.2. Software

9.2.1. As mentioned above, hand calculations are time consuming and more prone to human error. Therefore, the use of computer software has become the accepted standard of care in siphonic roof drainage design. There are several suppliers of calculation software on the market.

9.2.2. Preparation of Reports: Whatever software package you choose to use, it should be capable of preparing hard-copy reports of the calculations. The minimum information is outlined in ASPE Technical Standard 100, Section 10.2.

9.3. Selection or Substitution of Roof Drain Manufacturer

9.3.1. Hydraulic calculations establish the pipe diameters and developed lengths of each segment of the drainage system. These calculations use estimated resistance coefficient values for the elbows, reducers, and junctions, Siphonic roof drains are also treated as fittings with a minor energy loss with a resistance coefficient determined by flow tests. These values are supplied by the roof drain manufacturer. Each drain product has a unique resistance coefficient.

9.3.2. Some European manufacturers have claimed that if an engineer uses their sizing software, only their drain can be used in the installation. This has placed the engineer in an unnecessarily difficult position of having to specify a proprietary source. However, the reason is purely financial and not technical. Many drain suppliers provide the sizing software for free and make their profit from drain sales. This should be of no concern to the specifier. A roof drain is only one minor loss in a large series of other minor and major losses. Substitution of a drain product is possible if the alternate drain can meet the installation requirements, has the capacity to drain the area assigned, and meets the requirements of ANSI/ASME A112.6.9 "Siphonic Roof Drains."

10. Specification Writing

10.1. General: Many engineers prepare project specifications with an all-encompassing "Plumbing" section usually in the old CSI 15400 series. However, as for many systems, it is much more effective and clearer to specify siphonic roof drainage piping, drains, submittals, and installation requirements in a stand-alone specification section.

10.2. Part I

10.2.1. Related Sections: This section lists any other sections of the Project Manual that may contain pertinent information through cross-referencing. Typically, the plumbing piping or mechanical piping section should be referenced if all plumbing and mechanical pipe is contained in a separate section. Also, the specification section for the roofing system may contain information relevant to roof drain installation.

10.2.2. References: This section lists all of the standards appearing in the body of the specification from bodies such as ANSI, ASTM, ASME, etc. For siphonic roof drainage, the following should be included:

ANSI/ASME A112.6.9 "Siphonic Roof Drains,"
ASPE Technical Standard 100 "Siphonic Roof Drainage"

When thermoplastic pipe is specified, also include:

ASTM F 2021 "Standard Guide for Design and Installation of Plastic Siphonic Roof Drainage Systems"

10.2.3. System Description: The following text is recommended for this section:

A. General

1. This siphonic roof drainage system is classified as an "Alternative Engineered Design". The use of this system is based on consent by the local inspecting authority subject to plan review upon submittal for permit.

2. This is an engineered system. Guidance for the installation of this system is supplied by this specification and the related Drawings. The performance of this system is related directly to the pipe configuration, pipe diameters, elevations, fittings and orientation. Any changes to the pipe configuration outside of specified tolerances are required to be examined and approved by the Designer prior to installation.

3. Proper installation of this system requires a detailed set of fabrication drawings including relationship to surrounding structure, mechanical systems, etc. Such fabrication drawings shall include pipe cut lengths for each pipe segment.

B. Basis of Design

1. This system is designed to drain rainwater from the roof at a rate equal to or greater than __ inches per hour of rainfall.

2. The depth of water on the roof around the roof drains at dimensional rainfall intensity is __" to __".

10.2.4. Submittals: Specify the usual submittal requirements for products, pipe, insulation, etc. This section should further require submittal of fabrication drawings for the piping system to include dimensions, lengths, position of fittings, etc.

10.2.5. Quality Assurance: The following statement is recommended: “A plumbing contractor duly licensed with local and/or state authorities shall install the siphonic roof drainage system.” It probably goes without saying, but is clarifies any possible confusion that a non-licensed third party “specialist” might required.

10.3. Part II

10.3.1. Manufacturers

Drains: There are several siphonic roof drain manufacturers on the market. There is no actual need for a specifier to be held to proprietary sources. A specifier may design a system with a specific drain manufacturer and use that product’s resistance coefficient to calculate the minor loss through the drain, however, any drain product that has been tested to ANSI/ASME A112.6.9, is by definition compatible with any other so tested. The resistance coefficient may vary, but a specifier only needs to substitute this coefficient in the hydraulic calculations if an alternate product is submitted by a contractor. Any drain specified should be tested to ANSI/ASME A112.6.9.

