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Roof Drainage Design

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Doorways to the ***Future***

ABSTRACT

The purpose of this paper/presentation is to provide the reader with an overview of roof drainage design requirements. This will include an historical overview of roof drainage design, a discussion of the evolution of the various national codes, and an overview of the current International Building and Plumbing Code requirements with a comparison to the Uniform and National Standard Plumbing Codes. Also included will be a discussion of the critical life safety issues involved with roof drainage design, a case history of various roof collapses with a discussion of the causes, and an overview of the roof design requirements involving roof drainage design requirements for today's roofs.

SPEAKER

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Stephen co-authored *Roof Design and Practice,* a roof design manual published by Prentice Hall, and *Wind Pressures on Low Sloped Roofs* and *Roof Drainage,* published by the Roof Consultants Institute Foundation. Mr. Patterson has designed numerous roof drainage systems and investigated more than 30 major roof collapses involving roof drainage issues.

Roof Drainage Design

INTRODUCTION

Every year, roofs collapse primarily as a result of improper roof drainage design and other related issues. Roof collapses are catastrophic roof failures that cause the loss of millions of dollars in property damage. More importantly, many times roof collapses result in the loss of life. On May 5, 1995, a series of severe thunderstorms passed over the Dallas/Fort Worth area, causing more than $2 billion in property damage from large hail. Softball size hail injured hundreds of people who were caught outside at an outdoor festival. However, the only fatalities were the result of a roof collapse due to heavy rains.

A correctly designed roof drainage system provides for a roof that slopes properly without resulting in ponding water and similarly provides for a properly designed primary and secondary drainage system to prevent an excessive build-up of water on the roof. This build-up of water is almost always the key factor in roof collapses. This paper discusses the evolution of the codes and industry design standards and the issues related to roof drainage design.

HISTORICAL VIEW OF THE BUILDINGS CODES

The Early Codes

Roofing problems and building codes have been linked together since the first building ordinances in America. The first building ordinances in America dated back to the late 17th Century and involved restrictions on thatch roofing in Boston and New Amsterdam (New York). The ordinances were the result of performance issues and fire hazards associated with thatch roofing. Roofing problems were a prominent issue in the late 19th Century. Major fires devastated many cities in the last half of the 19th and early 20th Centuries. Fire losses were estimated at $1.2 billion between 1860 and 1915. The famous Chicago fire of 1871 resulted in the loss of 17,450 buildings alone. These fires led to research by the forerunner of Underwriters Laboratories. This research provided the basis for the first modern building codes dealing with roofing issues. Roof drainage was also included.

Roof Drainage in the Building Codes

Roof drainage requirements were included in the first edition of the Uniform Building Code (UBC) published in 1927. Issues of slope, drainage, and overflow were addressed simply but rather eloquently in Section 3206 of the Code, which stated the following.

> **Roof Drainage, Section 3206.** *Roofs of all buildings shall be sloped so that they will drain to gutters and downspouts which shall be connected with conductors to carry the water down from the roof underneath the sidewalk to and through the curb. Overflows shall be installed at each low point of the roof to which the water drains.*

From 1927, the evolution was gradual. It was not until the 1964 Edition of the UBC that roof drains are specifically mentioned in the code. Section 3206 of the 1964 UBC stated:

> *Roof drains shall be installed when required at each low point of the roof to which the water drains, and shall be adequate in size to drain the roof. Overflow drains shall be installed with the inlet flow line located two inches (2") above the low point of the roof, or overflow scuppers may be installed in parapet walls at each low point of the roof with the flow line not more than two inches (2") above the adjacent roof.*

There is no reference to a specific plumbing code in the Uniform Building Code until 1967. However, it should be noted that the National Bureau of Standards published the first national plumbing code in 1928 (*Publication BH 13*). This publication was commonly referred to as the Hoover Code. The National Association of Master Plumbers published its Standard Plumbing Code in 1933. The American Standards Association published a preliminary Plumbing Code A40 in 1942. The Western Plumbing Code drafted its first Uniform Plumbing Code in 1938. After World War II, a joint committee, the Uniform Plumbing Code Committee, was formed and extensive research was performed at the National Bureau of Standards and several universities, which ultimately culminated in the American Standard National Plumbing Code, ASA A40.8-1955.

Clearly, roofing and the building codes have been intertwined from the beginning, generally as a result of increased problems in the industry. Today's International Building Code represents the merging of the three national building codes – the BOCA Building Code, the Uniform Building Code, and the Standard Building Code – into one unified building code. The goal was to have a single national building and plumbing code. The International Building Code has been universally accepted for the most part, but there are still three national plumbing codes, which include the Uniform Plumbing Code, the National Standard Plumbing Code, and the International Plumbing Code, each with slightly different philosophies.

Key Drainage Issues in the Codes

The key design issues addressed in the codes include roof slope and the structural issues related to ponding, the design of the primary roof drainage system, and the design of the overflow or secondary drainage systems. From the beginning, Building Codes have stated the obvious – roofs should drain, there needs to be a backup drainage system in case something happens to the primary drainage system, and the structures should be designed to support all the anticipated loads so they do not collapse. Those are pretty simple concepts, but it is alarming how many roof drainage problems persist and how many roofs collapse every year.

ROOF SLOPE AND STRUCTURAL ISSUES

Roof Slope Defined

The need for sloping roofs should be obvious. Roofs that drain well last longer than roofs that do not drain well, and roofs that do not accumulate water are not likely to collapse. Clearly, however, there are still misunderstandings regarding the issues related to roof slope. In 1927, the UBC stated, "Roofs of all building shall be sloped so that they will drain." How could it be any clearer? The NRCA published its first *Manual of Roofing Practice* and stated, "enough slope should be built-in so that water does not collect in the low areas between the roof-framing members." Unfortunately, the NRCA finished the sentence with "… so that the roof is completely dry 48 hours after it stops raining." Water standing for 48 hours does not constitute good drainage, but this 48-hour standard found its way into the roofing literature and became part of the first International Building Code in 2000.

