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Roof Drainage Systems

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Among the most fundamental of architectural elements is the roof. Its principal purpose is to shelter a building's occupants, contents and structure from the elements, most critically from precipitation. While the various layers of the roof assembly play a key role in keeping moisture from infiltrating into the interior, adequate weather protection also depends on the roof's ability to drain moisture away from the building. If rain water, snow, and ice accumulate, the moisture can degrade and permeate the roofing assembly. Not only does standing water negatively impact the performance, integrity and longevity of the building enclosure, but it also can deteriorate the structural and interior elements the building enclosure is meant to protect.

Different roof types demand different drainage strategies.

Historically, roof drainage was accomplished by simply sloping the roof downward. Water could then pour off overhanging roof eaves onto the ground below, or, in more sophisticated assemblies, flow toward the perimeter and into a clay, wood or metal gutter system, or through a drainage outlet in the exterior walls.

Responding to the local climate of different regions, modern roof systems evolved to include not just steep slope assemblies, but also low slope roofs, often (mistakenly) referred to as "flat roofs." Originally found in arid locations with little annual rainfall, low slope roofs have a subtle pitch, allowing the roof assembly to be hidden behind a ***parapet wall,*** or portion of the facade that extends above the roof plane.

In regions with substantial precipitation, steep slope roofs were more common. The pitch can be quite prominent and play a significant role in the building's overall design. Steep pitches are achieved by a variety of roof shapes, but gable, hipped and mansard roofs are among the most prevalent.

As mechanical and plumbing system technologies and programmatic requirements evolved with the modern world, roof types began to respond less to climactic conditions, and more to interior layout and contemporary styles. Low slope roofs are now commonly used for high-rise and long-span commercial and industrial buildings, as well as urban residential buildings. Steep slope roofs are more typically

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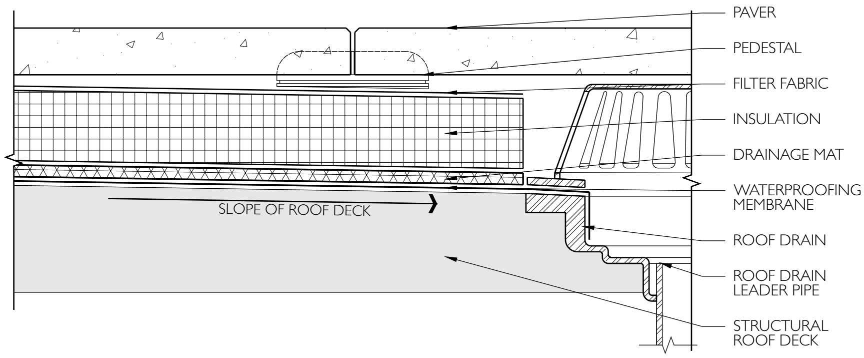
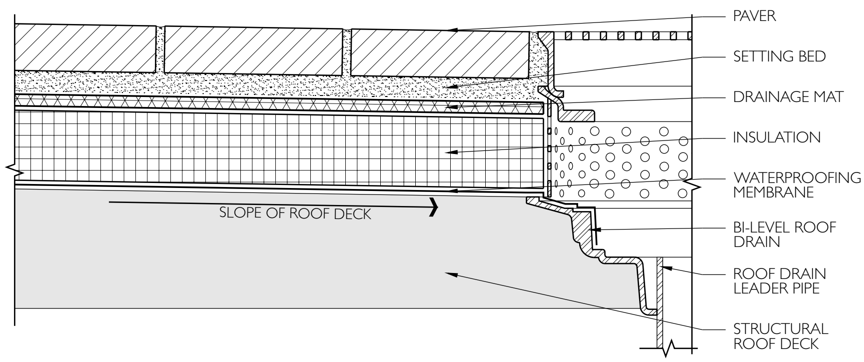
Typical PRMA Low Slope Roof Assemblies