Pipe, Fittings and Couplings:

10.3.2. Open Specification vs. Proprietary Specification: Certainly for a publicly funded project, an open specification is required by procurement laws, unless some special circumstance exists. Because there are a few siphonic roof drain manufacturers on the market, closed specification is not necessary. Also, the contractor should have the chance to shop around for the best price as long as the product meets the specification. For private projects, a closed specification is a choice. However, most owners want to know that they are getting the best deal.

10.4. Part III

10.4.1. Tolerances: No plumbing system can be installed to precise dimensions. Construction tolerances apply for any element of a building. In the case of siphonic roof drainage, deviation from the specified lengths of pipe is permitted within tolerances. These are specified in ASPE technical Standard 100. For piping 4 inches and smaller, pipe lengths may vary by plus or minus 4 inches. For pipe larger than 4 inches, pipe lengths may vary by plus or minus 8 inches.

10.4.2. Conflicts: Conflicts are bound to occur. Good coordination during the design phase is important to minimize the number and impact of conflicts encountered in the field. The specification should inform the contractor that any changes to the system must be validated by the engineer prior to installation.

11. Installation

11.1. Proposing Changes: If a conflict is encountered and the only resolution is to modify the siphonic roof drainage piping, the contractor must contact the engineer with their proposed solution. The engineer needs to then update the hydraulic calculations to determine the impact on system balancing. Any further changes or adjustments revealed by the calculations should then be noted and sent back to the contractor as an authorized modification. However, experience has shown that siphonic systems are very flexible and accommodating.

11.2. Pipe and Drain Protection during Construction: The pipe and drains should be protected by means dictated by common sense. Drains may be used as temporary drainage, but the contractor needs to take care to ensure significant construction debris does not become lodged in the piping. Also, if a roof deck is constructed of poured concrete, roof drains must not be used for temporary drainage. Cement dust and other residual materials can enter the piping and cause a permanent blockage. Therefore, the roof drains should not be used for drainage until the roof waterproofing system has been put down over the concrete.

11.3. Inspection and Testing: The only testing necessary for a siphonic roof drainage system is a simple pressure test to verify that joints are properly installed. Pipe testing criteria is included in ASPE Technical Standard 100. However, any additional testing required by the local inspecting official should also be conducted. More than once, inspectional authorities have asked for full operational testing (i.e. simulating a design rainfall event). However, the quantity of water required to achieve full bore flow as well as the method of properly distributing the water over the roof is so great that it is impractical and presents an unnecessary hazard to people handling hoses and pipes, etc. The ability of the system to work properly is documented through hydraulic calculations, just like hydraulically designed automatic sprinkler systems meeting NFPA 13 requirements.

12. Authority Approval

12.1. Client Consent: It is always “good form” to obtain consent from the owner of a project prior to contacting local officials. Many times the owner or its representatives will have already established contact with local officials and formed “official channels” to go through. Always check to make sure you are contacting the correct person.

12.2. Contacting Authority Having Jurisdiction: It is critical to establish contact with the local official(s) having jurisdiction at the very beginning of a project. Most often this can be done with a simple phone call to describe to the inspector or plan reviewer what is being proposed and to answer any questions. Depending on the State, there may be more formal processes to follow and the inspector should inform you what those steps may be.

12.3. “Approval Subject to Plan Review”: More often than not, existing siphonic roof drainage systems already installed in the United States were given verbal consent by the local official. This consent was followed by a written letter to document that the conversation had taken place and that the engineer intends to submit an engineered roof drainage system. The inspector then has the opportunity to do a “plan review” of the submitted drawings to ensure the level of equivalency is met. This usually means that the engineer demonstrates that the required rainfall intensity was used for the hydraulic calculations and secondary overflow drainage is provided.

12.4. Variance Requests: In some states (Massachusetts for example), more formal procedures are required at the state level. The engineer should always follow these rules and attend whatever meetings or hearings that the state board my hold.

13. Controlled Flow Systems

13.1. General: Siphonic roof drainage systems are by their very nature “controlled flow” systems. Because the energy available to a system is limited to the potential energy or Disposable Head, there is only one unique operating point (i.e. flow and energy) for a given system. Therefore, the designer can set the maximum flow capacity of the system through selection of the design rainfall intensity.

