drainage system is discharging water and that the primary drainage system is likely clogged and should be checked.

When the drainage system incorporates free drainage over the roof edge, the likelihood of clogging the free edge is very low. Section 4.6 outlines the required length of the free-draining roof edge for a given drainage area.

4.3 Capacity of Secondary Drain Outlets

Secondary drains consist of a drain bowl with a pipe outlet that is generally located at the bottom, a strainer screen or grating over the top, and an external dam or internal standpipe [**Figure G4-4(g) and (h)**]. The strainer is helpful in preventing debris from entering the drain and clogging the downstream piping system. Generally, the strainer consists of a metal or plastic upside-down thimble-shaped grate with numerous openings that are approximately 1/2 in. wide on the sides and top.

In all cases, the strainer needs to be of sufficient size and have sufficient free open area to allow substantial flow to pass through it with minimal head loss. As such, the IPC provides requirements for the minimum open area for the strainer based on the outlet diameter.

The two general categories of secondary drains are those with an external dam and those with an internal standpipe. For the external-dam-type secondary drain, the overflow elevation, or depth of static water for initiation of flow through the secondary drain, is typically 2 in. to 3 in. to prevent the flow of the first flush of water into the secondary drainage system and to minimize the static depth of water on the roof. The overflow elevation of the dam or standpipe component is part of the static head (**Figure G4-2**) and in the case of a standpipe can be substantial. The dam or standpipe component does not exist on primary drains and is in many cases the sole difference between a primary and a secondary drain. If the dam/standpipe is not used and the drain is installed at the low point in the roof surface, the secondary drainage system would clog at the same time as the primary drainage system and would defeat the purpose of the secondary outlet.

The flow through the secondary drain begins when the water depth overtops the standpipe or perimeter dam. When the water depth is at the top of the standpipe or the dam, the flow rate is zero (**Figure G4-1** shows the flow versus depth for several types of outlets), and the increase in flow rate versus depth of water will depend on the drain geometry, which varies based on manufacturer and model number. The following variables impact the flow capacity of a drain:

1. Geometry of strainer, including height, diameter, and size of strainer openings;
2. Diameter of dam or standpipe;
3. Diameter of drain bowl;
4. Depth of drain bowl; and
5. Outlet diameter size.

Table G4-1 is a reproduction of Table C8.3-1 in ASCE 7-16 and shows the depth (hydraulic head) versus discharge capacity for secondary drains (dam type drain with 3, 4, 6, 8, and 10 in. diameter outlet and a single standpipe type drain with an outlet diameter of 4 in.). The table provides the hydraulic head for two 6 in. diameter drain outlets, one with an 8 in. diameter dam and another with a 12.75 in. diameter dam. As expected, the required hydraulic head for a particular flow rate is equal to or higher than the smaller diameter dam, and often higher particularly at higher flow rates. The table provides Variables 2 through 5 from the preceding list. Variable 1 is fairly consistent between different drain manufacturers. Therefore, it generally has little impact on the outflow rate for a given hydraulic head.

The capacity of conventional roof outlets (i.e., drains and scuppers but not siphonic drains) is based on gravity flow, generally classified as either weir flow, orifice, or transition flow (transition flow is the flow regime between weir and orifice flow) depending on the depth of water over the outlet. At low water depths (i.e., low hydraulic head) for drains and pretty much all water depths for scuppers, the outflow is because of weir flow (similar to flow over the edge of a roof) for which the outflow is theoretically proportional to the hydraulic head to the 1.5 power. At increased water depths, the flow rate through a roof drain is controlled by orifice flow through the outlet pipe at the base of the drain bowl (similar to water flow through an opening in the bottom of a full open-top tank) for which the outflow is theoretically proportional to the square root of the hydraulic head. As shown in **Table G4-1**, orifice flow for a drain occurs in the shaded region, generally when the hydraulic head is between 50% and 100% of the drain outlet diameter.