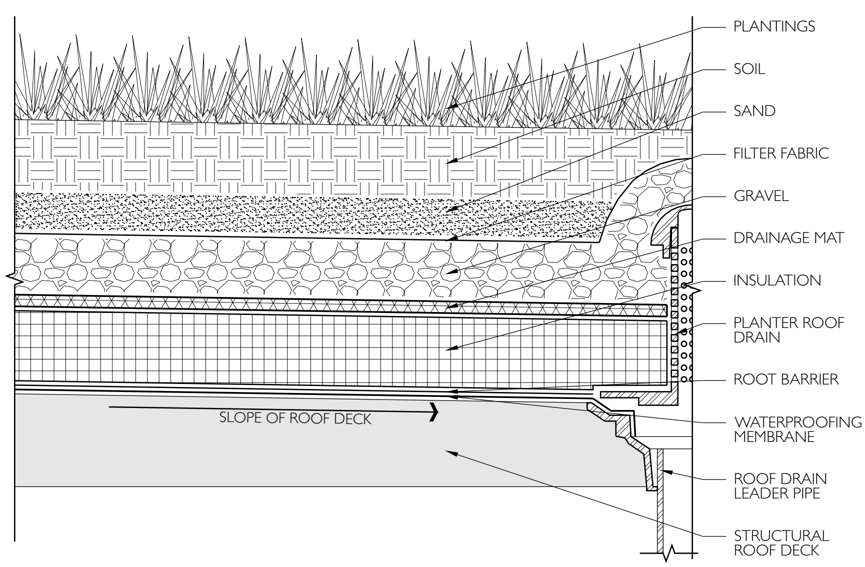
Pavers on Pedestals



Pavers in Setting Bed



Intensive Green Roof



ILLUSTRATIONS: STEFFANY MALARIK

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found on suburban and rural residential buildings, as well as many cultural, civic and institutional buildings of diverse scales and locations.

To promote the efficient function of roof drainage assemblies in these different roof types, it is important to recognize typical deficiencies and apply preventive maintenance strategies that keep the system working effectively. In some cases, persistent problems cannot be addressed through maintenance alone, and a design professional should evaluate the capacity, configuration, and detailing of drainage assemblies to determine whether they are adequate for the climate and roof area. Appropriate slope to drains, as well as flashing details and drain outlets, should also be considered as part of a thorough investigation.

Often an afterthought in a reroofing or new construction project, roof drainage systems tend to be given little attention – until they fail. Considering the damage water can do when allowed to pond on roofs and overflow from gutters, it is clear that ignoring roof drainage issues can lead to urgent problems. Better to design appropriate drainage assemblies and address incipient concerns now, than to chase after water damage later.

Low Slope Roofs

Low slope roofs are not actually flat, as they may appear, but instead have a subtle pitch (slope) of between one quarter inch per foot (2%) and two inches per foot (17%). The pitch of the roof is created by varying the height of building columns to slope the structural roof deck, by installing tapered insulation, or a combination of both.

Positive Drainage

Achieving expeditious drainage is critical to maximizing the lifespan of a roof. The goal is to direct all water towards roof drains and create ***positive***

roof drainage: "the drainage condition in which consideration has been made for all loading deflections of the roof deck, and additional slope has been provided to ensure drainage of the roof within 48 hours of precipitation" (Chapter 2, 2015 *International Building Code*).

The number and location of primary interior roof drains is determined by structural requirements limiting deflection, and by plumbing requirements, based on vertical drain leader diameter, roof slope, roof area per drain, and rainfall rate. Typically, a low slope roof is designed with one primary roof drain and one secondary roof drain -- or overflow ***scupper*** (drainage outlet) at the perimeter of the building -- per structural bay.

Typical Problems and Design Considerations

Clogged Drains. Standing water can cause myriad problems, and, if left unaddressed, can damage the waterproofing membrane, void the waterproofing warranty, and cause dirt and debris to collect, resulting in unwanted vegetation. Eventually, long-term water accumulation could cause detrimental structural deflection. Any sign of ponding water should be promptly addressed.

