

Manual for the Design of Roof Drainage Systems

**A guide to the use of European
Standard BS EN 12056-3:2000**

R W P May

**Report SR 620
March 2003**

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Summary

Manual for the design of roof drainage systems

A guide to the use of European Standard BS EN 12056-3:2000

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March 2003

This manual provides comprehensive guidance on how roof drainage systems for buildings should be designed using information given in European Standard 12056-3:2000 “Gravity drainage systems inside buildings – Part 3: Roof drainage, layout and calculation”. The manual is intended to be used in conjunction with BS EN 12056-3 and contains separate chapters dealing with the following topics:

- Rainfall data
- Effective catchment area
- Design flow loads
- Capacity of freely-discharging gutters
- Outlets from gutters
- Capacity of gutters with restricted discharge
- Drainage of flat roofs
- Overflow weirs
- Rainwater pipes and drains inside buildings
- Siphonic systems.

Each Chapter consists of two parts. The first provides background information, either explaining the basis of the recommendations in BS EN 12056-3 or, in some cases, giving additional data. The second part describes in detail the steps that should be followed in the calculations. A series of worked examples is also included to illustrate the design procedures.

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1. INTRODUCTION

Some of the first recommendations on the hydraulic design of roof gutters to be widely adopted in the UK were contained in BRS Digests 116 (First Series) and 34 (Second Series) [Refs. 1 and 2] published by the Building Research Station (now the Building Research Establishment, BRE). A metricated version of both documents appeared as BRS Digest 107 in 1969 [Ref. 3].

In 1974, a new British Standard Code of Practice CP 308 “Drainage of roofs and paved areas” [Ref. 4] was produced, and introduced a new design method for valley, parapet and boundary-wall gutters based on hydraulic theory developed by Beij [Ref. 5].

In 1983, CP 308 was replaced by a completely revised British Standard Code of Practice BS 6367 [Ref. 6] with the same title as before. In BS 6367, Beij’s theory was applied consistently to all types of gutter and new design equations were given for the capacity of outlets in gutters and box-receivers. The Meteorological Office also provided new detailed information on the incidence of short-period rainstorms in the UK. BRE revised Digest 107 to maintain conformity with CP 308 and this was published as Digest 189 [Ref. 7] in 1976.

In 2000, BS 6367 was replaced by European Standard BS EN 12056-3 [Ref. 8], which was prepared by CEN Task Group TC 165/WG 21/TG3 with active involvement by the UK. BS EN 12056 deals with gravity drainage systems for buildings up to the point where the flows reach the external walls of the building. Some of the information in the old BS 6367 that related to the drainage of paved areas is now contained in BS EN 752-4 [Ref. 9].

BS EN 12056 consists of the following five parts:

Part 1: General and performance requirements

Part 2: Sanitary pipework – Layout and calculation

Part 3: Roof drainage – Layout and calculation

Part 4: Waste water lifting plants – Layout and calculation

Part 5: Installation and testing, instructions for operation, maintenance and use.

The initial draft of Part 3 was prepared by the UK based on the same general design principles as BS 6367 but with different procedures for some of the calculations. Account was taken of results of new data from tests carried out in Switzerland on the capacity of level and sloping gutters and of some differences in design practice in other European countries. General performance criteria for siphonic roof drainage systems were also included. However, overall, the basis of BS EN 12056-3 is equivalent to that of BS 6367, and in many cases the two documents give closely similar results.

The common European text of BS EN 12056-3 does not include national meteorological data, and provides less background information than BS 6367 on the layout and design of roof drainage systems. Also, a majority of the European countries decided that they did not require a design procedure for gutters with restricted discharge due to their using different methods of gutter construction or types of outlet. The UK therefore added six National Annexes (NA to NF) covering meteorological data and relevant design information from BS 6367 where this did not conflict with the common text of the European Standard. These National Annexes are denoted as “Informative”, as opposed to the main text and Annex A (dealing with the testing of gutters and outlets) which have a “Normative” status. The use of Annexes NA to NF is therefore not mandatory in the UK, although they can be cited in contracts if required. BS EN 12056-3 has the status of an Approved Document in Part H of the UK Building Regulations [Ref. 10].

This manual deals only with Part 3 of BS EN 12056 and the UK National Annexes. The objectives of the manual are to:

- explain the basis of the information in EN 12056-3 relating to the design of roof drainage systems;
- describe, in a sequence of appropriate steps, how the information should be applied to various types of design problem.

The manual does not cover straightforward, factual information in EN 12056-3 relating to: Materials and components for rainwater goods (National Annex NA); and Layout, installation, inspection, testing and maintenance (National Annex NE).

2. LAYOUT AND SCOPE OF MANUAL

This manual is intended to be used in conjunction with BS EN 12056-3, but is not a replacement for it. The manual therefore describes the various stages in the design of a roof drainage system but it is necessary to refer to BS EN 12056-3 for particular Figures or items of information. The steps in the design process (following the direction of flow through a rainwater system) are described in the following Chapters of this manual:

Chapter Number	Design step
3	Rainfall data
4	Effective catchment area
5	Design flow loads
6	Capacity of freely-discharging gutters
7	Outlets from gutters
8	Capacity of gutters with restricted discharge
9	Drainage of flat roofs
10	Overflow weirs
11	Rainwater pipes and drains inside buildings
12	Siphonic systems

Each Chapter consists of two parts. The first provides background information, either explaining the basis of the recommendations in BS EN 12056-3 or, in some cases, giving additional data. The second part describes in detail the steps that should be followed in the calculations.

Although BS EN 12056-3 gives some general criteria for the satisfactory performance of siphonic roof drainage systems, it does not provide calculation procedures for sizing the pipework. The detailed design of siphonic systems is normally carried out using proprietary software, the principles of which are explained in Chapter 12. However, siphonic systems normally need to cater for the same rainfall requirements as conventional systems in which the rainwater pipes are designed to flow only part full, and the flow capacity of the gutters depends on the same factors whether the outlets are of conventional or siphonic type. The information in Chapters 3, 4, 5, 6, 8, 9 and 10 of this manual is therefore equally applicable to siphonic systems.

The various design procedures in BS EN 12056-3 are illustrated by five worked examples included in Appendix A.

3. RAINFALL DATA

3.1 Background information

3.1.1 Rainfall characteristics

In BS EN 12056-3, the values of rainfall intensity, r , are expressed in units of l/s per m² of effective catchment area on which the rain falls. The value of r can be related to the corresponding rainfall intensity, r_o in mm/h by the formula:

$$r_o = 3600 r \quad (3.1)$$

The design rainfall intensity to be used for sizing a rainwater drainage system depends on three factors:

- the duration of the rainfall event (D , in minutes);
- the geographical location of the building;
- the return period of the event (T , in years).

As an example, an event with a return period of 50 years will occur, on average, once every 50 years. However, events of this magnitude will not normally occur regularly at 50 year intervals. Thus, there is a finite chance that one 50-year event could be quickly followed by another and then, perhaps, not be repeated for a much longer period than 50 years.

Statistical data for a particular location are obtained by scanning a rainfall record with a “window” of duration D minutes and counting how frequently a depth of rainfall (M , in mm) falling in that time is exceeded by heavier storms. These measurements can then be analysed to determine the return period T of that particular rainfall depth M ; the value is called the D min MT depth (e.g. 2min $M5$ depth, for a two minute storm event with a return period of 5 years). The corresponding average rainfall intensity for the event is $r_o = (60 M) / D$ in mm/h, or $r = M / (60 D)$ in l/s per m² using the units in BS EN 12056-3.

The word “event” is used here purposefully rather than the word “storm”. This is because the design value of rainfall depth occurring in D minutes will usually form the most intense part of a longer storm in which the intensity varies continuously with time. The design “event” used for sizing a roof drainage system will, therefore, not normally come out of a clear blue sky and then end equally suddenly, but will have been preceded by a period of less intense rainfall.

Rainfall records from around the world all show that, at any particular location, the value of rainfall intensity, r , increases as the duration, D , of the event decreases and its return period T increases. The general relationship between r , D and T for any location in the UK can be established (for $D = 2-10$ minutes) from Figures NB.6 and NB.7 in National Annex NB of BS EN 12056-3, as explained below in Section 3.2.2.

3.1.2 Design rainfall duration

As mentioned above, the shorter the duration of the event considered, the higher will be the value of the design rainfall intensity. However, it is also necessary to consider the time of concentration of the drainage system, i.e. the time taken for rain falling on the most upstream part of the roof to reach the outlet from the roof or gutter. If the time of concentration, T_C , is greater than the design rainfall duration D , the flow rate at the outlet will not reach the maximum value that could be produced by the rainfall intensity r if all the roof were contributing. Thus, for design purposes, the worst case situation occurs when D is just equal to T_C .

Note 1. The above description is a little simplified because, in practice, rainfall intensities vary continuously with time and alter somewhat the relationship between D and T_C that gives rise to the worst-case condition. However, for engineering purposes, it is reasonable to assume that the design case occurs when $D = T_C$, and this is the basis for the well-established Rational Method for the design of piped drainage systems.

The value of T_C depends upon the size and layout of the roof and the drainage system. In the case of a building with gutters, T_C will usually be the sum of the time taken for water to flow down the roof and the time taken for it to flow along the gutter to an outlet. There will obviously be some differences in the values of T_C for small, pitched roofs and those for large, nearly flat roofs. Although a few studies have been made to determine the contribution of roofs to the amount of run-off entering sewerage systems, the only known field study in which the time of concentration at roof level was evaluated for natural rainfall conditions was one carried out by Escarameia [Ref. 11]. Measurements of major storms on a pitched roof (with a slope of 4.4° and a maximum drainage length of 30.7 m) gave an average time of concentration of about 45 s (with a maximum observed time of 90 s). Corresponding measurements on a flat roof (with cross-falls of about 1° and a maximum drainage length of 18.3 m) gave an average time of concentration of about 80 s (with a maximum of 240 s). Several of the monitored storms produced flow volumes that were equivalent to 100 % run-off from the areas of roof drained. These results support the recommendations in BS EN 12056-3 that drainage systems for impermeable roofs should normally be designed assuming 100% run-off and a critical storm duration of 2 minutes.

Some small buildings may have a time of concentration of less than 2 minutes, but it will usually not be appropriate to consider design rainfall durations below 2 minutes. This is because the volume of spillage from a rainwater system depends upon both the rainfall intensity and the length of time during which overtopping occurs; very short events will usually not have serious practical consequences. On the other hand, some large flat roofs may have times of concentration greater than 2 minutes, and more economic designs may be produced if this is taken into account by using a longer rainfall duration equal to T_C . An approximate value of T_C can be obtained by estimating the average speed of water travelling between the most upstream part of the roof catchment and the outlet into which it drains; dividing the distance travelled by this average speed will give an estimate of T_C . A method is given in Clause NB.2.2 of BS EN 12056-3 (p. 58) for estimating rainfall intensities for durations of up to 10 minutes.

3.1.3 Geographical location

Figures NB.1 to NB.4 in National Annex NB of BS EN 12056-3 provide maps of the UK showing contours of rainfall intensity, r (in l/s per m^2), for events of 2 minutes duration having return periods of $T = 1, 5, 50$ and 500 years. Figure NB.5 gives contours of the probable maximum rainfall intensity that might occur if all factors (such as thermodynamic storm efficiency) were to be maximised. The choice of a suitable value of design return period for a building is considered in Section 3.1.4. Use of the maps enables rainfall data to be obtained that is specific to any particular location in the UK. Contrary to what might be expected, the areas with the highest rainfall intensities are in East Anglia and the south-east of England where annual rainfall amounts are lowest. The reason for this apparent anomaly is that intense short-period events are most often associated with summer thunderstorms, and these tend to occur most frequently in the areas that have the highest average summer temperatures.

3.1.4 Risk and return period

In the UK, design rainfall intensities for rainwater drainage systems of buildings should be determined from the statistical data given in National Annex NB. The option allowed in Clause 4.2.2 of BS EN 12056-3 of selecting a minimum rainfall intensity from Table 1 and applying risk factors from Table 2 according to the type of gutter or building is NOT applicable in the UK. This option is adopted in some European countries that do not have or provide suitable statistical data (see Annex B for details).

For buildings in the UK, Clause NB.2.1 of National Annex NB in BS EN 12056-3 proposes four categories of design rainfall for rainwater drainage systems of buildings.

Category 1 corresponds to a storm return period of $T = 1$ year and will normally be suitable for eaves gutters that are able to overflow safely away from a building without causing damage to the structure or inconvenience at ground level. This Category can also be appropriate for flat roofs provided that the construction is fully watertight and able to cater for temporary ponding during rarer storm events. Values of design rainfall intensity, r (in l/s per m²), for storm events lasting 2 minutes can be obtained directly from Figure NB.1 in BS EN 12056-3.

Note 1. The fixed rainfall intensity of 75 mm/h (equivalent to 0.021 l/s per m²) recommended in the superseded BS 6367 [Ref. 6] for eaves gutters and flat roofs should no longer be used in the UK. Note that there is a significant regional variation in Category 1 rainfall intensity, between $r = 0.022$ l/s per m² in London and East Anglia and $r = 0.010$ l/s per m² in the north of Scotland.

Note 2. Some nominally “flat” roofs have internal cross-falls of 5° or steeper. From the point of view of the water, these roofs are steep and will produce rapid rates of run-off. Although not specifically required in BS EN 12056-3, it might be appropriate to adopt Category 2 for such cases.

Categories 2, 3 or 4 should be selected for valley, parapet gutters and boundary-wall gutters, and for any rainwater system where exceedance of the design flow capacity could result in damage to the fabric or contents of the building or inconvenience to users. These three Categories are defined in terms of the probability of the design rainfall value being exceeded in the life of the building. The concept of there being a finite risk of a roof drainage system overflowing sometimes causes difficulties because the initial reaction of a potential owner of a building is that any such risk should be eliminated. This is particularly the case with certain types of building construction (e.g. steel portal frames) where it may be practically impossible to maintain a watertight joint between the roof and an internal valley or parapet gutter; thus, if the gutter overflows, water is likely to enter the building. The intention behind Categories 2 to 4 is to make all those involved in the construction of a building aware that some degree of risk cannot be avoided and that a compromise must be struck between the competing needs for maximum security and maximum economy. Consideration should be given to these factors at an early stage in a project because it may influence the choice of roof construction or help identify changes to the structural design that would enable the hydraulic requirements to be satisfied more easily.