13.2. Function of Pipe Sizing: As mentioned above, the operating point of a system with a given Disposable Head can be set by designing a piping system with a system curve that passes through the target flow. The lower the discharge capacity, generally the smaller the pipe diameters and drain sizes.

13.3. Roof Deck: Any controlled flow roof drainage system is intended to detain a certain quantity of water temporarily on the roof, rather than detaining it in a pond or tank at or below grade. Therefore, any building using a controlled flow system should have a roof deck designed to hold the intended distributed load of water before the overflow point is reached.

13.4. Allowance by Code: Controlled flow systems are becoming much more common as cities and towns seek methods of reducing the impact of storm water runoff. New York City is an example of an area that commonly requires controlled flow off of roofs because space for ground detention is not available and storm sewer capacities are more and more maxed out. Therefore, these systems are becoming incorporated into local and model codes as engineered systems. Siphonic roof drainage tends to fall under this category. Since it can essentially guarantee a limited discharge through pipe sizing, it poses a more attractive solution to systems with flow control weirs at the roof drains.

14. Historic Renovation

14.1. Renovations to historic structures that must be preserved or renovations to a structure not otherwise historic but suitable for “recycling” sometimes present challenges to handling roof drainage. Typically, the roof drainage installed in an old building does not meet current code requirements in terms of rainfall capacity. It is often necessary to replace the piping with a new system. Of course, there may be ceilings, walls and other ornamental elements in the building that are best not disturbed or very expensive to replace. The pipe reduction and no-pitch configuration makes siphonic roof drainage very useful for providing higher rainfall intensity with smaller piping. This minimizes the impact on the building.

15. Benefits

15.1. <u>Smaller Piping, Cost Savings</u>: In general, pipe diameters can be cut in half. In other words, if traditional pipe sizing for horizontal pipe requires and eight inch pipe, a siphonic roof drainage system can drain the same quantity of water with a four or five inch pipe. This translates to cost savings. There have been many numbers posed, but a conservative estimate is around a 40 percent savings overall compared to a traditional system.

15.2. <u>Reduced Pipe Trenching</u>: Due to the “no pitch” capability of siphonic roof drainage, piping can be run overhead much further than is possible with pitched traditional piping. The typical strategy of traditional roof drainage design is to minimize horizontal runs and to drop down vertically as soon as possible. This requires usually to additional pipe chases and to underslab piping to convey internal stacks out the building to the storm drainage system. Because siphonic roof drainage piping can be run overhead and above ceilings much further, stacks can be placed at exterior walls thereby reducing or eliminating underslab piping. This reduces the cost of construction by reducing trenching and backfilling.

15.3. <u>Flexibility of Stack Placement</u>: The ability to run drainage pipe horizontally overhead much further gives the designer much more flexibility in selecting locations for the vertical stacks.

15.4. Pipe Consolidation: The ability to run drainage pipe horizontally overhead much further gives the designer the opportunity to combine several drains into one manifold and one stack. So it is possible for a building's roof drain system to use one eight inch stack (just for example) instead of three eight inch stacks.

15.5. Minimizing Pipe Inverts: Drainage pipe that must go below slab in the middle of a building's footprint must be pitched toward the building foundation. The further the run, the greater the pipe depth. Because siphonic roof drainage stacks can be more easily located at the building exterior walls, they start their exit beyond the foundation at the minimum depth possible. This saves in storm sewer excavation costs as well as the cost of retention/detention ponds or collection cisterns.

15.6. Reducing Storm Sewer Pipe and Structures: Because pipe can be consolidated inside the building and the stack location(s) can be placed closest to the site storm discharge, the size and quantity of pipe and manholes can be reduced around the building.

16. Closing Remarks: Siphonic roof drainage has turned out to be the "hottest" new technology to be introduced to the plumbing engineering field. Although it has been used worldwide since the mid-1960's, it did not appear in the United States until 1999, making the technology "new to us." However, an extensive body of knowledge has developed over the decades. When properly designed, these systems offer a much more efficient roof drainage solution. However, when we say "properly designed" we mean those issues that are common to all roof drainage systems like the selection of rainfall intensity and drain placement. In this sense, learning siphonic roof drainage design tends to "open our eyes" to several issues not commonly considered in roof drainage design in general. You should keep a copy of this course on hand as a reference as you practice the design of these systems.

17. Additional Study Materials: The attached research papers and patent provide further depth into siphonic roof drainage research and operation as well as to provide some historic context to the subject.

End of Course Content