One common cause of standing water, which can be quickly remedied, is clogged drains. It is recommended that roof drains be cleaned out regularly, and drain bodies replaced as part of roof replacement projects.

Inadequate Number of Drains. Drainage problems may also be attributed to an insufficient quantity of drains for the size of the roof area or for the amount of precipitation. The 2015 *International Plumbing Code* requires that emergency overflow roof drains or scuppers be provided wherever the roof perimeter construction could entrap water if the primary drains fail.


In this vegetative roof above a parking garage, insufficient drainage caused ponded water *(left)*. The new assembly *(right)* incorporates waterproofing membrane, drainage mat, and gravel.

It is common to add such ***secondary drains*** during a roof replacement project. Secondary / emergency overflow roof drains look similar to primary drains, but a standpipe or dam blocks water from entering the drain until it reaches a certain depth. Overflow scuppers can also act as secondary drains at the perimeter of the roof. Scuppers are typically easier to install during a roof replacement project when additional secondary drains are required; however, the visibility of the scuppers may be undesirable.

Roof Assembly Design Deficiencies. Other causes of standing water that require more extensive work to diagnose and fix are related to the roofing assembly.

Protected Roof Membrane Assemblies (PRMA) are one of the most common and efficient waterproofing systems for low slope roofs. Originally referred to as an Insulated Roof Membrane Assembly (IRMA), this type of roof system consists of a waterproofing membrane adhered directly to the structural deck, atop which sit drainage mat, insulation, filter fabric, and some type of ballast. Water flows through open joints in the ballast, down to the drainage mat layer, where the slope of the structural deck directs the water into drains.

Drainage mat is typically composed of a polystyrene core with an array of raised buttons that provide space for water to move. On the top side, woven filter fabric allows water to pass through, while trapping soil particles that could impede the flow of water. This is an essential layer in the PRMA. It is important for the ballast to allow water to seep down to the drainage mat layer. Large river gravel was the typical choice, but some areas, such as New York City, restrict use of stone ballast, and instead pavers on pedestals are standard. The pedestals elevate the pavers and allow water to flow through the joints and beneath pavers.

Another form of PRMA sets pavers in a sand or mortar setting bed, rather than on pedestals. Below the setting bed are drainage mat, insulation, and a waterproofing membrane adhered directly to the structural deck. In this type of assembly, most of the water does not flow down through the paving surface; rather, it flows along the top of the pavers. Some water will inevitably penetrate the sand or mortar joints, so it is important to include ***bi-level roof drains,*** which receive water through a grate at the paving surface level, as well as through a perforated screen at the roof membrane level, for water that seeps below the paving surface. This type of assembly is especially susceptible to unwanted plant growth, as water soaks through the joints and is not able to freely flow through the setting bed to the roof drains. Trapped water can also cause the pavers to spall, crack or develop efflorescence.

Vegetative roofs, commonly referred to as "green roofs," are another form of PRMA. Vegetated roofs typically consist of either a roof assembly and additional landscape material components, or pre-vegetated trays assembled on top of a roof covering.

In addition to elevated green roofs atop buildings, vegetative roofs at grade, consisting of lawn areas and plazas, may conceal underground parking garages or other usable space. Such green roof assemblies usually include gravel and sand in addition to the drainage mat. These additional layers of drainage media help prevent plantings from becoming too saturated for proper growth. When undertaking green roof replacement projects on an underground structure, it is important to consider the area of existing pervious (permeable) surfaces. If the area of impervious surfaces is increased beyond the capacity of the existing storm water management system, a new system must be designed and installed to accommodate the increased volume of water shed by the expanded impermeable area.