The degree of risk is defined in BS EN 12056-3 as the probability, P_R , that a particular design rainfall intensity will be exceeded in the life of a building. The value of P_R can vary between 0, corresponding to zero risk, and 1, corresponding to complete certainty that the design intensity will be exceeded. The risk that the intensity of a storm with a return period of T will be exceeded within the design life, L_Y , of a building is given approximately by Equation (NB.1) in Clause NB.2.1 of BS EN 12056-3. This result can be re-arranged as follows to give the value of storm return period needed to limit the risk of exceedance to a specified value of P_R :

$$T = \frac{I}{I - (1 - P_R)^\alpha} \quad (3.2)$$

where:

$$\alpha = \frac{1}{L_Y} \quad (3.3)$$

and T and L_Y are both in years. This result is valid provided $T \geq 5$ years. As an example of the application of Equation (3.2), it can be shown that the probability of a 50-year storm event being equalled or exceeded in a 50 year period is about 64% (i.e. $P_R = 0.64$). Similarly, the probability of a 500-year event being equalled or exceeded in the same 50-year period is about 10%.

The categories of risk proposed in Clause NB.2.1 of BS EN 12056-3 (p. 51) are:

Category 2 - $P_R = 0.5$, requiring approximately that $T = 1.5 L_Y$

Category 3 - $P_R = 0.2$, requiring approximately that $T = 4.5 L_Y$

Category 4 - $P_R \approx 0$, corresponding to the maximum probable rainfall.

These three categories provide convenient but somewhat arbitrary increments in the level of security. However, there is no reason why a specifier or designer should not decide to use a different value of probability factor, P_R , if this is considered more appropriate. It is important for everyone involved to appreciate that many aspects of a building are subject to some risk of failure, and that similar questions of probability apply to design values of wind loading or earthquake loading.

3.1.5 Determining the design rainfall intensity

Clause NB.2.1 of BS EN 12056-3 (p. 52) suggests that it should not normally be necessary to interpolate between the rainfall intensity values obtained from the maps in Figures NB.2 to NB.5, and that it should be sufficient to choose the first map that has a return period, T , greater than required by the appropriate category of risk. This can be justified for two reasons. Firstly, standardized rainfall records have not been kept at many sites for more than about 100 years and there is uncertainty in extrapolating to rarer events, particularly if there are longer-term climatic changes. Secondly, data on short-period storms ($D = 2\text{--}10$ minutes) have been collected at only a relatively few sites in the UK; the complex contours in Figures NB.2 to NB.5 therefore give a somewhat misleading view of the accuracy of the estimates that can be obtained.

Despite the uncertainty that is associated with the rainfall data, designers often find it necessary to attempt more accurate estimates of rainfall intensity. This need may be the result of economic factors since, for example, going from Figure NB.3 for a return period of 50 years to Figure NB.4 for a return period of 500 years would increase the design rainfall intensity in London from 0.056 to 0.088 l/s per m², which would represent a significant increase in the size and cost of a rainwater system. Similarly, more precise figures may be appropriate when investigating the performance of an existing roof drainage system. Specific values of rainfall intensity or corresponding return period can be obtained using Figures NB.6 and NB.7 in BS EN 12056-3 (pp. 61, 62) together with the methods described in Clause NB.2.2 (p. 58). As discussed above, it is perfectly acceptable for levels of risk other than Categories 2, 3, and 4 to be adopted if these would be more appropriate in particular circumstances.

3.2 Calculation steps

3.2.1 Category 1

This Category will normally be suitable for eaves gutters, particularly on domestic buildings, and for flat roofs. On average, the design flow rates will be exceeded once every year but in some cases more than one exceedance may occur in a single year while in other years there may be no exceedance at all. Higher rainfall intensities than those used in design may not automatically result in overtopping of gutters because the design procedures in BS EN 12056-3 include certain safety margins. However, the presence of safety margins should not be relied upon to provide protection to a higher standard because they may be cancelled out by factors such as the gutters not being installed correctly to the required level or fall, or to the presence of limited debris in the gutter invert. Therefore, Category 1 should only be selected in cases where the gutters can overflow safely and fairly regularly without causing damage to the building and its contents, or significant inconvenience to users or the public.

3.2.2 Categories 2, 3 and 4

In Categories 2, 3 and 4, a more detailed statistical approach is used to determine an appropriate design rainfall intensity for buildings in which overflowing of the rainwater system would lead to a significant risk of damage or serious inconvenience. Examples include valley, parapet and boundary wall gutters where a watertight joint between the gutter and the roof construction cannot be assured. Eaves gutters incorporating a fascia with an outer edge higher than the inner edge may also come within this category.

The steps in the calculation procedure are as follows:

- (a) Decide the duration of the storm event to be considered in design. Normally this will be 2 minutes, but see Section 3.1.2.
- (b) Determine the design life of the building, L_Y , in years; this information will usually need to be supplied by the designer or owner of the building.
- (c) Decide what degree of risk can be accepted that the design rainfall intensity may be exceeded during the life of the building. The value of the risk or probability factor, P_R , will be between 0 (no risk) and 1 (complete certainty that the design rainfall intensity will be exceeded). Guidance on the choice of Risk Category and P_R value is given in Section 3.1.4.
- (d) Calculate the appropriate return period, T , in years for the design storm using the figures given for Risk Category 2, 3, or 4 in Section 3.1.4 or from Equation (3.2) in the same Section.
- (e) **Alternative 1.** Use the rainfall map (NB.1 to NB.5) in National Annex NB of BS EN 12056-3 whose return period is equal to or just greater than the design value, T , found in step (d). Based on the geographical location of the building, determine from the contours of the map the value of design rainfall intensity, r in l/s per m². This alternative is suitable if the storm duration selected in step (a) is 2 minutes and no greater accuracy is required in the estimation of the design rainfall intensity.
- (f) **Alternative 2.** This method should be used if: (a) greater accuracy is needed in the value of rainfall intensity; or (b) the design storm duration is not 2 minutes; or (c) the design return period exceeds 500 years. The design rainfall intensity, r , corresponding to a particular storm duration, return period and geographical location is found by using Figures NB.6 and NB.7 of BS EN 12056-3 and the corresponding procedure given in Clause NB.2.2.
- (g) **Alternative 3.** If required, the Meteorological Office is able to provide rainfall data (intensity, duration, return period) for specified locations on payment of an appropriate fee.

4. EFFECTIVE CATCHMENT AREA

4.1 Background information

4.1.1 Effect of wind

Wind blowing against a sloping roof will cause it to intercept more rain than would be collected by a flat roof of the same plan area. Design practice varies between European countries and this is allowed for in Section 4.3 of BS EN 12056-3. In some countries, no allowance for wind effects is made so flow rates are calculated using only the plan area of the roof (see Section 4.3.1). Some other countries assume for design purposes that the rain falls at right angles to the pitch of the roof (see second option in Table 3 of BS EN 12056-3). [It may be noted that the corresponding formula given in Table 3 is not actually consistent with the stated assumption]. The first option in Table 3 is the one adopted by the UK, and assumes that under design conditions the wind causes the raindrops to fall at an angle of 26° to the vertical. It is also assumed that the wind can blow from any direction so it is necessary to identify the most critical direction for the section of roof draining to a particular length of gutter or flat roof outlet.

The angle of descent of rain is determined by the ratio between the horizontal wind speed and the vertical speed of the raindrops falling through the air; the latter in turn depends on the raindrop size which tends to become larger as the storm intensity increases. The problem is made more complex by the fact that heavier storms (e.g. thunderstorms) may be associated with lower wind speeds than less intense storms. Very little experimental information is available about typical angles of descent for rain, but calculations based on representative wind speeds and raindrop sizes suggest that a reasonable estimate of the angle is 2 units vertical to 1 unit horizontal, corresponding to an angle of about 26.6° from the vertical. This is the basis of the recommendation given as the first option in Table 3 of BS EN 12056-3.

4.1.2 Calculation of effective areas

The assumption of a descent angle of 2 units vertical : 1 unit horizontal makes the calculations of run-off from sloping and vertical surfaces straightforward because, in essence, the additional catchment is equal to one half of the exposed area in elevation, i.e:

$$\text{Effective catchment area } (A) = \text{Plan area } (A_H) + \frac{1}{2} \text{ Exposed area in elevation } (A_V) \quad (4.1)$$

As an example, a pitched roof with a slope of 6° will have an effective catchment area that is 5% greater than a horizontal roof with the same plan area. If the roof pitch is 26°, the increase in effective catchment area will be 24%.

For the case of roofs that are effectively flat, the effective area catchment area is equal to the plan area of roof draining to a particular outlet or length of gutter (see Figure NC.1a in BS EN 12056-3, p. 65).

When calculating effective catchment areas for sloping roofs, it is only necessary to have plans and elevations of the building; whether a surface is sloping or vertical does not matter because it is only the exposed area in elevation that is assumed to be relevant (see Equation (4.1)). The methods of calculating the exposed area for different types of gutter (see Section 6.1.1 of the manual for their definitions) are explained in National Annex NC of BS EN 12056-3 and are as follows:

- **Eaves gutters** – the exposed area is the area in elevation between the skyline of the building and the lower edge of the roof (see Figure NC.1b in BS EN 12056-3, p. 65).
- **Parapet or boundary-wall gutters** – the exposed area is measured between the skyline and the top of the parapet or boundary wall.

- **Valley gutters** – the exposed area is the difference in elevation area between the skylines on either side of the gutter (see Figure NC.1c in BS EN 12056-3, p. 65). If the two roofs are of equal height, the net exposed area is zero because the increase in run-off from the exposed roof is assumed to be matched by the decrease from the sheltered roof.

When determining the flow load in a gutter, it is assumed for design purposes that the wind is blowing in the direction that maximizes the run-off to that particular length of gutter.

4.1.3 Vertical surfaces

Where vertical surfaces drain on to a roof, the run-off that they contribute should normally be assessed using the same assumption about the angle of descent of the rain as for sloping roofs. Thus, Equation (4.1) can be used to calculate the effective catchment area for the roof.

In the case of tall multi-storey buildings, some of the rain collected by the vertical surfaces will tend to be blown off and carried away by the wind. The amount of run-off reaching ground level or lower roofs is therefore likely to be less than determined from Equation (4.1). For this reason, Section NC.4 in National Annex NC recommends that the effective catchment area should be taken as 50% of the exposed vertical area up to a maximum height of 10 m above the level of gutter or roof being considered. This should provide a reasonable estimate in most cases, but extra consideration should be given in situations where wind may be funnelled between tall buildings or the shape of the building or structure is unusual.

4.1.4 Complex roof layouts

If a gutter receives run-off from more than side, it is necessary to calculate the elevation areas of the contributing surfaces looking in four directions:

- $A_{V,0}$ - viewed from one side of the gutter (defined as direction 0°)
- $A_{V,90}$ - viewed from one end of the gutter (in direction 90°)
- $A_{V,180}$ - viewed from the other side of the gutter (in direction 180°)
- $A_{V,270}$ - viewed from the other end of the gutter (in direction 270°)

The wind is assumed to come from the direction that will maximize the rate of run-off into the gutter.

If one surface is exposed to the wind, the surface facing in the opposite direction will be sheltered. Using the formula given in Figure NC.2 of BS EN 12056-3, it can be shown that the effective catchment area, A_e , of the roof is given by:

$$A_e = A_h + \frac{1}{2} \sqrt{[(A_{V,0} - A_{V,180})^2 + (A_{V,90} - A_{V,270})^2]} \quad (4.2)$$

4.2 Calculation steps

- (a) Information on the layout of the roof in plan and elevation is necessary when calculating values of the effective catchment area, A_e .
- (b) Find the total plan area of the roof, A_H (in m²), that drains to the length of gutter that is being considered (or to an outlet in a flat roof).
- (c) For each part of the roof, calculate the area in elevation, A_V (in m²), measured between the skyline of the building and the top of the gutter (or the surface of a flat roof).
- (d) For an eaves gutter, the effective catchment area (in m²) is given by:

$$A_e = A_H + \frac{1}{2} A_V \quad (4.3)$$

- (e) For valley gutters or more complex roof layouts, it is necessary to calculate the elevation areas $A_{V,0}$, $A_{V,90}$, $A_{V,180}$ and $A_{V,270}$ (looking in directions 0° , 90° , 180° and 270°) as described in Section 4.1.4 above; some of these areas may be zero. The effective catchment area, A (in m^2), is obtained using Equation (4.2).

5. DESIGN FLOW LOADS

5.1 Background information

5.1.1 Basis of calculations

It is assumed throughout BS EN 12056-3 (though not explicitly stated) that flow conditions at all points in a roof drainage system (roof, gutter, outlet and rainwater pipe) have reached a steady state. Therefore, each component of the system should be designed to cater for the peak flow rate obtained by multiplying the design rainfall intensity and the total effective catchment area draining to that point. The design flow load, Q (in l/s), is determined from Section 4.1 of BS EN 12056-3 (p. 8) as:

$$Q = r A C \quad (5.1)$$

where the effective catchment area, A , is in m^2 and the design rainfall intensity, r , is in l/s per m^2 . The factor C is the run-off coefficient of the roof or vertical surface. For BS EN 12056-3, the UK has adopted a value of $C = 1$ for design, and this recommendation is supported by flow monitoring carried out by Escarameia [Ref. 11]. In the case of buildings with garden roofs, losses due to infiltration and evaporation are likely to reduce the run-off coefficient below a value of $C = 1$.

Under some conditions, peak flow rates may be reduced by storage effects in a gutter or on a flat roof. However, as explained in Section 3.1.1 above, the design event may be part of a longer storm so it is not possible to predict how much or little of the available storage might have been used up before the storm peak occurred. For this reason, it is recommended (and assumed in BS EN 12056-3) that each component of a roof drainage system should be designed for the peak design flow rate at that point.