The 2006 International Building Code defines positive drainage as:

> *The drainage condition in which consideration has been made for all loading deflections of the roof deck, and the additional slope has been provided to ensure drainage of the roof within 48 hours of precipitation.*

The Code further requires low-sloped roofs to slope a minimum of 1/4:12 except for coal tar pitch built-up roofs, which can be sloped 1/8:12. It is important, however, to understand that there can be serious problems with roofs having slopes of less than 1/4:12. These issues are addressed in the structural requirements in the codes for ponding instability.

Structural Issues

Roof slope is not only important for roof performance, but roof slope is extremely important in the structural design of a roof. Roof structures with slopes less than 1/4:12 must be evaluated for ponding instability. The concept of ponding instability is not new. The requirement to specifically design roofs for ponding water first appeared in the Uniform Building Code in 1967 in Section 2305.(f).

> ***2305.(f) Water Accumulation.*** *All roofs shall be designed with sufficient slope or camber to assure adequate drainage after the long-time deflection from dead load or shall be designed to support maximum loads including pos-*

> *sible ponding of water due to defection. See Section 2307 for deflection criteria.*

Ponding instability is critical in roof drainage design, because one of the typical factors in many roof collapses involves the failure of the structure due to progressive deflection under water loads. As water builds up on a roof, the roof structure deflects, and if the slope is inadequate to permit free drainage, accumulation of water will result. Water continues to build up deeper and deeper as the structure deflects. This progressive build-up of water is one of the key factors in many collapses. Below is the section from the 2006 IBC dealing with ponding instability, which is a new revision.

> ***1622.2 Ponding instability.*** *For roofs with a slope less than 1/4-inch per foot [1.19 degrees (0.0208 rad)], the design calculations shall include verification of adequate stiffness to preclude progressive deflection in accordance with Section 8.4 of ASCE 7.*

Water weighs 62.4 pounds per cubic foot (pcf), and therefore each inch of water weighs approximately 5.2 pounds per square foot (psf). It is precisely this weight of water that provides the live load on most roofs that leads to roof collapses. The codes have long provided for live-load reductions, which commonly allow the reduction in the live load on bar joists and other roof framing members to be as low a 16 psf, which equals slightly more than 3 inches of water uniformly distributed across the roof.

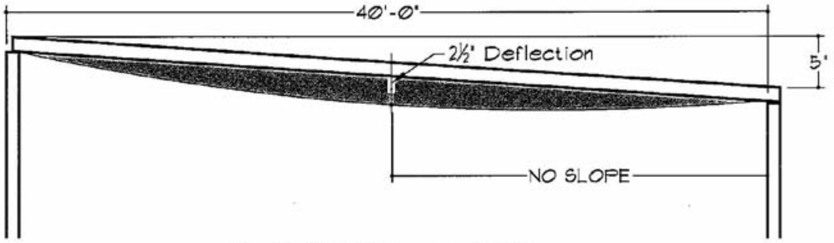
A standard deflection criteria allows for a deflection equal to 1/240th of the length of the span of the structural element, which is 2 inches of deflection in a 40-foot span. Potentially, roof slopes of less than 1/4-inch in 12 inches can have enough deflection to restrict the drainage and allow for water build-up.

Below are illustrations that show how slope and deflection are interrelated and can result in the build-up of water on roofs. The illustration at the top shows a roof deck with a slope of 1/8-inch per foot and a deflection equal to L/240 (the length of span divided by 240). The deflection is equal to 2.5 inches at the mid-span, which results in no slope from the mid-span to the eave (2.5 inches in deflection and 2.5 inches in fall). The illustration that shows that roof with the 1/4-inch slope still has a slope of 1/8-inch from the mid-span to the eave, which eliminates any ponding. This is an important reason for having a minimum slope of 1/4-inch per foot.

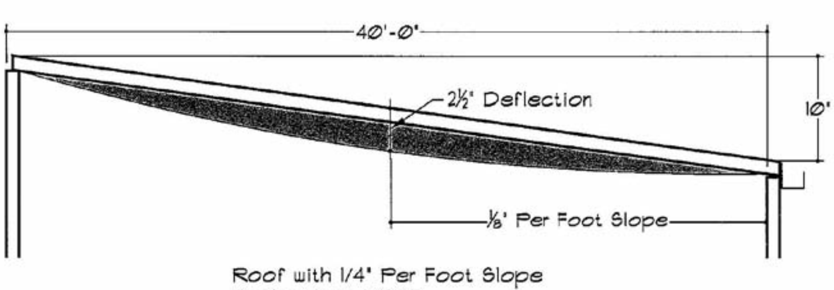
The International Building Code that allows roof slopes to be reduced to 1/8-inch per foot for coal tar pitch roofs ignores the importance of positive drainage. Also, the code requires that anytime there is less than a 1/4:12 slope, the roof should have been evaluated for ponding instability.

The illustration on the next page from *Roof Drainage* shows the importance of slope and the depth of water that can accumulate. The lower the slope, the greater the load caused by the head (depth) of water at the perimeter. Decreasing the slope from 1/4:12 to 1/8:12 doubles the load on the structure.

The more slope on a roof, the less likely that significant water accumulations will occur, and the less likely a roof is to collapse as a result of rainwater loads. The manner in which water builds up on a roof is discussed below, in the section on “Controlling Water Depth of Roofs (Overflow Drainage Systems).” Suffice it to say that water does build up on roofs, and the lack of slope can result in catastrophic consequences unless the structure is designed for those loads.