In addition to the transition from weir to orifice flows, there are other complications (e.g., flow through the strainer) that make an analytical evaluation of the head-flow relationship challenging. As a result, the most reliable method to determine the head-flow relationship is via physical/laboratory tests.

Frequently, engineers erroneously believe that the piping capacity downstream from the drains governs the capacity of the roof drainage system and the resulting water depth on the roof. The sizing of the drainage system downstream of the roof drains is solely the responsibility of the plumbing engineer. The capacity of the downstream piping almost never controls if sized according to the IPC requirements because it is oversized to reduce pressurization and surcharge the piping system. The assumption for partial flow in the vertical and horizontal drainage piping is shown in **Figure G4-5**.

As noted, the flow capacity of drains is generally based on test data. An estimated capacity for a particular outlet can be developed if there are only slight geometry differences between it and a laboratory-tested outlet. Unfortunately, many drain manufacturers do not currently provide model-specific flow rate data. They tend to have more data for large-capacity drains (i.e., large-diameter dam with an 8 in. or 10 in. diameter outlet). Also, the test for drain capacity is not standardized. Some of the most comprehensive testing done to date appears to have been performed by FM Global (2016), which is the basis for the revised ASCE 7-16 capacity tables (**Table G4-1**).

Table G4-1 (ASCE 7-16 Table C8.3-1). Secondary Drain Capacities

	Hydraulic head (in.) above dam or standpipe						
	Overflow dam 8 in. diameter			*Overflow dam 12.75 in. diameter*		*Overflow dam 17 in. diameter*	*Overflow standpipe 6 in. diameter*
	Drain outlet size (in.)						
	3	*4*	*6*	*6*	*8*	*10*	*4*
	Drain bowl depth (in.)						
Flow rate (gal./min)	*2*	*2*	*2*	*2*	*3.25*	*4.25*	*2*
50	0.5	0.5	0.5	0.5	0.5	—	1.0
75	1.0	—	—	—	—	—	—
100	1.5	1.0	1.0	1.0	0.5	1.0	1.5
125	2.0	—	—	—	—	—	—
150	2.0	1.5	1.5	1.0	—	—	2.5
175	3.0	—	—	—	—	—	—
200	—	2.0	2.0	1.5	1.5	1.5	2.5
225	—	—	—	—	—	—	—
250	—	2.5	2.5	1.5	—	—	2.5
300	—	3.0	3.0	2.0	2.0	1.5	3.0
350	—	3.5	3.5	2.5	—	—	3.5
400	—	5.5	3.5	3.0	2.5	2.0	—
450	—	—	4.0	3.0	—	—	—
500	—	—	5.0	3.5	3.0	2.5	—
550	—	—	5.5	4.0	—	—	—
600	—	—	6.0	5.5	3.5	2.5	—
650	—	—	—	—	—	—	—
700	—	—	—	—	3.5	3.0	—

(Continued)

Table G4-1 **(ASCE 7-16 Table C8.3-1). Secondary Drain Capacities *(Continued)***

	Hydraulic head (in.) above dam or standpipe						
	Overflow dam 8 in. diameter			*Overflow dam 12.75 in. diameter*		*Overflow dam 17 in. diameter*	*Overflow standpipe 6 in. diameter*
	Drain outlet size (in.)						
	3	*4*	*6*	*6*	*8*	*10*	*4*
	Drain bowl depth (in.)						
Flow rate (gal./min)	*2*	*2*	*2*	*2*	*3.25*	*4.25*	*2*
800	—	—	—	—	4.5	3.0	—
900	—	—	—	—	5.0	3.5	—
1,000	—	—	—	—	5.5	3.5	—
1,100	—	—	—	—	—	4.0	—
1,200	—	—	—	—	—	4.5	—

Notes:

1. Assume that the flow regime is either weir flow or transition flow, except where the hydraulic head values are in shaded cells below the heavy line that designates orifice flow.

2. To determine total head, add the depth of water (static head, d_s) above the roof surface to the secondary drain inlet (which is the height of the dam or standpipe above the roof surface) to the hydraulic head listed in this table.