5.1.2 Division of flow load between outlets

The positions at which outlets are located along a run of gutter determine the direction in which the water flows in each individual gutter length. Throughout this manual a **gutter length**, L , is defined as the distance between a downstream outlet (or box-receiver) and the upstream point of zero flow (which may be a stop end or the point at which flow divides between two outlets). L is defined by the hydraulics of the flow and is distinct from the manufactured length of a gutter or the length of a continuous gutter run, for example along one face of a building.

The effect of outlet location on gutter length is illustrated by Figure ND.1 of National annex ND in BS EN 12056-3 (p. 70). In the case of Figure ND.1b, the two outlets are placed at the quarter points along the gutter run and this divides the run into four equal gutter lengths. Each length needs to be able to cater for a flow rate of $Q = Q_T/4$, where Q_T is the total flow load entering the gutter run. In the case of Figure ND.1c, the two outlets are placed at either end of the gutter run. This divides the run into two equal gutter lengths, each of which needs to have a flow capacity of $Q = Q_T/2$. The influence of gutter location on the hydraulic design is most marked when a gutter run is drained by only a few outlets.

As explained above, the gutter height, L , is defined by the position of the point of zero flow. For a roof with an irregular profile in plan or elevation, the point of zero flow between two adjacent outlets in a level or nearly level gutter should be identified as follows:

- (a) Calculate the flow load entering the gutter between the two outlets.
- (b) The point of zero flow will be located so that the flow load divides equally between the two outlets.
- (c) The position of zero flow is therefore located by finding the position along the gutter run where the effective catchment area of that run is divided in half (see Figure ND.1a).

This procedure is based on a slight simplification of hydraulic theory, but will be perfectly adequate except in unusual situations where adjacent outlets are very dissimilar or the spacing of the outlets is very irregular.

5.2 Calculation steps

- (a) Determine the design rainfall intensity, r (in l/s per m^2), for the rainwater system from Chapter 3 above. Similarly the effective catchment area, A_E (in m^2), draining to the gutter or flat roof outlet being considered should be found from Chapter 4 above.
- (b) The total design flow load entering the gutter or flat roof outlet is calculated from Equation (5.1) with a value of run-off coefficient $C = 1$ for impermeable roof surfaces. (For roof gardens, a value of $C < 1$ may be appropriate).
- (c) Decide (or assume) the number and location of outlets along the gutter. Divide (for purposes of calculation) the overall gutter run into the individual gutter lengths that drain to each outlet. A gutter length, L (in mm), is: either, the distance from an outlet (or box-receiver) to an adjacent stop end; or the distance from an outlet to an upstream point of zero flow (i.e., a point between two adjacent outlets where the flow load in the gutter is divided into two equal parts); see Section 5.1.2 above for more details.
- (d) Determine from the geometry of the roof, the design flow load, Q (in l/s), for each individual gutter length along the gutter run.
- (e) The calculation procedures given in the following Chapters 6 to 12 are used to check that each component of the rainwater system (gutter, outlet, rainwater pipe, internal drain) has sufficient flow capacity to cater for its particular design flow load.

6. GUTTERS WITH FREE DISCHARGE

6.1 Background information

6.1.1 Definitions

- **Eaves gutter** - a gutter fixed externally to a building and located so that it collects run-off from the eaves of a roof and is able to overflow along its length away from the face of the building.
- **Valley gutter** - an internal gutter located along the valley formed by two roofs or catchment areas.
- **Parapet gutter** - a gutter around the perimeter of a building either with a higher outer edge or located behind a parapet or fascia that prevents it from overflowing along its length clear of the building.
- **Boundary-wall gutter** - similar geometrically to a parapet gutter but typically located across the width of a roof either side of a boundary wall between two adjacent properties (e.g. on terraced buildings).

All four types of gutter are hydraulically similar but, in design terms, eaves gutters are different because they can overflow safely clear of a building whereas internal damage may be caused if the three other types of gutter overflow.

6.1.2 Hydraulics of gutter flows

The key feature of flow in a gutter is that the run-off enters along the length of the gutter causing the rate of flow to increase steadily from the zero-flow point to the outlet. The water has to be accelerated as it travels towards the outlet and this requires the flow depth (and hydrostatic pressure force) to be higher at the upstream end of the gutter length than at the downstream end (see Figure ND.1 in National Annex ND of BS EN 12056-3, p. 70). The difference in water level between the two ends is what drives the flow and enables gutters with level inverts to operate satisfactorily. The hydraulic resistance of the gutter also contributes towards the difference in flow depth between the upstream and downstream ends, but in level or nominally level gutters this effect is very much less than the effect caused by the acceleration of the water along the gutter. Two important facts about nominally level gutters stem from this:

- the discharge capacity of a gutter is determined by its cross-sectional geometry and (in many cases) is effectively independent of the gutter length;
- a gutter will tend to overflow first at the zero-flow point, where the water is deepest, and not at the outlet.

6.1.3 Free discharge from gutter

When designing a gutter it is important to determine whether the individual lengths of gutter are able to discharge freely into the outlets. If the outlets are not large enough, the water will be held back in the gutters and their flow capacities will be reduced.

Consider steady flow into a level gutter with a small outlet that restricts its discharge. The water surface along the gutter will be fairly flat but still higher at the upstream end than at the outlet. If the size of the outlet is increased (while keeping the rate of inflow constant), the water levels along the gutter will decrease but with a somewhat greater reduction near the outlet than at the upstream end. However, beyond a certain point, changes in the size of the outlet will cease to produce any further reduction in the water levels in the gutter; the flow conditions will be equivalent to those upstream of a waterfall. The gutter is then said to be discharging freely and will be able to achieve its maximum possible flow capacity. In this condition, the water surface profile will be approximately as shown in Figure ND.1 of BS EN 12056-3 (p. 70). The water depth in the gutter just upstream of the outlet is termed the critical depth, Y_C , and is

determined only by the flow rate, Q_C , at that point and the cross-sectional geometry of the gutter. The relationship between these factors is given by the equation:

$$Q_C = 9.90 \times 10^{-5} \left(\frac{A_C^3}{B_C} \right)^{0.5} \quad (6.1)$$

where B_C (in mm) is the surface width of flow and A_C (in mm²) is the cross-sectional area of flow in the gutter corresponding to the critical depth, Y_C . If a gutter discharges freely, it is possible to find Y_C from Equation (6.1) and then determine, from established hydraulic principles, the depth of water, Y_U , at the zero-flow point at the upstream end of the drainage length. The depth Y_U is the maximum depth of water that will occur along the gutter under those flow conditions and therefore determines whether or not the gutter will be able to discharge the flow rate Q_C without overflowing.

If an outlet requires a certain depth of water, h , at the downstream end of a gutter in order to discharge the flow into a rainwater pipe, the condition for the gutter to be able to discharge freely is:

$$h \leq Y_C \quad (6.2)$$

where Y_C is the corresponding value of critical depth in the gutter. The design methods for gutters given in the normative sections (i.e. main text) of BS EN 12056-3 are all based on the assumption that the outlets will be made large enough to enable the gutters to discharge freely and attain their maximum capacity. These methods are explained in the following Sections 6.1.5 and 6.1.6.

If an outlet is smaller than a certain size, the head, h , that it requires will exceed the corresponding value of Y_C in the gutter and the flow will be restricted. In the UK, the types of gutter and outlet systems used for non-eaves gutters generally operate with restricted flow conditions at the outlets. For this reason, National Annex ND in BS EN 12056-3 provides a supplementary design method that can be used to determine the flow capacity of gutters with restricted discharge. The method is consistent with the design procedures for freely-discharging gutters in the normative sections of BS EN 12056-3 and can allow designers to develop more economical solutions to roof drainage problems. However, it is recommended in Clause ND.3.1 that eaves gutters should not be designed for restricted discharge because the lack of freeboard makes them sensitive to any design errors or minor blockages. The design procedure for non-eaves gutters taking account of restricted flow conditions at the outlets is described in Chapter 8 of this manual.

6.1.4 Differences between BS EN 12056-3 and BS 6367

The design equations given in BS EN 12056-3 for the capacity of eaves gutters (Section 5.1), and for valley, parapet and boundary-wall gutters (Section 5.2), are derived from theoretical solutions for level gutters just flowing full and discharging freely at the downstream end; full details of the solutions are given in HR Wallingford Report IT 205 [Ref. 12] and May [Ref. 13]. The theoretical solutions neglect the effect of hydraulic resistance in the gutter which, as explained in Section 6.1.2 above, is much less than the effect produced by the acceleration of the water towards the outlet. However, since real flow conditions in gutters do differ from the simplified assumptions in the theory, the theoretically predicted flow capacities are reduced by factors chosen so as to provide an appropriate margin of safety compared with available experimental data [see Refs. 8 and 9].

Although the calculation procedures for gutters in BS EN 12056-3 appear quite different from those in the superseded BS 6367, they share a common theoretical basis and method of derivation. The results for level gutters given by the two documents are very similar for level gutters that are hydraulically **short** and only differ because of slightly different choices or definitions of safety factor. Capacities of hydraulically **long** gutters may be greater or smaller than equivalent capacities given by BS EN 12056-3 depending on the particular conditions, but in many cases the differences are not very substantial.

In BS EN 12056-3, the safety factors are introduced in two stages. The first factor (equal to 0.81 for eaves gutters or 0.9 for non-eaves gutters) is applied to the theoretically predicted capacity to determine the **nominal capacity**, Q_N , of the gutter and is not apparent to the user of the Standard. This value of capacity is what might be expected to be obtained under ideal conditions, and allows for real-flow effects not taken into account by the theoretical solution. A second factor of 0.9 converts from the nominal capacity, Q_N , to the actual **design capacity**, Q_L , and provides a margin of safety to allow for effects such as variations in level, increased roughness due to debris, etc. Note that this safety factor is not equivalent or an alternative to the freeboard that is provided in non-eaves gutters, the purpose of which is to prevent any overtopping due to waves and splashing. In the case of eaves gutters, it is assumed that slight overtopping due to these causes will be acceptable and not cause damage or inconvenience.

One of the reasons for the definition of the nominal capacity in BS EN 12056-3 was to allow gutter manufacturers to substitute values of flow capacity obtained directly from tests. It is likely that such tests will be carried out very carefully with an accurately installed gutter that may not be completely typical of normal construction practice. The flow capacity of a gutter obtained from test is therefore considered to be equivalent to the nominal capacity, Q_N . In this way, a safety factor of 10% is added when converting from the test value to the design value, Q_L , that the designer should use when sizing the rainwater system. This enables predicted capacities and capacities derived from tests to be considered on the same basis. If a manufacturer wishes to provide users with flow data from tests rather than values calculated from the equations in BS EN 12056-3, the tests need to be carried out according to the procedures given in Normative Annex A of BS EN 12056-3 (pp. 31-32).

A significant difference between the two Standards is that BS EN 12056-3 provides information on the flow capacity of sloping gutters as well as level gutters. This aspect is considered in Section 6.1.5.

6.1.5 Effect of gutter slope

Even though gutters are usually considered to be level or nominally level, a small fall along the invert is often provided to minimise possible ponding problems (due to construction tolerances, building movement or settlement). If the fall is equal to or less than 3 mm per m (i.e. 1/333), BS EN 12056-3 recommends that the flow capacity should be assumed to be equal to that of the gutter when level.

In some European countries, it is normal practice to install gutters at a more significant gradient to obtain an increase in flow capacity. BS EN 12056-3 therefore provides information on the relative increase in flow capacity between equivalent level and sloping gutters. The maximum recommended fall is 10 mm per m (i.e. 1/100) at which the flow capacity can be up to 55% greater than the equivalent level gutter. Gutter slopes greater than about 1/100 are normally undesirable because the resulting high flow velocities and turbulence increase the risk of local overtopping of the gutter. Also, the collection efficiency of the outlets may be significantly reduced due to the high velocity of the approaching flow.

Although the use of sloping gutters can increase flow capacity and lead to potentially cheaper rainwater systems, it is also necessary to take into consideration the following practical points:

- A sloping eaves gutter can give an unsatisfactory external appearance to a building.
- At its lower end, a long sloping eaves gutter may be located too far below the edge of the roof to collect run-off effectively.
- Falls can be difficult to provide if a gutter is supported directly by a horizontal beam.
- Standard outlets may be unable to deal with the higher flow rates achievable with sloping gutters.
- Structural deflections or discrepancies in levels during installation may reduce the slope of the gutter and the expected increase in flow capacity.

In addition the benefits of sloping gutters are only obtained if each drainage length of gutter has a downward slope towards the outlet that drains it. If multiple outlets are installed along a gutter with a continuous fall in one direction, only those drainage lengths with a downward slope will have an increased flow capacity. In the case of the drainage lengths with an adverse slope, their capacities will be correspondingly reduced with the result that there will be no net gain in the overall flow capacity of the system. It is therefore recommended in Clause 5.2.6 of BS EN 12056-3 that sloping gutters having multiple outlets and a continuous fall should be designed as if the gutters were level.

6.1.6 Design method for eaves gutters

It is recommended in Section 5.1 of BS EN 12056-3 that eaves gutters should be provided with outlets or box-receivers that are large enough to allow each gutter length to discharge freely. Separate design equations are given for two categories of gutter profile:

- Eaves gutters of semi-circular or similar shape – e.g. deeper profiles with rounded inverts, ogee profiles, etc.
- Eaves gutters of rectangular, trapezoidal or similar shape.

Note that in the case of eaves gutters, the design depth of flow, W , is equal to the overall depth, Z (in mm), of the gutter, which is measured from the invert level to the level at which overflowing first occurs.

A gutter is assumed to be **hydraulically short** if the drainage length, L (see Section 5.1.6) is not more than 50 times the maximum design depth of flow, W (in mm), in the gutter. In this case, the effect of flow resistance on the capacity is relatively small (see Section 6.1.2) and is allowed for implicitly within the design equations (by the first safety factor mentioned in Section 6.1.4). If $L > 50 W$, the gutter is **hydraulically long** and the resistance causes an increase in water depth towards the upstream end of the gutter, which has the effect of reducing its maximum flow capacity.