Roof with 1/8" Per Foot Slope
Deflection= L/240



Roof with 1/4" Per Foot Slope
Deflection= L/240

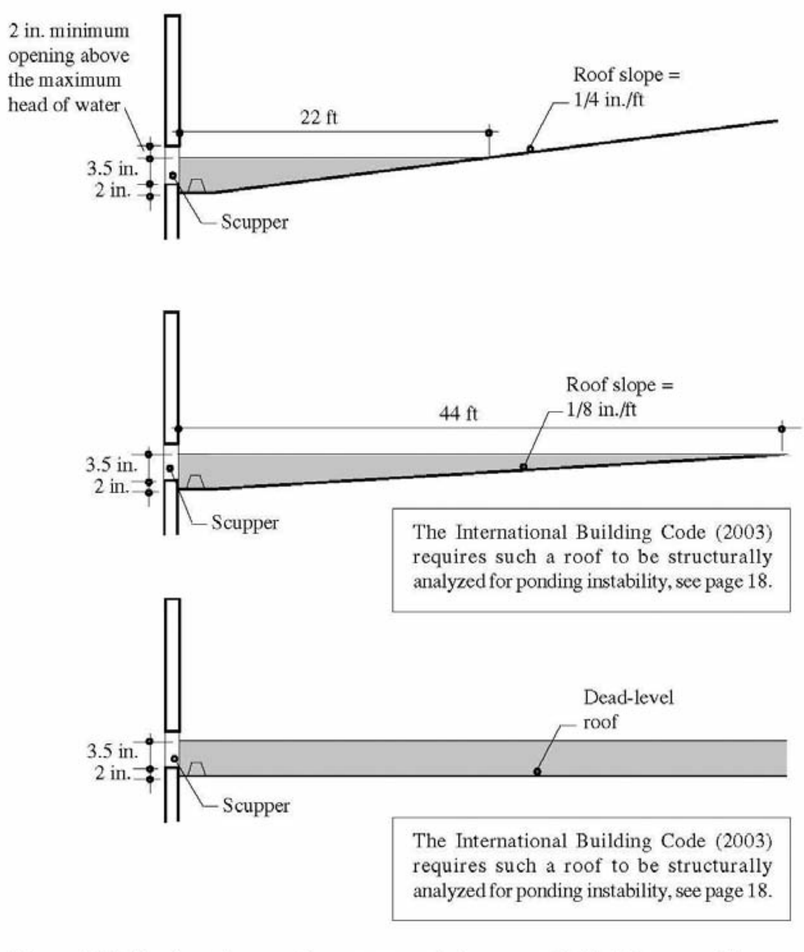


Figure 2.20 *Depth and extent of water accumulation on roof with different roof slopes.*

The building codes have taken a step backwards in their requirements relating to slope, particularly as it relates to reroofing. The 1988 Uniform Building Code addressed the issues related to roof slope and reroofing better than any other code before or after. Below is an excerpt from Chapter 32 in the Appendix to the 1988 UBC.

> ***Inspections***
>
> ***Sec. 3210.*** *New roof coverings shall not be applied without first obtaining an inspection by the building official and written approval from the building official. A final inspection and approval shall be obtained from the building official when the re-roofing is complete. The pre-roofing inspection shall pay special attention to evidence of accumulation of water. Where extensive ponding of water is apparent, an analysis of the roof structure for compliance with Section 3207 shall be made and corrective measures, such as relocation of roof drains or scuppers, resloping of the roof or structural chances, shall be made.*
>
> *An inspection covering the above-listed topics prepared by a special inspector may be accepted in lieu of the pre-inspection by the building official.*

Further, the 1988 UBC required that the new roof meet the requirements of Chapter 32 in this building code, which required the roof to have a slope of 1/4:12. Essentially, the roof had to be inspected and if there were drainage problems, the roof structure had to be analyzed and the drainage corrected.

It is a mistake to assume that because a building has been around for a long time that the drainage system is adequate. One of the first collapses investigated by this author involved a 50-year-old building that never had a drainage problem – that is, until someone tossed a *Sunday Fort Worth Star Telegram* newspaper up on the roof. That paper was the perfect size to block the scupper drains on this building. And unfortunately for the owner of the building, there were no overflow drains or scuppers.

Slope is one of the three critical elements of roof drainage design. It is essential that the roof have adequate slope to drain the roof without accumulating water on the roof. The depth of water that can accumulate on the roof is critical, and the next section deals with the concept of overflow design in order to prevent excessive water build up.

CONTROLLING WATER DEPTH OF ROOFS (OVERFLOW DRAINAGE SYSTEMS)

The Need for an Overflow Drainage System

Probably the most important element of roof drainage design is controlling the depth of water that can accumulate on the roof. Controlling this depth is a function of the overflow drainage system or, as it is sometimes referred to, the secondary drainage system. Overflow scuppers are prominently mentioned in the 1929 *Standard Practice in Sheet Metal Work*, which is the forerunner to the *Architectural Sheet Metal Manual* published by the Sheet Metal and Air Conditioning Contractors National Association, better known as SMACNA. Also, overflow was one of the requirements in the first Uniform Building Code. Why, then, is it that so many existing buildings have no overflow drainage system?

Most of the collapses investigated by this author have been caused, in part or completely, by the lack of an overflow drainage system. At some point it is likely that a roof drain is going to become blocked. It may take 50 years before someone throws a Sunday newspaper on the roof or a hailstorm occurs severe enough to block the drains or blowing debris in a hurricane blocks the drains. At some point, the primary drainage system will likely become blocked. Water flowing to the drains will carry debris and deposit it at the low point of the roof, which is where the primary drains are located. Some drains are more likely to become blocked than others. Drainage scuppers are more susceptible to blockage than roof drains. Below is an illustration from *Roof Drainage.* As can be seen, the roof drain with a proper strainer can still function, even with debris accumulated around the perimeter of the strainer, whereas the scupper is virtually blocked by the same debris.