Traditional roofing assemblies consist of rigid insulation adhesively or mechanically attached to the structural deck, with waterproofing membrane installed on top. In this assembly, all water flows along the waterproofing membrane and is directed into roof drains. When an existing structural roof deck does not provide the minimum required slope, or other components of the roof, such as skylights or curbs, disrupt the slope of the structural deck, ***tapered insulation,*** as part of a traditional roofing assembly, can be utilized to establish an appropriate pitch.

The two most common layouts for tapered insulation are the "two-way" and "four-way" systems. Two-way tapered insulation functions by splitting the roof drain catchment area into two parts and creating a primary slope at each part, forming a V-shaped linear valley that directs water toward the center of the roof. Another layer of tapered insulation, referred to as a ***saddle,*** is then used to divert water into the appropriate roof drain.

A four-way system functions by creating square roof drain catchment areas with tapered insulation panels sloped equally in four different directions with the high point at the perimeter of the roof and the low point at the roof drain. The intersection of the panels creates mitered valleys that direct water into the roof drain.

Crickets are additional layers of tapered insulation installed on the high side of large penetrations to direct water around the obstacle. Crickets and saddles are typically twice the slope of the adjacent roof.

Low Slope Roof Solutions

Standing water due to clogged or inadequate drains, or because of insufficient slope to drains, is, unfortunately, commonplace for low slope roof assemblies. The first step to address persistent ponding is to determine the cause of poor drainage, which may involve investigative probes into the roof assembly, as well as evaluation of existing drainage components. In addition to regular maintenance to prevent clogged drains, the roof assembly may need modification to improve water flow to drains and to provide sufficient drainage capacity during heavy rainfall. Providing a clear path for water movement across the roof assembly, as well as adequate roof slope and flow around penetrations, can improve the longevity of the roof and deliver reliable water management for the life of the system.

Steep Slope Roofs

Principal Design Considerations

As with low slope roofs, the first and most essential step in achieving a functioning drainage system for steep slope roofs is to maintain a minimum roof slope. Typically, a steep slope roof slope is equal to or greater than 3 inches of rise per 12 inches of run (25%).

Establishing a minimum slope is critical, because most steep slope roofing assemblies include claddings of asphalt, slate, clay tile or wood shingles, or seamed metal. Although the shingled elements are lapped to provide positive downward drainage over the assembly, the lower and side seams between lapped shingles are generally not uniformly sealed. Apart from ice and water barriers required at eaves, typical felt underlayments do not perform as full moisture barriers. Therefore, if the roof slope is too low, it can allow for standing water trapped behind melting snow and ice (known as ***ice damming***), or resulting from other blockages, to infiltrate beneath the shingles and into the roof structure.

Of equally great importance to slope is a continuous and controlled path for water to drain once it has reached the lower perimeter of the steep slope roof. This is ordinarily achieved with either prefabricated or custom-designed pitched gutters attached to downspouts or leader pipes placed at certain intervals or intersections along a building's facades. ***Conductor heads,*** enlarged catch basins that improve drainage capacity, are sometimes used as connector pieces between gutters and downspouts.

Although perimeter drainage components can be concealed, as with built-in gutter linings hidden behind parapets, or leader pipes placed inside walls, they can also be prominent design features, especially on historic structures. Gutters and conductor heads may double as a decorative cornice or fascia, and exterior downspouts may complement a facade's masonry ornamentation. These ornate drainage elements are a major consideration in restoration and roof replacement projects for landmark structures, as the relevant local and/or state regulating agencies, such as the State Historic Preservation Office (SHPO), often require matching replacement parts with historic profiles and original material type, finish, and/or color.

Primary Problems, Solutions, and System Maintenance

Perhaps the most critical issues with steep slope drainage systems are roofs with inadequately sized, poorly placed, or even missing drainage components. Per International Building Code (IBC) requirements and design standards published by Sheet Metal and Air Conditioning National Association (SMACNA), gutters and downspouts must be designed to accommodate the hourly rainfall intensity of the geographic area in which the building is located.