- (a) **Eaves gutters of semi-circular or similar shape.** The nominal flow capacity, Q_N (in l/s) of a level, hydraulically short gutter of this type is determined from the following equation given in Section 5.1.2 of BS EN 12056-3:

$$Q_N = 2.78 \times 10^{-5} A_E^{1.25} \quad (6.3)$$

where A_E (in mm²) is the cross-sectional area of water in the gutter when it is filled to its overspill level.

- (b) **Eaves gutters of rectangular, trapezoidal or similar shape.** The nominal flow capacity, Q_N (in l/s) of a level, hydraulically short gutter having a flat sole is determined from the following equation given in Clause 5.1.4 of BS EN 12056-3:

$$Q_N = 3.48 \times 10^{-5} F_D F_S A_E^{1.25} \quad (6.4)$$

where A_E is as defined above.

The factor F_D allows for the effect of the relative depth of the gutter W/T , where W (in mm) is equal to the overall depth of the gutter and T (in mm) is the top width of the gutter. For a square gutter, $F_D = 1$. For other shapes in this category, the value of F_D can be read from Figure 5 in BS EN 12056-3 or calculated from the corresponding equation:

$$F_D = \left(\frac{W}{T}\right)^{0.25} \quad (6.5)$$

The factor F_S depends on the shape of the gutter as defined by the ratio S/T , where S (in mm) is the width of the flat sole of the gutter and T (in mm) is the top width of the gutter. For a square or rectangular gutter, $F_S = 1$. For the limiting case of a triangular gutter $S/T = 0$ and $F_S = 0.893$ (although this will normally not be a practical option). For gutters of trapezoidal profile, the value of F_S can be read from Figure 6 in BS EN 12056-3 or calculated from the following best-fit equation:

$$F_S = 0.8943 + 0.2013\left(\frac{S}{T}\right) - 0.0965\left(\frac{S}{T}\right)^2 \quad (6.6)$$

It should be noted that this equation is not the fundamental equation from which the curve in Figure 6 was derived but a best-fit approximation to it.

Having determined the value of the nominal flow capacity, Q_N , from either (a) or (b) above, the actual flow capacity, Q_C (in l/s), of the particular length of eaves gutter being considered is calculated from:

$$Q_C = 0.9 F_L Q_N \quad (6.7)$$

where the coefficient of 0.9 converts from the nominal capacity to the design capacity (see Section 6.1.4), and the factor F_L allows for the effects of gutter length and/or slope if the gutter is hydraulically long (i.e. if the gutter length, L , is more than 50 times the gutter depth, W). The value of F_L depends on the relative length of the gutter compared with its depth (i.e. upon the ratio L/W). If $L/W \leq 50$, then $F_L = 1$. For length ratios of $L/W > 50$, the values of F_L can be determined from Table 6 in BS EN 12056-3, with interpolation being used if appropriate. Alternatively, F_L can be calculated from the following equations:

Nominally level gutters (longitudinal gradient, i , between 0 mm/m and 3 mm/m)

$$F_L = 1.0 - \frac{0.2}{150} \left[\frac{L}{W} - 50 \right] \quad ; \text{ for } 50 < L/W \leq 200 \quad (6.8)$$

or

$$F_L = 0.8 - \frac{0.2}{300} \left[\frac{L}{W} - 200 \right] \quad ; \text{ for } 200 < L/W \leq 500 \quad (6.9)$$

Sloping gutters (longitudinal gradient, i , between 4 mm/m and 10 mm/m)

$$F_L = 1.0 + \left[\frac{0.10 + 0.075(i - 4)}{150} \right] \left[\frac{L}{W} - 50 \right] \quad ; \text{ for } 50 < L/W \leq 200 \quad (6.10)$$

or

$$F_L = 1.10 + 0.075(i - 4) \quad ; \text{ for } L/W > 200 \quad (6.11)$$

where the value of the longitudinal gradient of the gutter, i , is in units of mm per m.

As mentioned above, all the capacity formulae for eaves gutters given in BS EN 12056-3 assume that the outlets are large enough to allow free discharge. Although Section ND.3 in National Annex ND covers the case of restricted discharge, the calculation procedure should not be applied to eaves gutters.

Angles in eaves gutters cause additional energy losses and can produce significant reductions in flow capacity if they are located near to outlets. In the superseded BS 6367 the effects of angles were allowed for by means of discharge factors that were obtained from experiments at the Building Research Establishment carried out by Crabb & Turner [Ref. 14]. These factors took account of bend angle and position along the gutter, but proved difficult to interpret or apply consistently to all cases. As a result, in BS EN 12056-3, it was decided to simplify the recommendations and use a single discharge factor of 0.85, which is applied to any gutter length containing one or more angles greater than 10° irrespective of the relative position of each angle. Therefore, the design flow capacity, Q_A (in l/s), of a gutter with an angle is given by:

$$Q_A = 0.85 Q_C \quad (6.12)$$

where Q_C is the capacity of an equivalent length of straight gutter as determined from Equation (6.7). It should be noted that an angle only reduces the flow capacity of the gutter length in which it is installed (i.e. the section of gutter between a stop end or zero-flow point and the adjacent outlet, see Section 5.1.2).

6.1.7 Design method for non-eaves gutters

Valley, parapet and boundary wall gutters are typically of rectangular or trapezoidal cross-sectional shape, and in the UK are usually formed from sheet metal to suit the requirements of individual buildings.

Section 5.2 of BS EN 12056-3 (pp 14-15) therefore provides a general procedure for designing any size of non-eaves gutter having a rectangular, trapezoidal or triangular profile. The design method is based on the same hydraulic principles and types of calculation procedure as the method for non-circular eaves gutters described in Section 6.1.6. Attention will therefore be concentrated on the particular differences between the two cases.

With non-eaves gutters, it is important to eliminate the risk of any overtopping occurring in storms that are less severe than the design condition since in many situations it may not be possible to construct or maintain a fully watertight joint between the gutter and the roof construction. The design equations for gutter capacity do not take account of periodic fluctuations in water level due to splashing or waves generated by wind blowing along the gutter. For this reason, Table 5 in BS EN 12056-3 recommends that non-eaves gutters should be designed to have a minimum freeboard allowance, Y (in mm), as follows:

<u>Overall depth of gutter, Z</u>	<u>Minimum freeboard, Y</u>
Less than 85 mm	25 mm
85 mm – 250 mm	0.3 Z mm
Greater than 250 mm	75 mm

The overall depth of the gutter, Z (in mm), is measured from the invert to the level at which overflowing would first occur. The maximum design depth of flow, W (in mm), in the gutter is therefore given by:

$$W = Z - Y \quad (6.13)$$

The nominal flow capacity, Q_N (in l/s) of a level, hydraulically short, non-eaves gutter is determined from the following equation given in Clause 5.2.3 of BS EN 12056-3:

$$Q_N = 3.89 \times 10^{-5} F_D F_S A_W^{1.25} \quad (6.14)$$

where A_W (in mm^2) is the cross-sectional area of flow in the gutter when the water depth is equal to the maximum design depth, W , given by Equation (6.13). The depth factor, F_D , depends on the value of the ratio W/T , where T (in mm) is the width of the water surface in the gutter corresponding to the flow depth, W . Values of F_D can be determined from Figure 5 in BS EN 12056-3 or from Equation (6.5) in this manual. The shape factor, F_S , depends on the ratio S/T , where S (in mm) is the width of the flat sole of the gutter. For a square or rectangular gutter, $F_S = 1$. For the limiting case of a triangular gutter $S/T = 0$ and $F_S = 0.893$ (although this will normally not be a practical option). For gutters of trapezoidal profile, the value of F_S can be read from Figure 6 in BS EN 12056-3 or calculated from the best-fit Equation (6.6) in this manual.

Having determined the value of the nominal flow capacity, Q_N , the actual flow capacity, Q_C (in l/s), of the particular length of non-eaves gutter being considered is calculated from:

$$Q_C = 0.9 F_L Q_N \quad (6.15)$$

where the coefficient of 0.9 converts from the nominal capacity to the design capacity (see Section 6.1.4), and the factor F_L allows for the effects of gutter length and/or slope if the gutter is hydraulically long (i.e. if the gutter length, L , is more than 50 times the gutter depth, W). Installing a length of non-eaves gutter with a fall to the outlet that drains it will result in a higher flow capacity than an equivalent level gutter. However, consideration should be given to some of the practical issues described in Section 6.1.5. The value of F_L in Equation (6.15) depends on the relative length of the gutter compared with its depth (i.e. upon the ratio L/W). If $L/W \leq 50$, then $F_L = 1$. For length ratios of $L/W > 50$, the values of F_L can be determined from Table 6 in BS EN 12056-3, with interpolation being used if appropriate. Alternatively, F_L can be calculated from Equations (6.8) to (6.11) in this manual.

BS EN 12056-3 recommends that angles should not be used part way along individual lengths of non-eaves gutter. This is because turning of the flow at an angle can cause water to pile up against the outside of the bend, producing a risk of local overtopping. If it is necessary to change direction along a section of non-eaves gutter, it is recommended that a box-receiver should be located at that point. An alternative, but less favoured, option would be to use an outlet in the sole of the gutter in place of a box-receiver; in this case, it is recommended that the selected outlet should be large enough to allow free discharge from the gutter. If one of these options is adopted, the gutter lengths will be straight and there is no need to apply a discharge factor to the value of gutter capacity calculated using the above equations.

If part of the flow area of a non-eaves gutter is blocked by an obstruction such as a walkway, the resulting loss of flow capacity can be allowed for as follows. Calculate the maximum cross-sectional area, A_B (in mm^2), of the obstruction at any point along the gutter length. If the unobstructed flow area in the gutter is A_W (in mm^2) at the design depth of flow W , then the effective value of flow area that should be used in Equation (6.14) is:

$$A'_W = A_W - 2 A_B \quad (6.16)$$

The design procedure described in this Section is contained in the normative part of BS EN 12056-3 and assumes that the outlets are large enough to allow free discharge. The method of checking whether this is the case is explained in Chapter 7. National Annex ND of BS EN 12056-3 allows rainwater systems to be designed with outlets in the sole of the gutter that are smaller than those needed to ensure free discharge. This can be advantageous in cases where the gutters are effectively oversized due to space requirements for access and maintenance. Giving up some of the excess capacity of the gutter can therefore lead to savings in the sizes of the outlets and rainwater pipes. However, the disadvantage is that minor blockage of an outlet by debris may have a more direct effect on water levels in the gutters than would be the case if the outlet were large enough to permit free discharge.

6.2 Calculation steps

6.2.1 Overall procedure

The overall procedure for designing a roof gutter is as follows:

- (a) For a given gutter length, L (as defined in Section 5.1.2 above), calculate the design flow load, Q , from the roof using the method given in Section 5.2 above.
- (b) Choose or assume the size and cross-sectional shape of the gutter.
- (c) Determine the maximum allowable depth of flow in the gutter for safe operation without overflowing.
- (d) Calculate the discharge capacity, Q_C , of the gutter, i.e. the flow rate at which the water depth in the gutter reaches the allowable limit found from (c).
- (e) If the discharge capacity, Q_C , is equal to or greater than the flow load, Q , the choice of gutter is satisfactory.
- (f) If the choice of gutter is not satisfactory either:
 - use more outlets so as to reduce the drainage length until the design flow load, Q , is less than or equal to the discharge capacity, Q_C , of the gutter; or
 - use a larger gutter and repeat steps (c) and (d) in order to check whether $Q_C > Q$.

6.2.2 Eaves gutters

The following procedure should be followed to calculate the discharge capacity, Q_C , of a length of eaves gutter. It is assumed that the outlet draining that length is large enough to allow the gutter to discharge freely.

- (a) No allowance for freeboard is normally necessary for eaves gutters which are installed so that they can overflow safely away from the buildings that they drain. If the latter is not the case, the calculation method given in Section 6.2.3 or 6.2.4 of this manual should be followed.
- (b) Determine the maximum water depth, W (in mm), in the gutter above which overtopping would occur.
- (c) Calculate the cross-sectional area, A_E (in mm^2), of the gutter corresponding to the water depth, W .
- (d) If the gutter shape is semi-circular or similar, determine the nominal flow capacity, Q_N (in l/s), of the gutter from Equation (6.3) of this manual. For other shapes of eaves gutter having a flat sole (e.g. rectangular or trapezoidal), determine Q_N from Equation (6.4) with values of the factors F_D and F_S obtained either from Figures 5 and 6 in BS EN 12056-3 or from Equations (6.5) and (6.6) in this manual.
- (e) The design flow capacity, Q_C (in l/s), of the gutter length being considered is calculated from Equation (6.7). If the drainage length, L (in mm), of the gutter does not exceed $50 \times$ the maximum water depth, W , the length factor F_L has a value of $F_L = 1$. If $L > 50 W$, the value of F_L depends on the drainage length and the longitudinal fall, i (in mm per m), towards the outlet; the value can be determined either from Table 6 in BS EN 12056-3 or from Equations (6.8) to (6.11) in this manual.

- (f) If the gutter length, L , contains one or more angles that turn the flow through an angle greater than 10° , the design flow capacity of that particular length will be reduced to a value, Q_A (in l/s), given by Equation (6.12).

6.2.3 Non-eaves gutters of rectangular or trapezoidal shape

The following procedure should be used to determine the discharge capacity of a length of non-eaves gutters (e.g. valley, parapet or boundary-wall types) having a rectangular or trapezoidal cross-sectional profile. It is assumed that the outlet draining that length is large enough to allow the gutter to discharge freely. If a smaller outlet is used the flow capacity of the gutter will be reduced; the method of determining its design capacity is described in Chapter 8. Since angles are not recommended in non-eaves gutters, an outlet should be installed at each change of flow direction.