3. Linear interpolation for flow rate and hydraulic head is appropriate for approximations.

4. Extrapolation is not appropriate.

Source: Adapted from FM Global (2012).

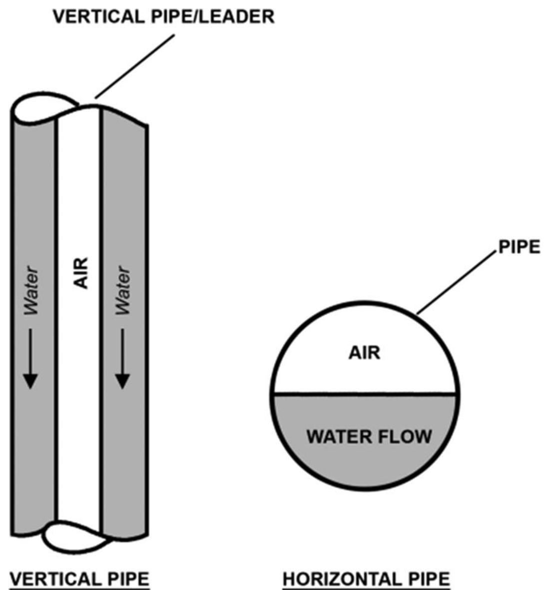

***Figure G4-5*. IPC assumed flow in vertical piping and open channel flow in horizontal piping to prevent surcharging.**

The nomenclature for classifying drain size can be confusing. Some manufacturers describe the size of their drains based on the diameter of the drain bowl, which is much larger than the outlet at the bottom of the drain bowl [**Figure 4-4(g)**]. It is typical for manufacturers to produce drains with the same drain bowl size but with a variety of drain outlet size options (i.e., 15 in. diameter drain bowl with options of 3 in., 4 in., 5 in., 6 in., 8 in., and so on, drain outlet sizes). In ASCE 7-16, the drain size is the outlet diameter; however, the size information also includes the dam or standpipe diameter and the depth of the drain bowl.

The hydraulic head versus flow data for drains in the ASCE 7-16 commentary (**Table G4-1**) can be interpolated but not extrapolated. In practice, a structural engineer may be presented with a secondary roof drainage system prepared by a plumbing engineer using the IPC 100-year return period/1 h duration event. However, when checked against the ASCE 7 100-year return period/15 min duration event, the required flow through the secondary outlets may be well beyond the maximum value listed in the ASCE head-flow tables, and, as noted, extrapolation is prohibited. This should trigger a conversation between the structural engineer and plumbing engineer. In such cases, the available options are to either (a) provide a larger drain size for the secondary drains with a tested capacity equal to or exceeding the calculated flow rate per the ASCE 7 design event, (b) obtain manufacturer-specific flow versus depth data up to the ASCE 7 design flow rate, or (c) revise the roof drainage layout to reduce the tributary area and resulting flow to the drains.

As the name suggests, dual outlet assemblies incorporate the primary and secondary drainage means into a single unit. **Figure G4-4(i)** shows an example of a drain that has a drain bowl and outlet for the primary drainage and an internal standpipe and separate outlet for the secondary drainage within one assembly. Because the standpipe does not have a strainer protecting the piping, the downstream piping for the secondary system is more prone to clogging.

In some cases, stone ballast is used to counteract wind uplift pressure on the roofing membrane. The stone ballast piling up around the primary drain strainer openings, as shown in **Photo G4-4**, will impact the primary roof drain capacity. Because the ballast is typically below the elevation of the secondary drains, it mostly impacts the capacity of the primary drainage system and is generally ignored in relation to the secondary outlets. However, if roof ballast is used, the dead load of the ballast must be incorporated into the roof loads. Also, because the static head is measured from the roofing surface and not the top of the ballast, the ballast additionally reduces the static water load component on the roof. For a ballasted roof, the structural engineer conservatively can add the full static head and ballast load or use **Equations (G4-1) and (G4-2)** for calculating the ballast dead loads and the resulting load due to the effective static head of water, both in pounds per square foot, as sketched in **Figure G4-6**. That is, the total load of ballast and water is equal to the weight of ballast plus the weight of water filling the voids in the ballast plus the weight of water over the ballast.