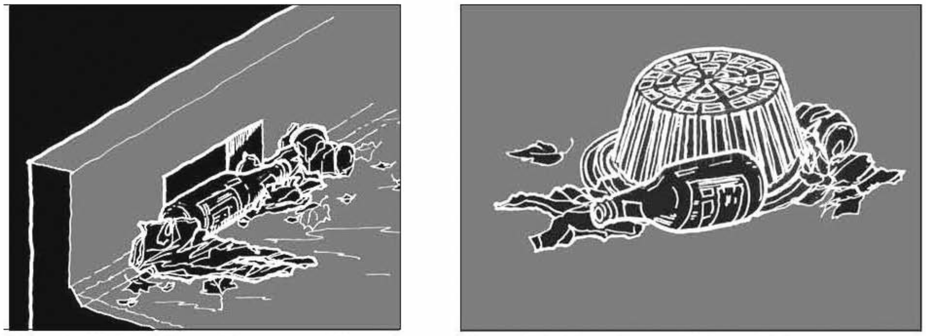


Figure 2.15 *Relative performances of a scupper and a roof drain under conditions of blockage.*

The American Society of Civil Engineers recognized the importance of blocked drains and provided the following recommendations for structural engineers in the first ASCE Standard entitled ANSI/ASCE 7-88, Minimum Design Loads for Buildings and Structures, which replaced ANSI A58.1-1982.

> ***8.2 Blocked Drains.*** *Each portion of a roof shall be designed to sustain the load of all rainwater that could accumulate on it if the primary drainage system for that portion is blocked. Ponding instability shall be considered in this situation. If the overflow drainage provisions contain drain lines, such lines shall be independent of any primary drain lines.*

Overflow Drainage Requirements

There have been revisions of ASCE 7, but the issues related to overflow have remained the standard in ASCE 7 since its inception in 1988 and the International Building Code since its inception in 2000. The structural engineer must assume the primary drains are blocked, calculate the depth of water that could accumulate on the roof, and design the structure to support those loads. Again, these are pretty simple, common-sense concepts, which have been universally accepted in today's design standards.

However, there are variations in overflow drainage design theory. Historically, most primary and secondary roof drainage systems were designed based upon the 1-hour duration, 100-year rainfall rate. This 1-hour duration, 100-year rainfall rate is the amount of rain that is likely to fall in one hour once every 100 years. However, in 1991, the Standard Building and Plumbing Code changed the requirements for overflow design. The 1991 Standard Plumbing Code adopted the 15-minute duration rainfall rate for design overflow drainage systems, which is the amount of rainfall that can be expected to fall in 15 minutes once every 100 years. To put it in perspective, the 15-minute, 100-year rainfall rate is approximately twice the 1-hour, 100-year rainfall rate.

> ***1507.3 Maximum Rainfall Rate for Secondary Drains.*** *Secondary (emergency) roof drain systems or scuppers shall be sized based on the flow rate caused by the 100-year, 15-minute precipitation as indicated on Figure 1507.3. The flow through the primary system shall not be considered when sizing the secondary roof drain system.*

The National Standard Plumbing Code has also adopted this criterion. The rationale for using the 15-minute duration, 100-year rainfall is based on the concept that roof drains may become blocked during extreme storms like hailstorms and hurricanes. The Standard Plumbing Code was formerly the Southern Building Code, which was adopted primarily throughout the Southeast part of the United States, including the hurricane-prone Gulf and Atlantic Coast states. Blowing debris during hurricanes commonly block roof drains, and hurricanes often produce extraordinary rainfall. The combination of blowing debris and extraordinary rainfall can be catastrophic for roof drainage systems. The first International Plumbing Code (1997) also adopted this 15-minute, 100-year rainfall rate, but reverted to using the 1-hour, 100-year rainfall rate for overflow systems in 2000.

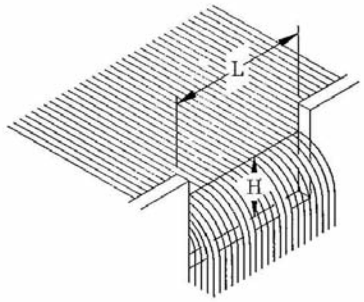
Also gone is the old Uniform Building Code standard of using overflow scuppers three times the area of the roof drains. The Uniform Building Code first provided the overflow scupper option in the 1967 Edition, which follows:

> ***(c) Overflow Drains and Scuppers.*** *Where roof drains are required, overflow drains having the same size as the roof drains shall be installed with the inlet flow line located two inches (2") above the low point of the roof, or overflow scuppers having three times the size of the roof drains may be installed in adjacent parapet walls with the inlet flow line located two inches (2") above the low point of the adjacent roof and having a minimum opening height of four inches (4").*
>
> *Overflow drains shall be connected to drain lines independent from the roof drains.*

There is a major flaw in this drainage criterion. This criterion does not take into account the depth of water that develops at the scupper based upon the geometry of the scupper. The fundamental function of the scupper is to control the depth of water, so as to limit the load on the roof structure and prevent a collapse. The geometry of a scupper is critical.