- (a) Select the size and shape of the gutter.
- (b) Determine the overall depth, Z (in mm), of the gutter to the level at which overtopping would first occur.
- (c) Calculate the minimum required freeboard, Y (in mm), from Table 5 in BS EN 12056-3 or Section 6.1.7 of this manual.
- (d) Calculate the maximum design depth of flow, W (in mm), in the gutter from Equation (6.13) using the selected value of freeboard.
- (e) Determine the cross-sectional flow area, A_W (in mm^2), of the gutter corresponding to the water depth, W . If necessary, allow for any obstructions in the gutter by calculating the effective flow area, A'_W (in mm^2), from Equation (6.16).
- (f) Determine the nominal flow capacity, Q_N (in l/s), of the gutter from Equation (6.14) with values of the factors F_D and F_S obtained either from Figures 5 and 6 in BS EN 12056-3 or from Equations (6.5) and (6.6) in this manual.
- (g) The design flow capacity, Q_C (in l/s), of the gutter length being considered is calculated from Equation (6.15). If the drainage length, L (in mm), of the gutter does not exceed $50 \times$ the maximum water depth, W , the length factor F_L has a value of $F_L = 1$. If $L > 50 W$, the value of F_L depends on the drainage length and the longitudinal fall, i (in mm per m), towards the outlet; the value can be determined either from Table 6 in BS EN 12056-3 or from Equations (6.8) to (6.11) in this manual.

6.2.4 Non-eaves gutters of semi-circular or similar shape

BS EN 12056-3 does not cover cases in which a gutter of semi-circular or similar shape is used as a valley, parapet or boundary-wall gutter. Also, there are situations in which it might be wished to design an eaves gutter to a higher standard in order to reduce the frequency of any overtopping (e.g. over the entrance area to a building). In these cases, the design procedure given in 6.2.3 should be followed with an allowance being made for an appropriate amount of freeboard. The only change to the calculation procedure is that the nominal flow capacity, Q_N (in l/s), of the gutter should not be calculated from Equation (6.14) but from the following equation which provides a similar factor of safety:

$$Q_N = 3.09 \times 10^{-5} A_W^{1.25} \quad (6.17)$$

where A_W (in mm^2) is the cross-sectional flow area of the gutter corresponding to the maximum design water depth, W .

7. OUTLETS AND BOX-RECEIVERS

7.1 Background information

7.1.1 Flow conditions at outlets

In BS EN 12056-3 and this manual, an outlet is defined as an opening in the sole of a gutter or box-receiver (or in a flat roof) which discharges water directly into the head of a rainwater pipe. Outlets may be sharp-edged or alternatively include a vertical transition in which the flow area reduces from the top of the opening to the rainwater pipe.

At small rates of flow the lip of an outlet behaves like a weir. The depth of water around the lip is relatively small and, as it drops into the rainwater pipe, remains attached to the walls of the pipe, leaving a central air core; the pressure within the rainwater pipe therefore remains at, or very close to, atmospheric pressure. As the flow rate is increased, the depth of water around the lip of the outlet increases until the central air core inside the outlet disappears. At this point, the flow condition changes from weir-type flow to orifice-type flow. In the latter state, the flow rate is no longer proportional to the perimeter of the outlet lip but to the cross-sectional area that the outlet provides for the flow; also, the depth of water needed above the outlet begins to increase more rapidly as the discharge increases.

With orifice-type flow, beyond a certain discharge rate, the rainwater pipe may begin to run full over a portion of its upper length and act as a partial siphon. This increases the discharge capacity but may cause negative pressures in the pipe. Also, unless the outlets are specially designed, the siphonic action may be intermittent and result in undesirable gulping of air and significant fluctuations in the water level above the outlet. For this reason, the flow formulae for outlets given in BS EN 12056-3 are conservative and designed to avoid the development of siphonic action or negative pressures in the rainwater pipes.

Outlets and pipework that are specifically designed to operate siphonically can offer several advantages over equivalent conventional systems, including the capability for considerably higher flow capacities. However, siphonic systems require special expertise in design, manufacture and installation and need to meet the additional performance requirements described in Chapter 12 of this manual.

7.1.2 Formulae for outlet capacity

Table 7 of BS EN 12056-3 (p. 21) gives the following equations for the flow capacity of circular outlets installed in gutters with flat soles, box-receivers or flat roofs:

$$\text{Weir-type flow:} \quad Q_o = \frac{k_o D h^{1.5}}{7500} \quad ; \text{ for } h \leq D/2 \quad (7.1)$$

$$\text{Orifice-type flow:} \quad Q_o = \frac{k_o D^2 h^{0.5}}{15\,000} \quad ; \text{ for } h > D/2 \quad (7.2)$$

where Q_o (in l/s) is the total flow rate entering an outlet, h (in mm) is the head of water above the top of the outlet, and D (in mm) is the effective diameter of the outlet.

The value of the effective diameter, D , depends on the shape of the outlet, and Figure 9 of BS EN 12056-3 (p. 22) gives the following information for three types:

$$(a) \text{ straight taper :} \quad D = D_o \quad (7.3)$$

$$(b) \text{ round-edged :} \quad D = 0.9 D_o \quad (7.4)$$

$$(c) \text{ sharp-edged :} \quad D = D_o \quad (7.5)$$

where D_O is the top diameter of the outlet and k_O is an outlet coefficient having the following values:

Unobstructed outlets: $k_O = 1.0$

Outlets with strainers or gratings: $k_O = 0.5$

See Section 7.1.5 for further details on grated outlets.

Outlet types (a) and (b) provide higher flow capacities than the sharp-edged design, Type (c), for a given diameter, d_i , of rainwater pipe. With the round-edged type, the radius of the lip is $R = D_O/6$ so that the top diameter is $D_O = 1.5 d_i$. Because the transition is relatively sudden, the contraction slightly restricts the flow so that the effective diameter is only 90% of the top diameter (i.e. $D = 1.35 d_i$). With the tapered design, provided the contraction is not too great or too sharp, the effective diameter remains equal to the top diameter (i.e. $D = 1.5 d_i$); the limits for the transition are $D_O \leq 1.5 d_i$ with a vertical length $L_T \geq D_O$.

Note 1. The captions to Figure 9 in the present edition of BS EN 12056-3 are incorrect for the tapered and round-edged outlets. For the tapered outlet (a), the limit on top diameter should be $D_O \leq 1.5 d_i$. For the round-edged outlet (b), the limits should be $D_O \leq 1.5 d_i$ and $R \leq D_O/6$.

Under weir-flow conditions, it is important that the water can gain access to the full perimeter of the outlet, otherwise the flow capacity will be less than predicted by Equation (7.1). For this reason, Table 7 in BS EN 12056-3 recommends that there should be a gap between the top edge of the outlet and the side of the gutter equal to at least 5% of the top diameter, D_O , of the outlet.

Table 7 of BS EN 12056-3 (p. 21) gives the following capacity equations for non-circular outlets (i.e. rectangular or square) installed in gutters with flat soles, box-receivers or flat roofs:

$$\text{Weir-type flow:} \quad Q_O = \frac{k_O L_W h^{1.5}}{24\,000} \quad ; \text{ for } h \leq \frac{2A_O}{L_W} \quad (7.6)$$

$$\text{Orifice-type flow:} \quad Q_O = \frac{k_O A_O h^{0.5}}{12\,000} \quad ; \text{ for } h > \frac{2A_O}{L_W} \quad (7.7)$$

where k_O is the outlet coefficient defined above, L_W (in mm) is the wetted perimeter of the outlet lip over which flow enters the outlet, and A_O (in mm²) is the plan area of the outlet. These equations assume that the lip of the outlet is sharp-edged. The transition from weir-type flow to orifice type flow occurs when the head over the outlet exceeds $h = 2A_O/L_W$. [Equations (7.1) and (7.2) are almost equivalent to Equations (7.6) and (7.7), as can be seen by substituting the relationships $L_W = \pi D$ and $A_O = \pi D^2/4$ for the case of a circular outlet].

The results described in this Section were obtained from an extensive series of experiments commissioned by HR Wallingford and carried out by the British Hydromechanics Research Association; full results are given in HR Wallingford Report IT 205 [Ref. 12].

The three types of outlet shown in Figure 9 of BS EN 12056-3 (p. 22) are not intended to be restrictive. Other designs can equally be used but the relationships between head h and flow rate Q_O must be established by test.

7.1.3 Outlets in gutters with non-flat soles

As explained in Clause 5.3.1 of BS EN 12056-3, it is not possible to provide simple formulae for predicting the capacities of outlets connected to gutters that do not have flat soles. In the case of eaves gutters, it is important that the outlets are large enough to enable each length of gutter to discharge freely (see Section 6.1.3 of this manual). Connecting a rainwater pipe to a circular eaves gutter by means of a sharp-edged outlet will not normally ensure free discharge unless the rainwater pipe is considerably oversized. One alternative is to establish the suitability of an outlet by experiment using the test procedure described in Section A.3 of normative Annex A in BS EN 12056-3. The other alternative is to ensure that the geometry of the outlet meets the requirements shown in Figure 8 of BS EN 12056-3 (p. 20). This type of design provides a large and well-rounded transition from the gutter into the vertical rainwater pipe, the key requirement being that the top area of the transition should not be less than twice the cross-sectional area of the rainwater pipe.

7.1.4 Outlets in gutters with flat soles

If an outlet is connected directly to the sole of a gutter, it may prevent the gutter from discharging freely and achieving its maximum possible flow capacity. Designs with restricted discharge are permitted by BS EN 12056-3 for valley, parapet and boundary-wall gutters (see Chapter 8) but not in the case of eaves gutters (see Section 7.1.3).

The requirement to be satisfied for free discharge is that the head, h (in mm), at the outlet required to pass the design flow rate must not be greater than a certain limiting depth, h_L . If the head $h > h_L$, the outlet will cause backing-up of flow in the gutter length(s) draining to the outlet, with the result that the maximum design depth of flow at the upstream end of the gutter will be reached at a smaller flow rate than if the gutter were able to discharge freely. The limiting depth is given by:

$$h_L = F_h W \quad (7.8)$$

The outlet head factor, F_h , depends on the ratio S/T , where S (in mm) is the width of the flat sole of the gutter, and T (in mm) is the width of the water surface in the gutter at the maximum design depth of flow, W (in mm). The value of F_h can be found from Figure 10 in BS EN 12056-3 (p. 23) or from the following best-fit equation:

$$F_h = 0.6459 - 0.3084 \left(\frac{S}{T} \right) + 0.1415 \left(\frac{S}{T} \right)^2 \quad (7.9)$$

It should be noted that this equation is not the fundamental equation from which the curve in Figure 10 was derived but a best-fit approximation to it.

If $h > h_L$, the discharge from the gutter will be restricted and, provided it is not an eaves gutter or a non-eaves gutter with a longitudinal gradient exceeding 3 mm per m (see Section ND.3.1 of National Annex ND in BS EN 12056-3), its flow capacity can be determined using the procedure described in Chapter 8.

When checking whether an outlet will allow free discharge, it is important to remember that the head, h , is calculated for the total flow rate, Q_O entering the outlet (i.e. the sum of the flow rates in any individual gutter lengths that are drained by the outlet).

7.1.5 Grated outlets

BS EN 12056-3 does not place any particular restrictions on the use of grated outlets in gutters. However, previous advice in the superseded BS 6367 suggested that gratings should only be used for gutter outlets with nominal bores of 150 mm above. Gratings require regular cleaning because relatively small amounts of blockage can increase flow depths in gutters considerably. Outlets without gratings are less

troublesome; smaller debris such as leaves can be washed through them, although maintenance is still necessary to prevent blockage by larger objects such as balls or dead birds.

7.1.6 Side outlets

It is important to note that all the equations for the flow capacity of outlets given in BS EN 12056-3 assume that the longitudinal axes of the outlets are vertical. Installing an outlet in the side of a gutter with its longitudinal axis horizontal or at an angle to the vertical will severely reduce its capacity compared with the values given by these equations. If structural or other considerations make it impossible to locate an outlet in the sole of a gutter, a box-receiver should be formed in the side of the gutter (see following Section 7.1.6) and an outlet connected to the bottom of the box.

7.1.7 Box-receivers

Although not a requirement in BS EN 12056-3, Section NE.2.3 in National Annex NE mentions that in non-eaves gutters it is generally preferable to use box-receivers rather than sole outlets. This is because box-receivers:

- ensure that gutters are able to discharge freely and achieve their maximum flow capacity;
- separate the gutters from the outlets hydraulically and provide a greater margin of safety against the effects of blockages;
- can simplify the hydraulic design because there is no need to use the more complicated calculation procedure in Chapter 8 of this manual for restricted flow in gutters.

A box-receiver acts as a weir in the sole of a gutter and it is necessary to ensure that its wetted length is sufficient to allow the gutter to discharge freely. This can be done using Equation (7.6) above for the flow capacity of a rectangular outlet.

7.2 Calculation steps

7.2.1 Outlets in gutters with flat soles

The following procedure can be used to check whether an outlet in the flat sole of a gutter is large enough to allow the maximum flow capacity of the gutter to be achieved:

- (a) For a circular outlet with a top diameter, D_o (in mm), determine its effective diameter, D (in mm), using the information given in Figure 9 of BS EN 12056-3 (p. 22).
- (c) Determine from the appropriate Sections 6.2.2 to 6.2.4 of this manual the discharge capacity, Q_C (in l/s), of each gutter length drained by a particular outlet, assuming that the gutter is able to discharge freely.
- (d) Find from Equation (7.8) the value of limiting depth, h_L (in mm), needed to ensure free discharge. If there is more than one gutter length draining to the outlet, choose the smallest value of h_L .
- (d) Calculate the total flow rate, Q_T (in l/s), entering the outlet, i.e. the sum of the values of Q_C for the individual gutter lengths that it drains.
- (e) Calculate the flow rate, Q_O (in l/s), that can be accepted by the outlet with a head, h (in mm), equal to the limiting depth, h_L , from step (d). For a circular outlet, use either Equation (7.1) or (7.2) above, depending on whether h is less than or greater than $D/2$. For a rectangular or square outlet, similarly use either Equation (7.6) or (7.7).