$$W_{\text{ballast}} = \frac{D_1}{12}\gamma_d \tag{G4-1}$$

$$W_{\text{Static Head Water}} = \frac{D_1}{12}\, n\ 62.4\,\text{lb/ft}^3 + \frac{D_2}{12}/62.4\,\text{lb/ft}^3 \tag{G4-2}$$

where

W = Load in pounds per square foot (lb/ft^2),

n = Porosity (assumed to be 0.4),

γ_d = Dry density of ballast (lb/ft^3) (assumed to be 100 lb/ft^3),

D_1 = Depth of ballast (in.), and

D_2 = Depth of water overtop of ballast (in.).

Photo G4-4. **Roof drain with stone ballast.**

Source: Courtesy of Nicholas Simmons. Used with permission.

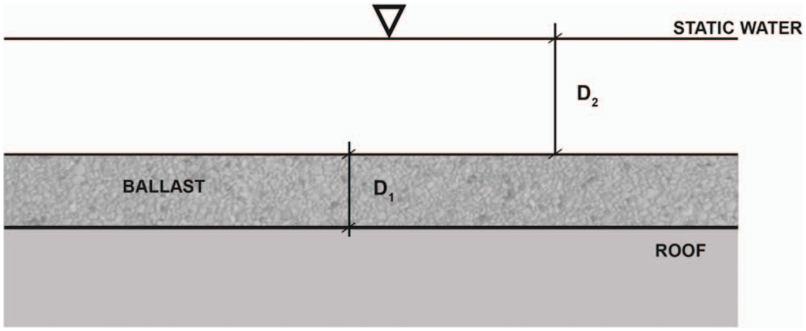

Figure G4-6. **Roof ballast load combined with static head load.**

4.4 Geometry-Based Adjustment

ASCE 7 provides adjustment procedures if the geometry of the secondary drain is different than the tested drain geometry. Specifically, the diameter of the dam or standpipe impacts the flow at low heads within the weir flow regime, while the drain bowl depth impacts the flow at higher heads within the orifice flow regime. As noted, the unshaded values in **Table G4-1** are weir and transition flow, while the shaded values are for orifice flow.

Adjustment for Weir Flow: Dam/Standpipe Diameter

Equation (C8.3-3) of ASCE 7-16 determines the capacity of a manufacturer's drain in the weir flow regime (low head) when the manufacturer's drain dam geometry differs from the geometry tested and listed in the ASCE 7-16 commentary. As noted, the calculated weir flow is proportional to the perimeter circumferential length of the drain and the hydraulic head to the 1.5 power. Hence, equating the flow rates, the adjustment factor is the ratio of diameters to the 0.67 power (1/1.5 = 0.67) as given in Equation (C8.3-3):

$$d_{h2} = \left[\left(\frac{D_1}{D_2}\right)^{0.67}\right] \times d_{h1} \qquad \text{(C8.3-3)}$$

where d_{h1} is the hydraulic head from **Table G4-1** for the tested drains with diameter D_1 at a given flow rate, and d_{h2} is the hydraulic head at the same flow rate for the referenced drain with diameter D_2. This adjustment does not apply if the flow is in the orifice regime (shaded portion of the table).

As noted in the ASCE 7-16 commentary, Section C8.3, "it is advisable not to use an adjusted design hydraulic head less than 80% of the hydraulic head provided in the tables (for a given flow rate) unless flow test results are provided to justify the hydraulic head values" when adjusting for a dam diameter that is different from those tested.