> *For example, a 6-inch drain has an opening of approximately 28 inches. Using the old Uniform Building Code's standard of providing an overflow scupper three times the area of the roof drain, the overflow scupper size would be 84 square inches. The problem with this standard was that a designer could select an 8-inch-wide by 10.5-inch-high scupper and meet the code requirements. However, the head (depth) of water at the scupper would have to be 8.4 inches to achieve the flow rate required.*
>
> *The net result would be a depth of water of 10.4 inches at the scupper, as the overflow scupper is located 2 inches (10.4 + 2) above the roof. This depth of water could easily cause a collapse in many circumstances. Based upon the old UBC, it was possible to collapse a roof using overflow scuppers three times the area of the roof drains.*

TABLE A1507.2
SCUPPER SIZING TABLE
Roof Area (sq ft)



Head (H) Inches	Length (L) of Weir (Inches)						
	4	6	8	12	16	20	24
1	273	418	562	851	1139	1427	1715
2	734	1141	1549	2365	3180	3996	4813
3	1274	2023	2772	4270	5768	7267	8766
4	1845	2999	4152	6460	8766	11073	13381
6	2966	5087	7204	11442	15680	19918	24160

Table based on rainfall of 4 inches per hour.

> *Roof drains are roughly three times more efficient than scuppers in terms of flow. The 8-inch-wide by 10.5-inch-high scupper has the flow capacity of almost 790 gallons per minute, which is slightly more than a 6-inch drain. Unfortunately, the head of water required to achieve that flow through the scupper is 8.4 inches, while the head of water required to achieve approximately the same flow is only about 3.6 inches.*

In 1991, the Standard Plumbing Code introduced a requirement to determine the depth of water that can accumulate on the roof and to notify the structural engineer to design the structure based upon this depth of water, assuming the primary drains are blocked, which is today's standard. The excerpt from the 1991 Standard Plumbing Code (above) shows the chart used to determine the depth of water that can accumulate at a scupper.

The 1991 Standard Plumbing Code began requiring designers to assume that the primary drains are blocked and to calculate the depth of water that could accumulate over the secondary or overflow drainage system. This is the basis of the design requirements provided in the initial ASCE 7 in 1988 and the initial International Building Code in 2000. This is the most logical approach and simply reinforces the concept that the structural engineer should design the structure to support the loads that could be expected to occur on a building.

ASCE/SEI 7-05 provides a basis for calculating the head of water over drains and scuppers. There are also methods for calculating the head of water over scuppers and drains provided in *Roof Drainage.* There are methods for determining the head of water (depth) in scuppers and over drains. At the right is the chart from data included in ASCE/SEI 7-05.

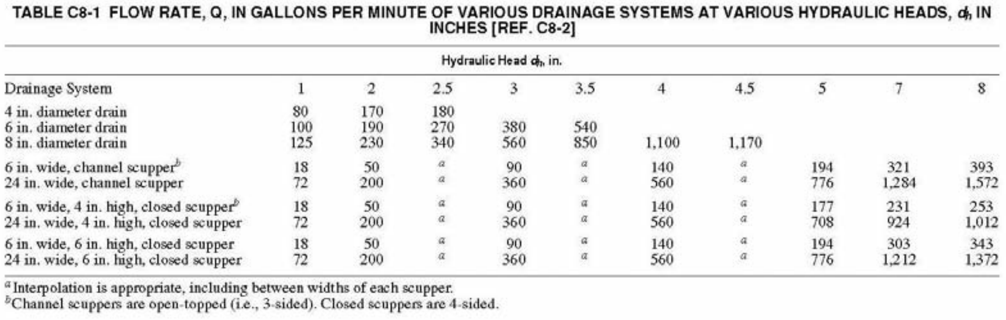


TABLE C8-1 FLOW RATE, Q, IN GALLONS PER MINUTE OF VARIOUS DRAINAGE SYSTEMS AT VARIOUS HYDRAULIC HEADS, d_h IN INCHES [REF. C8-2]

	Hydraulic Head d_h, in.									
Drainage System	1	2	2.5	3	3.5	4	4.5	5	7	8
4 in. diameter drain	80	170	180							
6 in. diameter drain	100	190	270	380	540					
8 in. diameter drain	125	230	340	560	850	1,100	1,170			
6 in. wide, channel scupper[b]	18	50	[a]	90	[a]	140	[a]	194	321	393
24 in. wide, channel scupper	72	200	[a]	360	[a]	560	[a]	776	1,284	1,572
6 in. wide, 4 in. high, closed scupper[b]	18	50	[a]	90	[a]	140	[a]	177	231	253
24 in. wide, 4 in. high, closed scupper	72	200	[a]	360	[a]	560	[a]	708	924	1,012
6 in. wide, 6 in. high, closed scupper	18	50	[a]	90	[a]	140	[a]	194	303	343
24 in. wide, 6 in. high, closed scupper	72	200	[a]	360	[a]	560	[a]	776	1,212	1,372

[a] Interpolation is appropriate, including between widths of each scupper.
[b] Channel scuppers are open-topped (i.e., 3-sided). Closed scuppers are 4-sided.

The overflow drainage system controls the depth of water that can accumulate on a roof and is the most critical part of the drainage system. The roof structure should be designed to support all the loads anticipated on the roof, and water build-up is one of the most important sources of loads on a roof. The requirement for overflow systems goes back to the beginning of the modern national codes, and these requirements have been refined over the years. Today, the codes are pretty simple and straightforward. Calculate the depth of water that can accumulate on the roof assuming the primary drainage system is blocked, and design the structure to support those loads. The structure must be evaluated for ponding instability any time the slope is less than 1/4:12. These are basic concepts that have been articulated in codes and standards for years.

Location of Overflow Drains and Scuppers

Overflow drains and scuppers should be located above the low point of the roof to help prevent the overflow drains and scuppers from becoming blocked. Debris is carried by the flow of water on the roof, which is to the low point. The primary drains are located at the low point, which is what makes them susceptible to becoming blocked by debris.