- (f) If the flow capacity, Q_O , equals or exceeds the total flow rate, Q_T , the gutter length(s) will be able to discharge freely and achieve the maximum flow capacity.
- (g) If $Q_O < Q_T$, the outlet is not large enough. If it is required that the gutter should be able to discharge freely, the options are to either: use a larger outlet and repeat steps (e) and (f); or use a box-receiver (see Section 7.2.2 below).
- (h) If it is decided that a non-eaves gutter need not discharge freely, the reduced flow capacity of the gutter can be determined using the method given in Section 8.2 of this manual.

7.2.2 Box-receivers

The following procedure may be used to determine the overall size and depth of box-receiver needed to drain a particular section of gutter.

- (a) Calculate the total design flow rate, Q_T (in l/s), entering the box-receiver, assuming that each gutter length drained by the box-receiver is able to discharge freely. Also, determine the corresponding value of limiting depth, h_L (in mm), for each of these gutter lengths. [Note : the same procedure should be followed as for steps (c) and (d) in Section 7.2.1 above].
- (b) Select the gutter length with the smallest value of limiting depth, h_L ; calculate the required wetted length of weir, L_w (in mm), for the box-receiver from the following equation (which is obtained by re-arranging Equation (7.6) above):

$$L_w = \frac{24\,000\,Q_T}{h_L^{1.5}} \quad (7.10)$$

- (c) Choose a suitable geometry for the box-receiver that will provide this minimum value of wetted perimeter, L_w (see Figure 11 of BS EN 12056-3 (p. 24) and Section NE.2.4 of National Annex NE (p. 73) for recommended layouts). The box-receiver need not be positioned centrally within the gutter sole but can be located to one side; however, only the portion of the perimeter over which water flows from the gutter into the box-receiver counts towards the value of L_w . The minimum length of the box-receiver in the direction of flow should be $0.75W$ if it receives flow from one gutter length, or $1.5W$ if it receives flow from two opposite lengths (see Figure 11 in BS EN 12056-3), where W (in mm) is the maximum design depth of flow in the gutter.
- (d) The required depth of the box-receiver depends on the size of outlet used in the base of the box. For the selected outlet geometry, use Equations (7.1) to (7.7) as appropriate to find the head, h (in mm), required above the outlet to pass the flow rate Q_T ; these equations can be written in the form:

$$\text{Weir-type flow:} \quad h = \left(\frac{7500\,Q_T}{D} \right)^{0.67} \quad (7.11)$$

$$\text{Orifice-type flow:} \quad h = \left(\frac{15\,000\,Q_T}{D^2} \right)^2 \quad (7.12)$$

The design depth of water in the box-receiver is the larger of the two values of h .

- (e) Figure 11 of BS EN 12056-3 (p. 24) recommends a freeboard of 25mm, so the minimum depth of the box-receiver is $h + 25\text{mm}$.
- (f) If it is required to reduce the depth of the box-receiver, select a larger outlet and repeat steps (d) and (e).

8. GUTTERS WITH RESTRICTED DISCHARGE

8.1 Background information

If an outlet prevents a gutter from discharging freely, the capacity of the gutter is reduced and the two components need to be considered in combination. In cases where the gutter has a surplus flow capacity (due to its size being determined by the profile of the roof or by maintenance requirements), it can be advantageous to give up some of this capacity in order to be able to reduce the size and/or number of outlets and rainwater pipes. However, restricting the discharge from gutters does remove an inherent safety factor that is present if outlets or box-receivers are large enough to allow free discharge. This is because, with restricted discharge, any small blockage at the outlet is likely to result in a direct increase in water depths in the gutter. With free discharge, minor blockages will only have a significant effect if the head at the outlet becomes high enough to begin restricting the discharge from the gutter.

As stated in Section ND.3.1 of National Annex ND in BS EN 12056-3 (p.67), eaves gutters should not be designed for restricted discharge (see also Section 6.1.6 of this manual). Also, non-eaves gutters with falls exceeding 3 mm per m should be not designed for restricted discharge because the increased velocity of the flow approaching an outlet may produce increased turbulence and adversely affect the capacity of the outlet.

Although the procedure given in Section ND.3.3 of BS EN 12056-3 (pp. 68) for calculating the flow capacity of a gutter with restricted discharge appears very different from the method contained in the superseded BS 6367, the two approaches share a common theoretical basis and give generally similar results. The design procedure in BS EN 12056-3 uses as its starting point the capacity of the gutter if it were able to discharge freely at the outlet. The relative increase in head at the outlet under restricted flow conditions is then used to determine the amount of the reduction in the flow capacity of the gutter. It is important to note that the calculated capacity relates to the gutter and the outlet acting in combination; changing either of the components will alter the flow capacity of the system.

Since the calculation procedures for restricted discharge is set out in detail in Sections ND.3.2 and ND.3.3 of BS EN 12056-3, it is not repeated in this manual as the steps are self-explanatory. Figure ND.2 (p. 71) gives the relationship between the flow restriction factor, F_R , and the ratio Q_{1R}/Q_1 , where Q_{1R} is the restricted flow capacity of gutter length no. 1, and Q_1 is the capacity if the same gutter were able to discharge freely (both in l/s). If required, this relationship can be determined from the following best-fit equation:

$$\frac{Q_{1R}}{Q_1} = 1.000 + 0.500 \log_{10} F_R \quad ; \text{ for } F_R \geq 0.1 \quad (8.1)$$

$$\frac{Q_{1R}}{Q_1} = 1.62 F_R^{0.51} \quad ; \text{ for } F_R < 0.1 \quad (8.2)$$

It should be noted that these equations are not the fundamental equation from which the curve in Figure ND.2 was derived but a best-fit approximation to it.

8.2 Calculation steps

- (a) Determine from Section 7.2.1 of this manual or from Section ND.3.2 of BS EN 12056-3 (p. 68) whether the outlet is large enough to allow free discharge from the gutter length(s) draining to it. If the outlet is large enough, the capacity of the gutter will be as calculated in Sections 6.2.3 or 6.2.4 of this manual. If the outlet restricts the discharge, proceed to step (b).

- (b) Use the step-by-step procedure given in Section ND.3.3 of BS EN 12056-3 (p. 68) to determine the maximum flow capacity of the gutter/outlet combination. The value of the discharge ratio Q_{1R}/Q_1 can be determined from Figure ND.2 (p. 71 in the Standard) or from Equation (8.1) or (8.2) above.

9. FLAT ROOFS

9.1 Background information

9.1.1 Layout

Clause NE.2.10 of National Annex NE in BS EN 12056-3 (pp. 75-76) gives recommendations on the layout and hydraulic design of drainage systems for flat roofs. Such roofs are very seldom truly flat, and areas of roof are usually laid to falls so as to drain in one of the following ways:

- towards a collecting gutter formed within the roof construction;
- towards a chute that discharges through a parapet around the perimeter of the roof;
- towards an outlet at a low point in the centre of a panel.

9.1.2 Design flow conditions

Section NB.2.1 of National Annex NB in BS EN 12056-3 recommends that flat roofs in the UK should normally be designed for the Category 1 rainfall intensity corresponding to a 2-minute storm event with a return period of 1 year. As explained in Chapter 3 of this manual, the design rainfall intensity for a roof drainage system is partly determined by its time of concentration. For a truly flat roof, this time may be longer than 2 minutes, and for large areas it might be reasonable to consider storm durations of up to 5 minutes. Section NB.2.2 of BS EN 12056-3 (p. 58) provides a general method for estimating rainfall intensities for storm durations between 1 and 10 minutes.

As mentioned above, most “flat” roofs are not truly flat and have internal cross-falls. If the angle of the cross-falls exceeds about 5° , the rate of run-off will be comparable to that on pitched roofs. In such cases, it may sometimes be appropriate to design the rainwater system for the appropriate Category 2 rainfall intensity (particularly if it is necessary to limit the temporary depth of water at outlets).

From a hydraulic point of view, there is no particular value of maximum water depth that needs to be specified; the greater the allowable water depth, the greater will be the flow capacity of the roof outlets and the more economical will be the scheme. However, factors such as the watertightness of the roof construction (including the level of laps) and the allowable live loading on the roof will usually determine the maximum design water depth. Clause NE.2.10.3 of BS EN 12056-3 (p. 75) mentions that a maximum design water depth of 35mm at outlets has traditionally been acceptable for nominally flat roofs laid to falls. However, design values greater or less than 35mm may be appropriate depending on the particular circumstances of different schemes.

9.1.3 Outlets and sumps

Outlets in flat roofs are often fitted with gratings to prevent leaves, gravel or other debris being washed into the rainwater pipes. However, in cases such as smooth-surfaced roofs, less maintenance problems may occur if ungrated outlets are used (as in the case of gutters, see Section 7.1.5 of this manual). The flow capacities of grated and ungrated outlets should be determined from Equations (7.1) to (7.7) above. Alternatively, the capacities of both types of outlet may be determined by test using the procedure given in Normative Annex A of BS EN 12056-3.

The flow capacity of a roof outlet may be limited by the allowable depth of water on the roof. The flow capacity can be significantly increased if the outlet is located in a sump formed within the roof construction. The sides of the sump act as a weir and its wetted perimeter can be made much greater than that of the outlet; also, the depth of the sump allows the head over the outlet to be increased. The hydraulic design of a sump is similar to that of a box-receiver (see Section 7.2.2 above).

9.2 Calculation steps

9.2.1 Gutters and outlets

If an area of flat roof drains to a gutter that conveys it to one or more outlets, the system formed by the gutter and outlets should be designed using the methods already described in Chapters 4 to 8 of this manual. A Category 1 rainfall intensity corresponding to a duration of 2 minutes and a return period of 1 year may often be appropriate but reference should be made to Section 9.1.2 above.

9.2.2 Chutes

The following procedure may be used to determine the size of chute needed to drain water through a parapet from an area of flat roof.

- (a) Determine the appropriate value of design rainfall intensity, r (in l/s per m^2), for the roof.
- (b) Calculate the effective catchment, A (in m^2), of the flat roof drained by the chute, taking account of any sloping or vertical surfaces that contribute run-off (see Chapter 4 of this manual).
- (c) Calculate the design flow load, Q (in l/s), from Equation (5.1) above.
- (d) Decide the value of maximum design water depth, W (in mm), for the roof (see Section 9.1.2 above).
- (e) Decide the invert level, Y_i (in mm), of the chute above roof level; if possible, it is best to make $Y_i = 0$. The available head, h (in mm), acting on the chute is therefore $h = W - Y_i$.
- (f) The required length, L_W (in mm), of the opening in the parapet is obtained from Figure 12 in BS EN 12056-3 (p. 25) or by re-arranging Equation (7.6) in the form:

$$L_W = \frac{24\,000\,Q}{h^{1.5}} \quad (9.1)$$

- (g) The height of the opening should be at least $h + 25$ mm above the invert of the chute to ensure that it is able to discharge freely.
- (h) If the chute discharges into a hopper head, the overall depth of the hopper below the invert level of the chute should be calculated using steps (d) and (e) of Section 7.2.2 above for box-receivers.

9.2.3 Outlets

The following procedure may be used to calculate the effective catchment area, A (in m^2), that can be drained by an outlet in a flat roof.

- (a) Determine the appropriate value of design rainfall intensity, r (in l/s per m^2), for the roof.
- (b) Decide the value of maximum design water depth, W (in mm), for the roof (see Section 9.1.2 above)
- (c) The head, h (in mm), acting on the outlet is $h = W - Y_i$, where Y_i (in mm) is the height of the outlet lip above the lowest point in the area of roof being drained (normally $Y_i = 0$).
- (d) If test data for the outlet are available, determine the flow rate, Q (in l/s), which the outlet can discharge with a head equal to h .

- (e) If test data are not available, use Equations (7.1) to (7.7) to determine the flow rate, Q , for the head h , taking account of whether the outlet is grated or ungrated.
- (f) The maximum catchment area, A (in m^2), that can be drained by the outlet under design conditions is obtained from Equation (5.1) above, which can be written in the form:

$$A = \frac{Q}{rC} \quad (9.2)$$

where C is the run-off coefficient of the roof (normally assumed to have a value of $C = 1$).

9.2.4 Sumps

The following steps should be followed to design a sump to drain a specified catchment area, A (in m^2), subject to a design rainfall intensity, r (in l/s per m^2).

- (a) Calculate the design flow load, Q (in l/s), entering the sump from Equation (5.1) above.
- (b) Decide the maximum design water depth, W (in mm), for the roof (see Section 9.1.2 above).
- (c) Find the wetted perimeter, L_W (in mm), of the sump needed to limit the water depth to W , using Figure 12 in BS EN 12056-3 (p. 25) or from Equation (7.6) which can be written in the form:

$$L_W = \frac{24\,000Q}{W^{1.5}} \quad (9.3)$$

- (d) Determine a suitable geometry of sump that will provide this wetted perimeter, L_W . If flow cannot easily reach part of the perimeter of the sump, this part should not be considered as contributing to the total weir length, L_W .
- (e) The required depth of the sump depends on the size and type of outlet used in the base of the sump. Use Equations (7.1) to (7.7) as appropriate to find the head, h (in mm), required to pass the flow rate Q , taking account of whether the outlet is grated or ungrated.
- (f) The minimum depth of the sump should be $h + 25\text{mm}$.

10. RAINWATER PIPES AND DRAINS INSIDE BUILDINGS

10.1 Background information

10.1.1 Vertical pipes

As explained in Section 7.1.1 of this manual, the capacity formulae for conventional outlets given in Table 7 of BS EN 12056-3 (p. 21) should normally ensure that vertical rainwater pipes to which the outlets are connected will run part full under atmospheric pressure. For the recommended designs of outlet transition shown in Figure 9 of BS EN 12056-3 (p. 22), the diameter of the rainwater pipe, d_i (in mm), should not be smaller than $2D_o/3$, where D_o (in mm) is the top diameter of the outlet.