Adjustment for Orifice Flow: Drain Bowl Depth

ASCE 7-16 also provides an adjustment for flow in the orifice regime. In this case, any reduction in the drain bowl depth should be added to the hydraulic head (i.e., if the tested drain had a 4 in. depth and the manufacturer's drain is 3 in.

deep, the engineer should add 1 in. to the hydraulic head values reported in the table). In the case where the depth of the manufacturer's drain bowl is deeper than the drain bowl depth tested, one can deduct the difference from the hydraulic head. This bowl depth adjustment does not apply in weir flow regime (unshaded portion of the table).

Similar to the weir flow regime, it is not advisable to use an adjusted design hydraulic head of less than 80% of the hydraulic head provided in the tables for orifice flow. Although not explicitly noted in ASCE 7-16, one should be hesitant to go below the largest value for the weir flow regime (i.e., the value immediately above the dark line separating the weir flow/unshaded region from the orifice flow/shaded region).

Engineers should be careful when specifying or evaluating roofs with retrofit drains that in some cases may reduce the capacity of the existing drainage system because the bowl depth or outlet diameter is reduced.

4.5 Capacity of Scupper Outlets

Scuppers are either rectangular or circular, with rectangular scuppers likely being the most common and certainly the most hydraulically efficient. In some cases, the rectangular scupper is closed at the top, and in other cases, it is open at the top, which is called a channel scupper in ASCE 7-16 (**Figure G4-7**). Rectangular open-top scuppers act as weirs (**Figure G4-8**), whereas circular scuppers and closed rectangular scuppers initially act as weir flow under low heads and orifice flow (vertically oriented orifice) under high heads. The curved invert of circular scuppers results in a complex calculation of the weir flow rate. **Tables G4-2 and G4-3** provide the hydraulic head versus discharge capacity for rectangular open-top channel scuppers, rectangular closed scuppers, and circular scuppers.