Placing the overflow drain or scupper approximately 2 inches above the low point of the roof reduces the likelihood that debris will flow into the overflow system and become blocked. Additionally, overflow drain outlets should be located in a prominent location so that maintenance personnel can readily observe water flowing out of the overflow. This is an indication that the primary drains may be blocked and maintenance needs to be performed.

Sometimes it is difficult to place overflow scuppers 2 inches above the low point of the roof, due to the location of the drains. Today, there is no specific requirement to locate the overflow drain or scupper 2 inches above the low point of the roof. The requirement is to find out how much water can accumulate above the overflow system and design the structure accordingly. However, the overflow drain or scupper should be located approximately 2 inches above the low point to prevent debris from blocking the overflow, but the scupper can be located at a higher elevation, provided the structure is adequate to support the load.

PRIMARY DRAINAGE DESIGN

General Requirements

The primary drainage system is an important element in drainage designs, but it is the least important of the three elements of drainage design. These elements include the slope of the roof and ponding instability, the overflow drainage system, and the primary drainage system. However, it is important that roofs drain freely, and the primary drainage system is designed to remove water efficiently. This author has investigated roof drainage systems that were under-designed, resulting in water depths deep enough to cause leaks at low curbs and expansion joints.

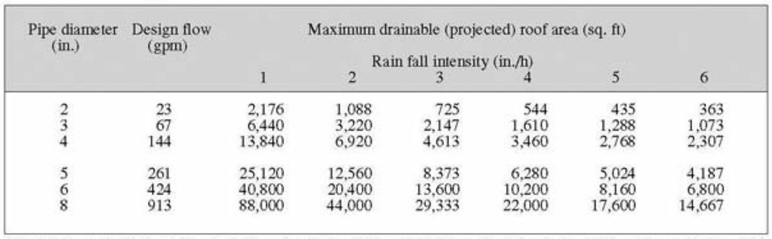
The primary drainage system generally consists of either roof drains or scupper drains. Most roof drains today are manufactured by companies like Josam, Zurn, and J.R. Smith and have standard flow rates, which are reflected in the various plumbing codes. These drains are designed with sumps and strainers that conform to the codes. Strainers are important, as they block the debris from getting into the drains' lines. Also, strainers can actually improve the flow into drains by breaking up the vortex of the water flowing into the drain.

Scupper drains, on the other hand, are generally shop- or field-fabricated, and generally, flow rates must be calculated. There are no standard strainers designed to promote water flow and function with debris. Scuppers also generally require a greater depth of water to achieve the designed flow, so the depth of water at scuppers can be significant. Scupper drains and overflow drains should be separate and should not be connected.

Drainage Rates for Roof Drains

The various plumbing codes generally agree on the design criteria in principle. However, there are variations in the flow rates between the rates provided in the International Plumbing Code and the other two national plumbing codes – the National Standard Plumbing Code and the Uniform Plumbing Code. It should be noted, however, that the flow rates in the International Plumbing Code are the same as the old BOCA Plumbing Code, old Standard Plumbing Code, and old Uniform Plumbing Code (prior to 1997). Adjacent is a comparison of the flow rates.

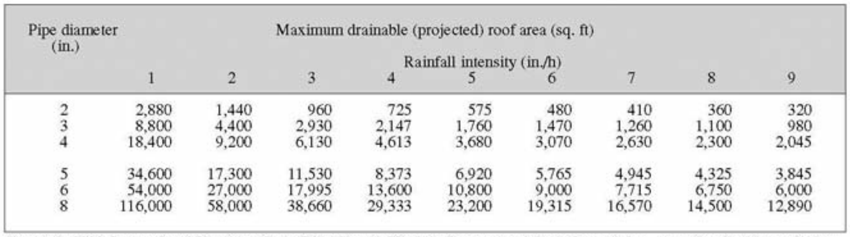
Table 3.5 Size of Vertical Conductors As Per The National Standard Plumbing Code and The Uniform Plumbing Code



Pipe diameter (in.)	Design flow (gpm)	Maximum drainable (projected) roof area (sq. ft) Rain fall intensity (in./h) 1	2	3	4	5	6
2	23	2,176	1,088	725	544	435	363
3	67	6,440	3,220	2,147	1,610	1,288	1,073
4	144	13,840	6,920	4,613	3,460	2,768	2,307
5	261	25,120	12,560	8,373	6,280	5,024	4,187
6	424	40,800	20,400	13,600	10,200	8,160	6,800
8	913	88,000	44,000	29,333	22,000	17,600	14,667

Adapted from the National Standard Plumbing Code, 2003, and Uniform Plumbing Code, 2003, with permission. This table is the same as Table 2.1(a)

Table 3.6 Size of Vertical Conductors As Per The International Plumbing Code



Pipe diameter (in.)	Maximum drainable (projected) roof area (sq. ft) Rainfall intensity (in./h) 1	2	3	4	5	6	7	8	9
2	2,880	1,440	960	725	575	480	410	360	320
3	8,800	4,400	2,930	2,147	1,760	1,470	1,260	1,100	980
4	18,400	9,200	6,130	4,613	3,680	3,070	2,630	2,300	2,045
5	34,600	17,300	11,530	8,373	6,920	5,765	4,945	4,325	3,845
6	54,000	27,000	17,995	13,600	10,800	9,000	7,715	6,750	6,000
8	116,000	58,000	38,660	29,333	23,200	19,315	16,570	14,500	12,890

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This table is the same as Table 2.1(b).

The National Standard and Uniform Plumbing Codes (after 1994) are more conservative. All these flow rates are based upon Manning's equations, but there are slightly different assumptions regarding the amount of open area in the pipe, which results in the differences in the charts. Roof drain manufacturers also publish drainage design literature, and most of these manufacturers use the same drainage design assumptions as the International Plumbing Code's standards.