However, in situations where the design head at the outlet is large in relation to the size of the outlet, or more than one outlet is connected to the same rainwater pipe, there is a possible risk of partial siphonic conditions occurring. Therefore, Clause 6.1.1 in BS EN 12056-3 (p. 26) requires that the design flow rate in the rainwater pipe should not exceed the limiting flow capacity, Q_{RWP} (in l/s), found from Table 8 in the Standard or from the corresponding Wyly-Eaton equation:

$$Q_{RWP} = 2.5 \times 10^{-4} k_B^{-0.167} d_i^{2.667} f^{1.667} \quad (10.1)$$

where k_B (in mm) is the hydraulic roughness of the pipe (assumed in Table 8 to have a value of 0.25 mm) and f is the allowable filling factor in the pipe necessary to prevent any siphonic action. The selected value of filling factor varies in different countries, but in the UK the recommended value is $f = 0.33$. Therefore, for buildings in the UK, Equation (10.1) for the limiting flow capacity of a vertical pipe can be simplified to:

$$Q_{RWP} = 5.0 \times 10^{-5} d_i^{2.667} \quad (10.2)$$

These equations can also be applied to sections of pipe with offsets provided that the offset makes an angle of at least 10° to the horizontal. If the angle of the offset is less than 10° , see Section 10.1.2 of this manual.

BS EN 12056-3 does not specify a minimum internal diameter for rainwater pipes but points out the risk of blockage if the diameter is less than DN 75.

Rainwater pipes in siphonic systems are designed to different criteria than those applying to conventional systems, as described in Chapter 12 of this manual.

10.1.2 Rainwater pipes and drains with gradients flatter than 10°

Conventional roof drainage systems may sometimes be designed so that flow from a series of outlets is collected by a nearly horizontal pipe below roof level and discharged to ground level via a single vertical rainwater pipe. Clause 6.1.2 of BS EN 12056-3 (p. 27) requires that the collector pipe should be installed with a longitudinal slope that is sufficient to enable the pipe to carry the design rate of flow at a water depth not exceeding 70% of the pipe diameter. Designing the collector pipe to run part full allows air to be carried through the system without causing surging or serious pressure fluctuations.

Clause 6.3.1 of BS EN 12056-3 (p. 28) allows the required slope of the pipe to be determined from any established hydraulic equation. However, in the case of dispute, the Colebrook-White equation for flow capacity should be used. Values of flow rate for pipe diameters between DN 100 and DN 300, and longitudinal gradients between 5 mm/m and 50 mm/m, obtained from the Colebrook-White equation are given in Table C.1 of informative Annex C in BS EN 12056-3 (p. 38). Table C.1 assumes that the pipe is flowing at a depth equal to 70% of the pipe diameter and has a hydraulic roughness of $k_B = 1.0$ mm.

Note 1. This value of roughness is appropriate for below-ground drainage pipes but is higher than the value of $k_B = 0.25$ mm assumed in Table 8 of BS EN 12056-3 for the capacity of vertical rainwater pipes.

As an alternative, required values of the longitudinal gradient of the pipe can be found directly from the Colebrook-White equation or from suitable flow tables [e.g. Ref. 15]. The Colebrook-White equation can be written in the form:

$$Q_P = -2 \times 10^{-6} \sqrt{\left(\frac{8 g i A_i^3}{P_i}\right)} \log_{10} \left[\frac{14.84 k_B P_i}{A_i} - \frac{6.275 \times 10^5 \nu P_i}{\sqrt{\left(\frac{8 g i A_i^3}{P_i}\right)}} \right] \quad (10.3)$$

where:

Q_P = flow capacity of the pipe (in l/s)

g = acceleration due to gravity (= 9.81 m/s²)

i = fall or longitudinal gradient of pipe (in mm per m)

A_i = cross-sectional area of flow in pipe (in mm²)

P_i = wetted perimeter of pipe

k_B = hydraulic roughness of pipe (in mm)

ν = kinematic viscosity of water (= 1.31×10^{-6} m²/s at 10° C)

For a pipe of internal diameter, d_i (in mm), flowing at a proportional depth of 70%, the values of A_i and P_i are given by $A_i = 0.587 d_i^2$ and $P_i = 1.982 d_i$.

Pipe fittings such as bends and tees introduce additional point head losses that need to be taken into account when checking the flow capacity of pipe systems with gradients flatter than 10°. The losses at pipe fittings can be estimated using the data given in Section NE.2.8 of National Annex NE in BS EN 12056-3 (p. 74).

Where a rainwater pipe discharges into a drain, the internal diameter of the drain should not be smaller than that of the rainwater pipe and not less than DN 100 (see Clause 6.3.3 on p. 28 of BS EN 12056-3). The diameter and gradient of the drain should be chosen so that the depth of flow in the drain does not exceed 70% of the pipe diameter at the design rate of flow. This can be checked using data in Table C.1 of Annex C in BS EN 12056-3 (p. 38) or by using Equation (10.3) above; a typical value of pipe roughness for drains inside buildings carrying only rainwater is $k_B = 1.0$ mm.

Clause 6.3.5 requires that drains inside buildings should be laid at a sufficient gradient to be self-cleansing. For pipes discharging only rainwater, a suitable minimum velocity for drains flowing 70% full of water would be of the order of 0.75 m/s (but requirements may vary depending on the diameter of the pipe and the length of internal pipe runs).

10.2 Calculation steps

- (a) Find from the above Section 7.2.1 (outlets in gutters), Section 7.2.2 (outlets in box-receivers) or Section 9.2 (outlets in flat roofs) the total design flow rate, Q_T (in l/s), entering the rainwater pipe.

- (b) Determine the maximum flow capacity, Q_{RWP} (in l/s), of the vertical sections of rainwater pipe using Table 8 in BS EN 12056-3 (p. 26) or Equations (10.1) or (10.2) above.
- (c) If $Q_{RWP} \geq Q_T$, the size of the rainwater pipe is satisfactory. If $Q_{RWP} < Q_T$, it is necessary to increase the pipe size and repeat step (b).
- (d) If the rainwater system contains sections of pipe or drain inside the building that are flatter than 10° to the horizontal, determine the maximum flow capacity, Q_P (in l/s), of the pipe when it is flowing at a depth equal to 70% of the pipe diameter. This can be done using Table C.1 of Annex C in BS EN 12056-3 (p. 38) or Equation (10.3) above. If necessary, take account of head losses at pipe fittings using the information in Section NE.2.8 of National Annex NE in BS EN 12056-3 (p. 74).
- (e) If $Q_P \geq Q_T$, the design is satisfactory. If $Q_P < Q_T$, it is necessary either to increase the pipe size or the pipe gradient (or both); then repeat (d).
- (f) For sections of pipe that are flatter than 10° to the horizontal (particularly drains inside the building), check that the flow velocity at the design discharge is sufficient to produce self-cleansing conditions (see Section 10.1.2 in this manual). If the velocity is too low, vary the pipe size or increase the gradient (or both) and repeat steps (d) to (f).

11. OVERFLOW WEIRS

11.1 Background information

11.1.1 Purpose of overflows

Overflows may be used for three different purposes, either singly or in combination:

- to provide a warning that a rainwater system has become wholly or partially blocked and that maintenance is necessary;
- to prevent or reduce flooding in the event of a system becoming blocked;
- to cater for rarer storm events so that the main rainwater system can be sized more economically for storms that occur more frequently.

11.1.2 Performance of overflows

If a section of gutter is drained by only one or two outlets, it may be straightforward to install overflows that can deal with a significant proportion of the total flow load entering the gutter. An overflow combined with a box-receiver, as shown by the upper of the two drawings in Figure 11 of BS EN 12056-3 (p. 24), is particularly efficient because the level of the overflow weir can be set low in the gutter, thereby maximizing the head over the weir. If an overflow is installed in the stop end of a gutter, the level of the weir will usually need to be set close to the design depth of flow, W , in the gutter if it is not to operate too frequently; the maximum amount of overtopping head will therefore normally be limited to about 30% of the overall depth of the gutter.

In the case of a long gutter run drained by several outlets, it can be much more difficult to provide an overflow system that will be able to discharge a significant proportion of the total flow load in the gutter. Overflows at either end of a gutter run will only have a limited effect on preventing overtopping near the centre of the gutter run. Additional outlets along the gutter can be used as overflows by setting them above the sole of the gutter, but the reduced head acting on them limits their capacity. The cost of a capable overflow system can therefore be comparable to that of the main rainwater system.

11.2 Calculation steps

The following procedure may be used to determine the size of overflow weir needed to provide a specified discharge capacity, Q in (l/s).

- Decide the invert level, Y_i (in mm), at which the overflow is required to start discharging.
- Determine from the design of the roof or gutter, the maximum water level, W (in mm), that can be allowed when the overflow is discharging a flow rate Q . The available head, h (in mm), acting on the overflow is therefore $h = W - Y_i$.
- The required length, L_W (in mm), of overflow weir can be obtained from Figure 12 in BS EN 12056-3 (p. 25) or from Equation (7.6) which can be written in the form:

$$L_W = \frac{24\,000\,Q}{h^{1.5}} \quad (11.1)$$

- Choose an arrangement of overflow (e.g. straight, rectangular, circular) that will have a wetted perimeter not less than L_W .

12. SIPHONIC ROOF DRAINAGE SYSTEMS

12.1 General description

The key feature of siphonic roof drainage systems is that the pipework, which connects the outlets at roof level to the site drainage system at or below ground level, is designed to flow full under design storm conditions. This makes the full head provided by the building available to overcome the hydraulic resistance of the pipes, and results in negative pressures (or “siphonic action”) developing within the system. By contrast, the pipework in a conventional system is designed to flow part-full at the design condition with pressures close to atmospheric being maintained in the pipes (see Chapter 10 of this manual). As a result, the flow rate entering a conventional system is controlled by the size of the outlets and by the allowable water depth in the gutter or on the roof (which normally does not exceed about 200 mm). In a siphonic system, the overall flow rate is determined by the total head losses in the pipework and by the height of the roof above ground level (which is typically of the order of 10 m). Therefore, a siphonic system can have a much greater flow capacity than an equivalent conventional system, with higher velocities and strongly negative pressures occurring in the pipework.

Siphonic systems are normally used on commercial and industrial buildings with large roof areas where maximum benefit can be obtained from the inherently high flow capacity. The most common arrangement is for flow from a series of outlets to be discharged via short tailpipes into a larger collector pipe running nearly horizontally within the roof space of the building and discharging via a single vertical downpipe located at the perimeter of the building. This arrangement avoids the need for multiple vertical downpipes and a below-floor drainage system within the building, and allows maximum flexibility in the use of the internal space. Siphonic systems are not usually appropriate for use on domestic buildings.

12.2 Removal of air and negative pressures

In order for a siphonic system to “prime” (i.e. for the pipes to fill and run under full-bore conditions), the air within the pipes at the beginning of a storm needs to be removed by the flow of the water, while new air needs to be prevented from entering at roof level. Outlets used in siphonic systems are therefore normally of special design, and contain baffles to restrict the entry of air and/or vanes to prevent the water from swirling and forming a vortex that would be able to draw in air. The most critical case usually occurs with flat roofs since allowable water depths above outlets are often limited to about 35 mm; water depths in gutters are usually several times greater than this and therefore help to reduce the amount of air that can be drawn in.

Strong negative pressures can develop within the pipes of siphonic systems, and the lowest values normally occur at, or near, the top of the vertical downpipe that connects the horizontal collector pipe to ground level. Negative pressures have a more severe effect than equivalent positive pressures on the strength of pipes because the pipe walls tend to deform and buckle asymmetrically under negative pressures. A variety of pipe materials has been used successfully in siphonic systems (e.g. HDPE, UPVC and cast iron). Whatever type is selected, it is important to ensure that the pipes, fittings and joints are able to withstand the expected negative pressures. On tall buildings (e.g. exceeding approximately 14 m in height), it is possible for negative pressures in the pipes to approach the vapour pressure of water (which corresponds to a pressure of about -10.2 m of water column below atmospheric pressure). When this occurs, the water will effectively boil and form cavities filled with water vapour. This process can result in serious turbulence and pressure fluctuations in the pipes, and will provide an upper limit on the flow capacity of a system. When vapour cavities collapse, they can generate extremely high impact pressures that are capable of causing serious damage to the strongest of materials (including stainless steel). Therefore, it is very important that negative pressures are correctly predicted in siphonic systems and that a margin of safety is adopted so that conditions do not approach too closely to the vapour pressure of water. The risk of cavitation is increased at bends and expansions because flow separation and turbulence occurring in these types of pipe fitting can increase the magnitude of the pressure fluctuations. Although

no specific limit is given in Clause 6.2.6 of BS EN 12056-3 (p.27), siphonic systems are often designed so that minimum pressures do not fall below -8.0 m of water column.

12.3 Performance features of siphonic systems

Most (but not all) proprietary makes of siphonic system are designed on the basis that all the pipes between the outlets at roof level and the point of discharge (at or close to ground level) will be flowing 100% full of water under the design rainfall condition. Therefore, if the design rainfall intensity is exceeded, there will usually be very little additional margin of safety. For a 10m high building, a 1% increase in flow rate above the design figure would increase the total head losses in a siphonic system by about 200 mm, which could lead to overtopping of gutters or internal flooding from flat roofs. Storage effects at roof level may reduce the amount of depth increase, but this example points to the need to select the design rainfall intensity with care. A siphonic system will tend to be more sensitive to the effects of an incorrect choice of rainfall intensity than an equivalent conventional system.

The flow capacity of a siphonic system is normally determined from the fundamental Bernoulli equation:

$$p_1 + \frac{1}{2}\rho V_1^2 + \rho g z_1 = p_2 + \frac{1}{2}\rho V_2^2 + \rho g z_2 + \rho g \Delta H_{12} \quad (12.1)$$

where subscript 1 refers to a point upstream of point 2, and:

p = static pressure in pipe (in N/m²)

ρ = density of fluid (in kg/m³)

V = velocity of fluid (in m/s)

g = acceleration due to gravity (= 9.81 m/s²)

z = vertical height of point above reference datum (in m)

ΔH_{12} = head loss due to pipe friction or losses in fittings between points 1 and 2.

Note that it is necessary to use consistent units (e.g. SI) throughout in this equation.