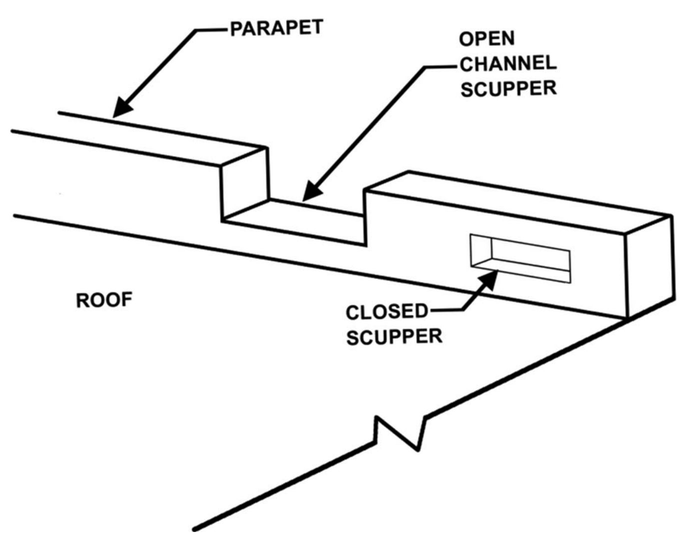

Figure G4-7. **Closed versus open-top rectangular scupper.**

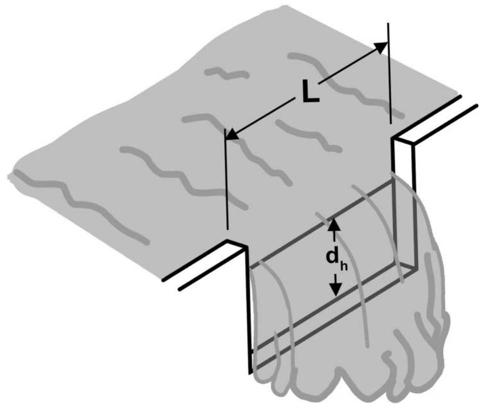

Figure G4-8. **Open-top rectangular channel scupper.**

Table G4-2 **(ASCE 7-16 Table C8.3-3). Rectangular Scupper Capacities**

	Hydraulic head, d_h, *in.*									
Drainage system	*1*	*2*	*2.5*	*3*	*3.5*	*4*	*4.5*	*5*	*7*	*8*
6 in. wide channel scupper[a]	18	50	[b]	90	[b]	140	[b]	194	321	393
24 in. wide channel scupper	72	200	[b]	360	[b]	560	[b]	776	1,284	1,572
6 in. wide, 4 in. high, closed scupper[a]	18	50	[b]	90	[b]	140	[b]	177	231	253
24 in. wide, 4 in. high, closed scupper	72	200	[b]	360	[b]	560	[b]	708	924	1,012
6 in. wide, 6 in. high, closed scupper	18	50	[b]	90	[b]	144	[b]	194	303	343
24 in. wide, 6 in. high, closed scupper	72	200	[b]	360	[b]	560	[b]	776	1,212	1,372

Source: Adapted from FM Global (2012).

[a]Channel scuppers are open-topped (i.e., three-sided). Closed scuppers are four-sided.

[b]Interpolation is appropriate, including between widths of each scupper.

For a given hydraulic head, the open-top rectangular scupper is slightly more efficient at larger heads because it is still subject to weir flow (flow rate proportional to head to the 1.5 power) at large hydraulic heads, whereas the closed scupper is subject to orifice flow (flow rate proportional to the square root of the hydraulic head). In addition, the open-top rectangular scupper is less likely to clog because debris larger than the height of the opening can be washed through the open-top rectangular scupper opening rather than becoming trapped against the closed scupper opening. Moderately sized (say, 12 in. or greater) channels and closed scuppers are less likely to be clogged by leaves, feathers, and other debris when compared with drains because the small openings in the strainer on the drain can be easily clogged with debris, while this same debris will likely be washed

Table G4-3 **(ASCE 7-16 Table C8.3-5). Circular Scupper Capacities**

	Scupper flow (gal./min)						
	Scupper diameter (in.)						
d_h *(in.)*	*5*	*6*	*8*	*10*	*12*	*14*	*16*
1	6	7	8	8	10	10	10
2	25	25	30	35	40	40	45
3	50	55	65	75	75	90	95
4	80	90	110	130	140	155	160
5	115	135	165	190	220	240	260
6	155	185	230	270	300	325	360
7	190	230	300	350	410	440	480
8	220	280	375	445	510	570	610

Notes:

1. Hydraulic head (d_h) is taken above the scupper invert (design water level above base of scupper opening).

2. Linear interpolation is appropriate for approximations.

3. Extrapolation is not appropriate.

Source: Data from Carter (1957) and Bodhaine (1968).

through the larger opening of the scupper. Although scuppers are less likely to clog, they still require a secondary outlet when they are used as the primary drainage outlets. Scuppers are typically used in the three following scenarios:

- As a secondary outlet in combination with a primary drain,
- As a primary outlet (likely with a scupper box and downspout), and
- As a secondary outlet in combination with a primary scupper.

The data in **Tables G4-2 and G4-3** show the capacities for 6 in. and 24 in. wide open-top rectangular scuppers as well as 4 in. and 6 in. tall closed scuppers (again for 6 in. and 24 in. widths). As expected for all hydraulic heads, the 24 in. wide open-top rectangular scupper is assumed to have exactly four times the flow of the 6 in. wide open-top rectangular scupper. This assumption of a linear relationship between scupper width and flow is reasonable for widths of 6 in. or more. Capacities for scupper widths less than 6 in. wide should not be extrapolated because the contraction losses at the vertical edges of the openings are significant and reduce the capacity substantially, particularly for scuppers with high hydraulic heads (a hydraulic head greater than the scupper width). Also, as expected, the closed rectangular scupper of a given width has exactly the same flow as an open-top rectangular scupper for hydraulic heads less than the closed scupper height.

One can estimate the hydraulic head versus discharge for a rectangular scupper with a width that differs from the standard 6 and 24 in. widths shown in