Typical Steep Slope Drainage Assembly

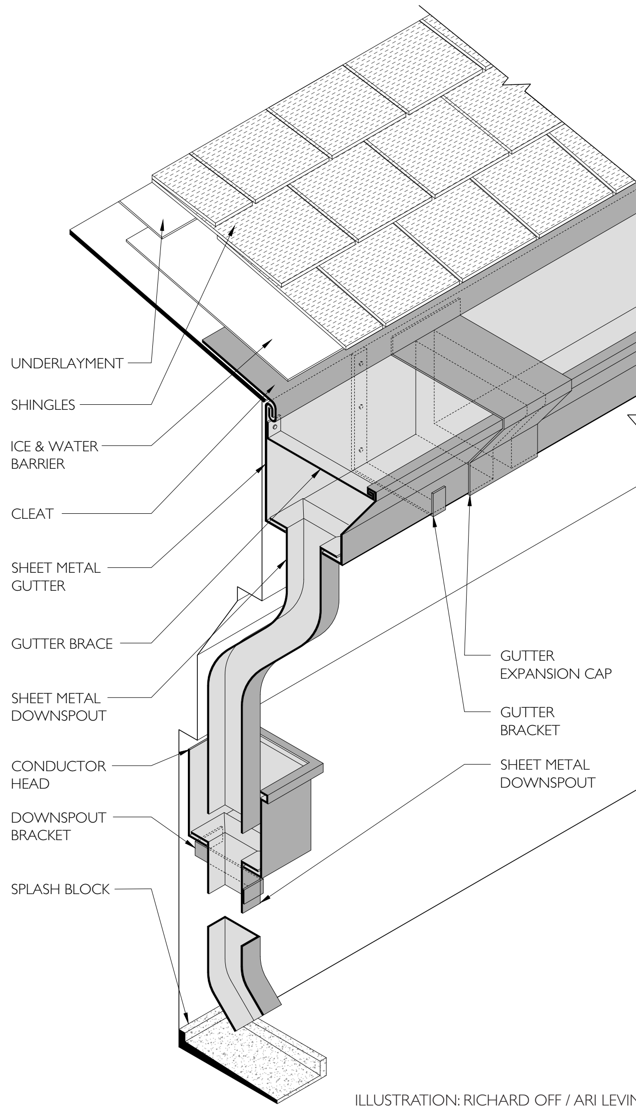

ILLUSTRATION: RICHARD OFF / ARI LEVINE

Insufficient Drainage Capacity. If gutters and downspouts do not provide an adequate cross-section for rainwater draining from a given roof catchment area and pitch, the water will become backed-up and spill over, potentially leading to moisture infiltration and eventual deterioration at adjacent roofs, and at facades below. If no gutters or downspouts exist, rainwater will be dumped directly onto adjacent roofs or ground, which can overcharge the neighboring roofs with additional rainwater, and/or oversaturate the ground. This may lead to structural damage at those adjacent roofs and moisture infiltration and deterioration in ground floors, basements, and foundations, and could create hazardous ice sheets at paved areas in winter months.

Incorrect Termination. Properly terminating the roof drainage system at the base of the facade is also an important consideration. At a minimum, downspout bases should be located above precast or stone splash blocks or drainage trenches to divert water in a controlled manner. However, it might be preferable to tie in the downspouts to the below-grade storm drain system. This may require consultation with a plumbing engineer to determine if the storm system can support the rainwater load from the roofs.

Material Deterioration. Distress and deficiencies in the materials of steep slope drainage system components are another significant concern. It is essential for materials to be carefully selected and treated to promote durability, provide protection against corrosion from long-term moisture exposure (rust), and avoid galvanic corrosion, which results from direct contact between dissimilar metals. Corroded metal ultimately becomes weak and brittle, causing it to lose mass and form holes. This increased porosity precipitates leaks by increasing the potential for moisture infiltration and eventual deterioration at adjacent surfaces. Therefore, significantly corroded components should be partially if not fully replaced.