Drainage Rates for Scuppers

Scupper drains must be designed, and there are also variations in the formulas used for calculating the flow through a scupper. It is important to understand that water has to build up to a relatively high elevation in order to achieve the design flow rate through the scupper. The depth of water that develops is primarily an issue of the width of the scupper. The wider the scupper, the lower the head of water that will develop at the scupper, which is desirable even if the structure is designed to support the loads from a large head of water.

The flow rate of water through scuppers is generally determined by the derivation of an equation known as the Francis Formula, which is $Q = 3.33LH^{1.5}$ where Q is the flow rate, L is the length of the weir (scupper), and H is the head of water. Because experiments have shown there is a contraction in the water flowing through the weir, the equation has been modified to adjust for this reduction. The modified form is $Q = 3.33(L-0.2H)H^{1.5}$. Below is a chart derived from this equation.

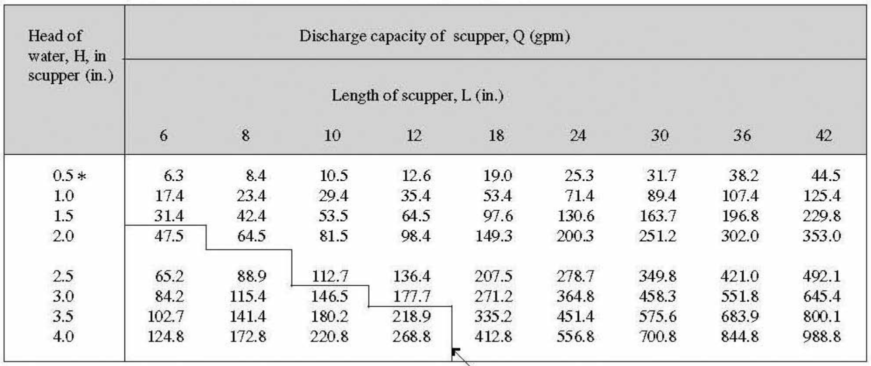
The design of the primary drainage system is relatively straightforward. There are variations in flow rates of drains and scuppers, and further research into these variables would be helpful in establishing consistent design guidelines.

DRAINAGE DESIGNS FOR ROOF REPLACEMENTS

Requirements to Modify Drainage for Reroofing

The 1967 Uniform Building Code added Chapter 32 to the appendix of the code, which was titled Re-Roofing, and the first section (3209) in that chapter stated that all re-roofing had to comply with Section 32 in the Building Code. This was a significant change in the code. However, the most significant change came in 1988 with the addition of the statement that roof systems shall be sloped a minimum 1/4-

Table 2.3 Drainage Capacity of a Rectangular Scupper (gpm)



Head of water, H, in scupper (in.)	Discharge capacity of scupper, Q (gpm) Length of scupper, L (in.) 6	8	10	12	18	24	30	36	42
0.5 *	6.3	8.4	10.5	12.6	19.0	25.3	31.7	38.2	44.5
1.0	17.4	23.4	29.4	35.4	53.4	71.4	89.4	107.4	125.4
1.5	31.4	42.4	53.5	64.5	97.6	130.6	163.7	196.8	229.8
2.0	47.5	64.5	81.5	98.4	149.3	200.3	251.2	302.0	353.0
2.5	65.2	88.9	112.7	136.4	207.5	278.7	349.8	421.0	492.1
3.0	84.2	115.4	146.5	177.7	271.2	364.8	458.3	551.8	645.4
3.5	102.7	141.4	180.2	218.9	335.2	451.4	575.6	683.9	800.1
4.0	124.8	172.8	220.8	268.8	412.8	556.8	700.8	844.8	988.8

Note: The accuracy of discharge capacity values for 0.5 in. head of water may not be accurate due to the effect of surface tension.

Note: Scupper length, L, below this (stepped) line is less than 4 times the head, 4H. These scupper dimensions should be avoided inch in 12 inches for drainage. This requirement to provide a minimum slope in Chapter 32 of the 1988 UBC in combination with the changes made to Chapter 32 in the appendix for Reroofing had major implications for reroofing design. Chapter 32 in the appendix required a re-roof to conform to Chapter 32 of the code, which required the roof be sloped a minimum 1/4 in 12 inches.

There was no reference to draining within 48 hours or allowing 1/8-inch per 12 inches for coal tar pitch. From a fundamental design perspective, this was the most appropriate code dealing with roof drainage and roof slope. A minimum slope of 1/4-inch in 12 inches has long been recognized as the most appropriate minimum slope for low-sloped roofs. A minimum 1/4-inch per 12 inches is also important from a structural design perspective, as any roof with less than this slope has to be designed for ponding instability. Deflections in structural elements with less than 1/4-inch per 12-inch slope can result in a progressive collapse due to deflection. In other words, the roof deflects, allowing more water to accumulate until the roof collapses. Clearly the authors of the 1988 UBC were addressing the issues that cause roof collapses. Below is Section 3210 from Chapter 32 in the appendix to the 1988 UBC.

> ***Inspections***
>
> **Sec. 3210.** *New roof coverings shall not be applied without first obtaining an inspection by the building official and written approval from the building official. A final inspection and approval shall be obtained from the building official when the re-roofing is complete. The pre-roofing inspection shall pay particular attention to evidence of accumulation of water. Where extensive ponding of water is apparent, an analysis of the roof structure for compliance with Section 3207 shall be made and corrective measures, such as relocation of roof drains or scuppers, resloping of the roof, or structural changes shall be made.*
>
> *An inspection covering the above-listed topics prepared by a special inspector may be accepted in lieu of the preinspection by the building official.*

These changes in 1988 were met with less than an enthusiastic response from elements of the roofing community. In fact, this change was a mind-altering event for many in the roofing industry. A great number of existing buildings did not have a minimum 1/4-inch per 12-inch slope. In some cases, it was not only impractical but it was virtually impossible to provide the minimum slope. Then there were the issues from the coal tar pitch industry, where 1/4-inch per 12-inch slope could be too much slope for the system. The result of these issues and others was a watering down of the requirements.