Valued for their high workability, longevity and natural resistance to rust, **tin, lead,** and especially **copper** sheet metal was favored historically for steep slope drainage system

Undersized gutters led to facade deterioration at eaves and downspouts.

Clogged with debris, these inadequate gutters are filled with standing water.

components. Over time, with exposure to the elements, copper gradually forms a ***patina,*** an outer layer with a distinctive green color that insulates the copper from deterioration and corrosion. Copper may also be lead-coated to protect against galvanic action when tied in to other metals, and to avoid patina staining of neighboring surfaces.

Although less workable, **stainless and galvanized steel** sheet metal are acceptable alternatives. Compared to galvanized, stainless steel provides the more long-term resistance to rust, as it relies on the properties of its chemical composition, and not just a thin zinc coating, to provide protection. While structurally weaker than steel, **aluminum and polyvinyl chloride (PVC plastic)** are options that have natural resistance to corrosion. Aluminum can be paint finish coated, and PVC can be injection-molded with dyes, allowing these materials to achieve a wide range of colors which can mimic other more expensive construction materials, such as copper or even wood. **Cast iron** is sometimes used for downspouts and, because of its rigidity, commonly employed for downspout boots and other below grade pipes.

Restrained Movement. Connections between materials are an equally important consideration in drainage systems, to allow for thermal expansion and further protect against galvanic corrosion. ***Expansion joints,*** regularly spaced openings filled with flexible, elastic material, or detailed to allow for movement, should be placed at a maximum of every 50 feet along sheet metal gutters, depending on the gauge of the metal, the depth-to-width ratio, and the edge distance from downspouts or other fixed points. To avoid leaking and corroded connections, joints between metals should be sealed with rubber gaskets, silicone sealant, or lead and oakum, or they may be fully soldered or welded, depending on the type of connection and metals used.

Standing Water. Arguably the most commonplace issue with steep slope drainage, as with low slope drainage, is standing water from clogged gutters and downspout drains. Clogging can result from excess dirt, debris, and vegetative growth accumulating in the drainage system. Roofs located beneath trees, especially deciduous trees, are most susceptible to clogging from leaves and small branches that fall into gutters and block the drainage path.

These accumulations, combined with the standing water they engender, create spillover in downpours and generate excess weight in gutters, potentially causing them to sag or break loose from the support brackets and connections. Therefore, clogged gutters not only increase the potential for leaks and moisture infiltration at facades and roofs, but they also pose the more immediate concern of falling material. It is essential for gutters and downspouts to have adequate securement and frequency of support, to preserve their structural integrity, resistance to wind uplift, and minimum pitch for drainage flow.

Clogs and standing water can also occur at built-in gutters when roof penetrations create obstructions in the gutter's drainage path. Where possible, such obstructions should be avoided by placing penetrations high along the roof slope, and by installing ***crickets,*** saddle-shaped flashing used to divert water around penetrations, similar to those used on low slope roof assemblies. It is also essential to provide robust waterproofing and flashing around built-in gutters, as they pose a high risk for water intrusion into the building.

Providing conductor heads (also known as ***leader heads***) at gutter/downspout connections is one way to mitigate some of these drainage issues. Not only do they act as cleanout points for downspouts, but they also improve flow rates and even reduce noise by introducing air into the system. During heavy storms, they also operate as an overflow drain, preventing gutters from becoming overcharged by allowing water to be released at a controlled point, rather than uniformly along the length of the gutter and onto the facade. The use of snow guards and/or fences along the perimeter of steep slope roofs is also beneficial for winter months, as it mitigates snow and ice build-up in gutters.

While other design measures can be taken to reduce debris accumulation, such as installing removable gutter screen covers and wire strainers at downspout drains, it is still imperative for building owners or managers to conduct routine cleanings of the

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representative projects

Roof Drainage

Persistent drainage issues can lead to big roof problems. Ponded water, vegetative growth, overflow, ice damming, and deterioration are just some of the many concerns that can arise from incorrectly designed or installed drainage systems.

Whether for traditional low-slope roofs, protected roof membrane assemblies, green roofs, historic slate, tile, or copper, or other systems, removing water from the roof as efficiently as possible is critical to roof lifespan and maintainability.

Hoffmann Architects has developed solutions to drainage issues at diverse facilities, including:

Morgan Stanley
Purchase, New York
Replacement of Green Roof, Stormwater Management System, and Roof Drainage

Vassar College
Sanders Classroom Building
Poughkeepsie, New York
Copper Roof Replacement, Redesign of Built-in Gutters

Worcester Polytechnic Institute, Boynton Hall in Worcester, Massachusetts. *Slate Roof Replacement, Correction of Deficiencies at Historic Water Diverters.*

Federal Reserve Bank of New York
New York, New York
Roof Replacement, Rehabilitation of Drains, Scuppers, and Drainage Layer

Farmingdale State College (SUNY)
Lupton Hall
Farmingdale, New York
Roof Replacement and New Drainage System for Complex Roof Geometry

First Presbyterian Church
New York, New York
Roof Replacement, Rehabilitation of Built-in Gutters, Masonry Restoration

Washington Irving Library
Brooklyn, New York
Slate Roof Replacement, Gutter System Redesign to Original Historic Proportions

Saint Fidelis Church and Rectory
College Point, New York
Building Enclosure Assessment, Evaluation of Roof Drainage Systems

Queensborough Community College
Medical Arts, Science, and Administration Buildings
Bayside, New York
Replacement of Roofs, Multiple Drain Types, Scuppers, Gutters, Downspouts

Solow Building, 9 W 57th Street
New York, New York
Redesign of Canopy Drainage Channel

Saint Mark's Episcopal Church
New Canaan, Connecticut
Parish Hall Gutter Reconstruction

Countee Cullen Library
New York, New York
Facade, Window, and Roof Replacement, Drain and Scupper Replacements

National Air and Space Museum, Udvar-Hazy Center in Chantilly, Virginia. *Roof Replacement, with Design for Complex Drainage Conditions at Aviation Hangar Barrel Roof.*

Kingsbridge Armory in Bronx, New York. *Roof Investigation and Drainage Design Analysis.*

Madison Square Garden
New York, New York
Roof, Drainage, and Waterproofing Consultation

Choate Rosemary Hall
Brownell Building
Wallingford, Connecticut
Roof Replacement, including Slope and Drainage Improvements

Whitman Requardt & Associates Headquarters
Baltimore, Maryland
Water Infiltration Investigation, and Evaluation of Roof Drainage Issues

United States Capitol
Washington, District of Columbia
Dome Internal Gutter System Restoration / Reconstruction

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At the surface, these pavers seem fine. But trapped water below may be causing leaks.

entire drainage system. This should be done by insured professionals at least twice per year, as much as three or four times during especially wet years, and even more frequently for steep slope roofs located beneath overhanging trees.

Key Tips for Steep Slope Roof Drainage

Pitched rooflines mean that steep slope roofs have the advantage of shedding water readily. However, once that water reaches the edge of the roof, it needs to be channeled in a controlled manner to the ground or storm water system. Missing, clogged, damaged, or undersized gutters and leaders can compromise roof lifespan and pose a danger to building users. By identifying and correcting steep slope drainage issues as they arise, building owners and managers can avoid the costly and disruptive rehabilitation of compounded problems.

Weathering the Storm

Effective roof drainage means reliable protection from the elements. Regular inspection of roof water management components, from drains and gutters to crickets and flashings, enables proactive remediation of emerging problems. Sometimes, the fix may be as simple as clearing a clogged drain. Other times, the intervention may be more involved. In either case, waiting until problems are severe and pervasive only serves to make finding the source of the problem, and repairing it, more complicated and expensive. Whether for steep or low slope roofs, it pays to spare some time and attention on a regular basis for the decidedly un-glamorous, but all too important, job of attending to roof drainage. ■

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