Current Design Standards

Today's International Building Code is relatively ambiguous regarding positive drainage. As defined, "positive drainage" is based upon ensuring drainage within 48 hours of precipitation. As previously stated, water standing for 48 hours does not constitute good drainage. What does "48 hours from precipitation" mean? Does it mean 48 hours in summertime conditions or wintertime conditions? A properly sloped roof should drain freely. Other than anomalies in the roof created around penetrations or crickets and valleys, there should be no water ponding after a rain.

Clearly, the code requires reroofs to have positive drainage, but since the definition is ambiguous, enforcement is difficult. Some building officials have ruled that the design professional is responsible for making the determination of what constitutes positive drainage, but often there is no design professional in the case of reroofing. Certainly, positive drainage is a benefit in terms of roofing longevity and performance, and providing 1/4-inch per 12-inch eliminates many structural concerns. In those cases where achieving 1/4-inch per 12-inch is not practical, care should be taken to help limit the amount of water that can accumulate on the roof and involving a structural engineer should be considered.

> It is important to understand that simply re-sloping a roof with tapered insulation may not be adequate. It is imperative that the drainage system function properly after the tapered insulation is installed. Often, increases in insulation thickness can restrict drains and overflow systems.

One of the most important requirements for reroofing is to make sure there is a proper overflow system. This is a code requirement that is often overlooked by many in the roofing industry, but the overflow system is critical in terms of limiting the amount of water that can accumulate on a roof and in preventing roof collapses. As a rule of thumb, some try to limit the depth of water to a maximum of 4 inches, which prevents the load from water buildup from exceeding the minimum 20-psf live load used throughout much of the southern regions of the country. It is also important to understand that even though there is a minimum 20-psf live load requirements in the code, there are live-load reductions that are allowed by code, which can reduce live loads on certain structural elements to 16 psf and even 12 psf in some cases.

CASE HISTORIES

Drainage design problems come in all types, from poor drainage deteriorating a roof to causing major roof collapses. Most of the roof collapses investigated by this author have involved defects in drainage design, usually in combination with other factors. The build-up of rainwater is nature's way of load-testing structure, and sometime structural design or construction deficiencies are identified. Realize that most drainage systems are designed based upon the 100-year rainfall occurrences, so it may take a long time before the structure really gets tested by one of these rainstorms. Below are some examples of some of the collapses investigated by this author.

- The first roof collapse investigated was a simple case of the contractor roofing over the scuppers during construction. Unfortunately, that roof received its first load test before the contractor had time to cut in and flash the scuppers.
- One of the first really large losses involved a computer assembly facility. A loose-laid, ballasted, single-ply had been installed over an existing built-up roof without evaluating the structure. The extra dead load for the roof dramatically reduced the live-load capacity of the structure, resulting in deflection between the drains. This structure failed as a result of a progressive deflection of the joists as the water depth kept increasing between the drains.
- One of the most expensive collapses occurred in a building that had no overflow scuppers. Instead of a conventional strainer, screens were installed in front of the drainage scuppers to catch debris. The screens worked efficiently and soon became blocked with debris. One eyewitness reported water lapping over the top of the 12-inch parapet wall just before the roof collapsed.
- Another large collapse in volved the irregular spacing of the roof drains and a defective joist girder. There were enough drains if the drains had been spaced evenly, but the end bays were 50% larger than the typical bays, resulting in 50% more water. Additionally, there were no provisions for overflow. The head of water over the drain was high enough to cause the defective joist girder to fail.
- One of the most dramatic collapses involved a concrete structure. The roof was designed to drain to an outside wall through drainage scuppers, but the roof had deflected as a result of long-term plastic deformation. The roof sagged in the middle, resulting in ponding. The roofer decided to install drains in the center and add slope from the outside walls to the center of the roof. The drains were too small, and the drain lines were not sloped, restricting drainage. There were no overflow scuppers or drains, and the roof collapsed during a heavy rain.
- One collapse was actually predicted by this author after a routine roof inspection. The core sample indicated that there were multiple roofs, one on top of the other, weighing more - than 20 psf. The recommendation was to remove the roofs immediately, as the roof could collapse during a heavy rain. The roof was flat, and the addition of all the roofs over the years reduced the live load capacity to zero. Unfortunately, the owner waited, and the roof collapsed several months after the inspection.

This sampling of collapses illustrates some of the issues related to collapses involving roof drainage design. Lack of overflow is a common problem, along with inadequate drainage and too much weight from the roof(s) installed. Sometimes the weight of the water simply finds the weak link in the structure.

FINAL COMMENTS

The basic concepts of proper roof drainage design have been around for many years, and there are extensive data and design guides available. *Roof Drainage*, published by the RCI Foundation, provides a much more complete discussion of roof drainage, and every roof consultant should have a copy in his or her library. There are still issues that need clarification and additional research is needed, particularly in the area of water accumulation on roofs and the appropriate flow rates of drains and scuppers.

The roof consultant can play an important role in preventing roof collapses. It is essential that there is a properly functioning overflow system on a building. Checking roofs for an appropriate overflow system and recommending corrective action to add or enlarge overflow drains and/or scuppers should be a standard part of the roof investigation process. Further, improving the drainage and the design and installation of overflow systems should be part of a reroofing project where these systems are inadequate.