Bernoulli's equation describes the changes in pressure that occur along a length of pipe caused by the variations in velocity and level, and by the loss of energy resulting from frictional resistance in the pipes and localised head losses at fittings such as bends and tees. In design, it is necessary to ensure that a system has the total flow capacity required, and that the overall head losses between each outlet and the point of discharge are approximately equal (i.e. that the system is "balanced"); see Clause 6.2.4 in BS EN 12056-3 (p. 27). If the degree of balance is not satisfactory, one outlet may have insufficient flow capacity while another may have excess capacity. The latter may cause an outlet to suck air into the pipework system and prevent satisfactory priming; in an extreme case, a system could fail to prime sufficiently quickly to deal with a heavy storm of short duration, even though the rainfall intensity was below the design value.

Pipe-full flow typically begins to occur in a siphonic system when the water flow rate reaches about 60% of the maximum flow capacity that applies when the pipes are 100% full of water. At flow rates between 60% and 100% of the maximum, the pipes contain a bubbly mixture of water and air. Below the 60% limit, the system will behave more as a conventional system with a free surface in many of the pipe lengths and pressures close to atmospheric. Since siphonic systems are usually designed to cater for storms of long return period (typically of the order of 100 years), it is likely that they will only prime and run siphonically

at infrequent intervals. Although the leafguards that are a common feature of siphonic outlets are able to prevent coarse debris entering a system, there is a risk of silt and smaller material gradually accumulating in the sections of horizontal pipe. In order to provide a suitable degree of self-cleansing, it is necessary to ensure that the flow velocities in the pipes exceed a certain minimum value at the design flow rate (see Clause 6.2.7 in BS EN 12056-3, p. 27). A typical value of minimum flow velocity for design is 1.0 m/s; larger pipes tend to need higher self-cleansing velocities than smaller pipes.

Another reason for avoiding low velocities in the pipework is that, at the start of a storm, the incoming flow needs to generate a sufficient degree of turbulence to entrain and transport air efficiently along the system. Low water velocities can increase significantly the time needed for a system to prime (see Clause 6.2.3 in BS EN 12056-3, p. 27). Since the duration of the design storm event for rainwater systems is normally two minutes (see Chapter 3 of this manual), siphonic systems need to be able to prime within a period of about one minute.

It is sometimes suggested that the design rainfall intensities for siphonic systems can be lowered below the appropriate figures determined from National Annex NB in BS EN 12056-3 (pp. 51–62) because of the storage available in pipes and gutters. This might be valid if a design storm lasted only two minutes and the rainwater system was initially empty of water. However, the design event will usually be part of a longer storm so flow depths tend to build up fairly gradually, reaching a peak during the heaviest part of the storm. Therefore, most of the available storage in the system will already have been used up and not available to help the system cope with the peak rate of flow. For this reason, Clause 6.2.1 in BS EN 12056-3 (p. 27) requires that siphonic systems should be designed to the same rainfall criteria as conventional systems without allowing for storage effects.

Due to the difficulty of designing siphonic systems to operate satisfactorily during smaller, more frequent storms as well as in the high-intensity design storm, there is an increasing tendency to install two parallel systems (“primary” and “secondary” systems). The outlets of the secondary system are set at a higher level in the gutter or flat roof, or are surrounded by circular weirs, so that they only come into operation during major storms. This allows the primary system to be sized so that a regular siphonic action can be achieved in smaller storms. In some cases, the secondary system may not be connected to the below-ground site drainage system but is arranged to discharge onto the ground away from the building that it drains.

When siphonic systems are running in the pipe-full state, they establish a direct link between flow conditions at ground level and flow conditions on the roof. Therefore, surcharging of the site drainage system due to blockage or a lack of capacity can cause an increase in water level on the roof (see Clause 6.2.5 in BS EN 12056-3, p. 27). For this reason, it is recommended that the first chamber of the site drainage system into which a siphonic system discharges should be provided with a ventilated cover. This will prevent a build-up of back pressure on the siphonic system above ground level. On this basis, it is recommended that siphonic systems should normally be designed assuming that the available head is equal to the difference in level between the roof outlets and ground level (i.e. not to the invert level of the siphonic system at the point where it discharges into the site drainage chamber).

12.4 Design of siphonic systems

The pipework in siphonic systems is often very complex with a large number of different pipe sizes and fittings. Therefore, accurate hydraulic design can usually be carried out only by means of a computer program. This is the reason why BS EN 12056-3 does not give detailed design methods and formulae for siphonic systems in the same way that it does for conventional systems. Instead, Section 6.2 of the Standard (p. 27) lists a series of general performance requirements that need to be met in order for siphonic systems to operate satisfactorily and reliably. The reasons for these performance requirements can be understood from the information provided in Sections 12.1 to 12.3 above.

It is important to note that the siphonic action only occurs within the pipework between the roof outlets and the point of discharge at or near ground level. Flow behaviour upstream of the outlets is unaffected by whether the pipework system is siphonic or conventional. Therefore, the recommendations given in Chapters 3, 4, 5, 6, 8, 9 and 10 of this manual are equally applicable to siphonic systems. In many building projects, separate contractors are used for the gutters, the siphonic system and the below-ground site drainage system. It is extremely important that information about each component of the overall system is exchanged between the various parties. As an example, the designer of the gutters needs to have data about the water depths that will be imposed by the siphonic outlets at the design rate of flow, and the siphonic designer needs to know whether surcharging may occur in the site drainage system.

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Appendix

Worked examples

Worked Examples 1 to 5 refer to the roof drainage system for the building shown in Figure A1.

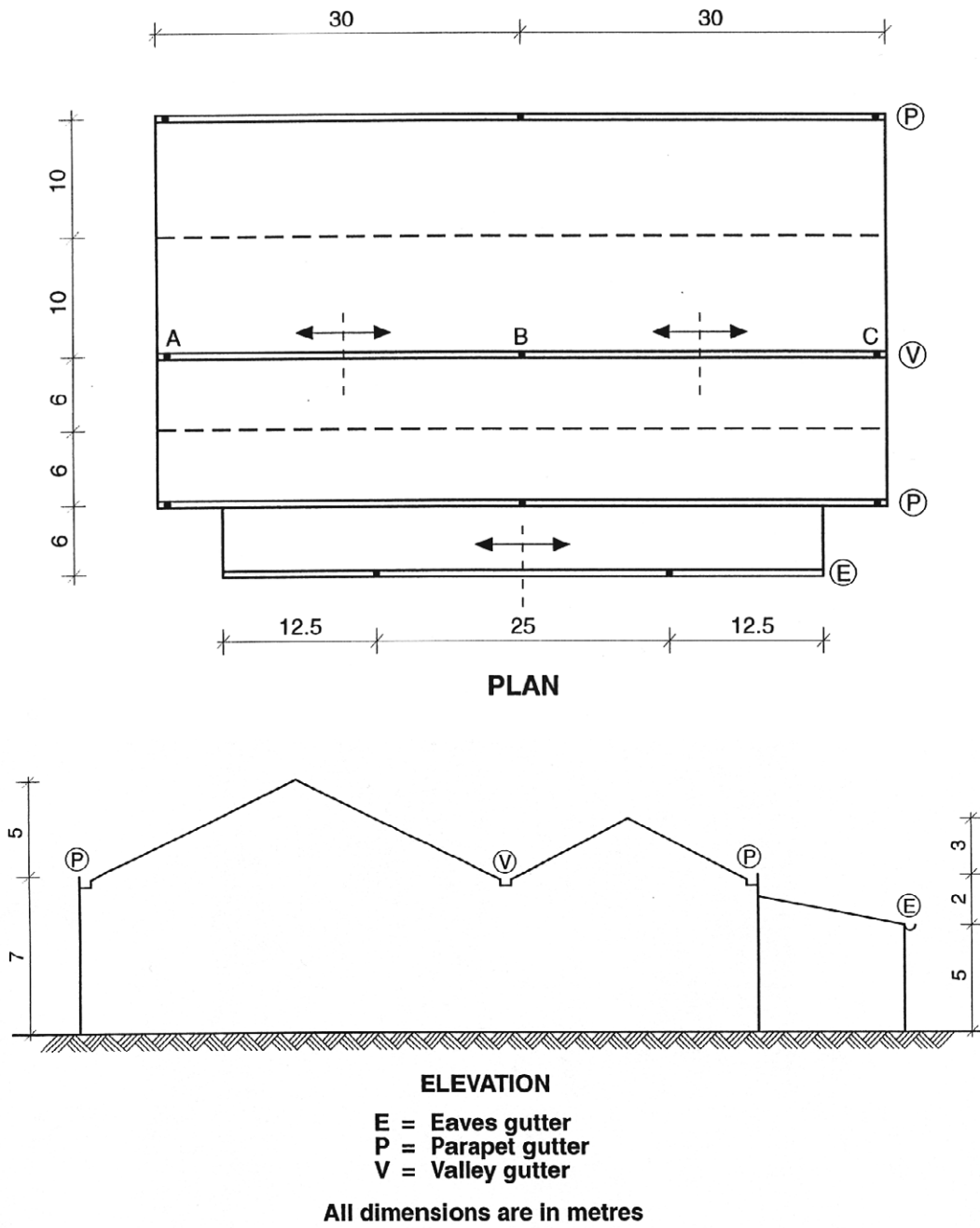


Figure A1 Layout of building for worked examples

Example 1

Rainfall, catchment areas and flow loads

Example A1 Rainfall, catchment areas and flow loads

A1.1 Design rainfall intensity (see Chapter 3)

(a) *Design data*

- 1) Building is located in Portsmouth
- 2) Design life of building is $L_Y = 20$ years
- 3) Required rainfall Category of “2½”, i.e. $P_R = 0.35$
(to illustrate choice of general calculation procedure).
- 4) Design for storm event with duration of 3 minutes
(to illustrate choice of general calculation procedure).

(b) *Find design storm return period, T , in years*

Using Eqn (3.2) in manual :

$$T = \frac{1}{1 - (1 - P_R)^\alpha} \quad ; \quad \text{with} \quad \alpha = \frac{1}{L_Y} = \frac{1}{20} = 0.05$$

$$T = \frac{1}{1 - (1 - 0.35)^{0.05}} = 46.9 \text{ years}$$

\therefore Use $T = 50$ years

(c) *Find design rainfall intensity from National Annex NB of BS EN 12056-3*

Figure NB.6 : 2 min $M5 = 3.5$ mm

Table NB.1 : ratio $\frac{3 \text{ min } M5}{2 \text{ min } M5} = 1.33$

$$\therefore 3 \text{ min } M5 = 1.33 \times 3.5 = 4.65 \text{ mm}$$

Figure NB.7 : ratio $\frac{3 \text{ min } M50}{3 \text{ min } M5} = 1.6$

$$\therefore 3 \text{ min } M50 = 1.6 \times 4.65 = 7.45 \text{ mm}$$

$$\text{Design intensity } r = \frac{3 \text{ min } M50}{60 D} = 0.0414 \text{ l/s per m}^2$$

\therefore Use $r = 0.041$ l/s per m^2

A1.2 Catchment areas (see Chapter 4)

(a) *Catchment area for eaves gutter*

See Figure A1 for location of gutter E

$$\text{Total plan area drained by gutter} = A_H = 50 \times 6 = 300 \text{ m}^2$$

$$\text{Total elevation area} = A_V = 50 \times 2 = 100 \text{ m}^2$$

$$\text{Effective catchment area} \quad A = A_H + \frac{A_V}{2}$$

$$A = 300 + \frac{100}{2}$$

$$\underline{A = 350 \text{ m}^2}$$

(b) *Catchment area for valley gutter*

See Figure A1 for location of gutter V

$$\begin{aligned} \text{Total plan area drained by gutter} &= A_H = 60 \times (10 + 6) \\ &= 960 \text{ m}^2 \end{aligned}$$

$$\begin{aligned} \text{Net elevation area} \\ \text{(difference between two ridges)} &= A_V = 60 \times (5 - 3) \\ &= 120 \text{ m}^2 \end{aligned}$$

$$\text{Effective catchment area} \quad A = A_H + \frac{A_V}{2} = 960 + \frac{120}{2}$$

$$\underline{A = 1020 \text{ m}^2}$$

A1.3 Flow loads (see Chapter 5)

(a) *Total flow load for eaves gutter*

Assume Category 1 rainfall intensity

From Figure NB.1 for Portsmouth area: $r = 0.020$ l/s per m^2 , $C = 1.0$

$$Q = r A C = 0.020 \times 350 \times 1.0 = 7.0 \text{ l/s}$$

$$\underline{Q = 7.0 \text{ l/s}}$$

(b) *Total flow load for valley gutter*

$$r = 0.041 \text{ l/s per m}^2 \text{ (Category 2}\frac{1}{2}\text{ for valley gutter, see A1.1)}$$

$$Q = r A C = 0.041 \times 1020 \times 1.0 = 41.8$$

$$\underline{Q = 41.8 \text{ l/s}}$$

Example 2

Design of eaves gutter

Example 2 Design of eaves gutter

A2.1 Design flow load (see Chapter 5)

See Figure A1 for position of gutter E

From A1.3: total flow load to gutter = 7.0 l/s

2 No. Outlets at $\frac{1}{4}$ points along gutter run

\therefore Gutter length $L = 12.5$ m

Design flow load in gutter length

$$Q = 7.0 \times \frac{L}{50} = \frac{7.0 \times 12.5}{50}$$

$$Q = 1.75 \text{ l/s}$$

E2.2 Flow capacity of gutter (see Chapter 6)

(a) Consider use of 150 mm true half-round gutter.

Assume free discharge.

Use procedure in Section 6.2.2 of manual.

No freeboard required, so design depth of flow: $W = 75$ mm.

(b) Corresponding cross-sectional area of flow: $A_E = \frac{\pi W^2}{2} = \frac{\pi \times 75^2}{2} = 8.836 \times 10^3 \text{ mm}^2$

(c) Find nominal flow capacity of semi-circular eaves gutter:

Use Fig 3 in BS EN 12056-3 or Eqn (6.3) in manual:

$$Q_N = 2.78 \times 10^{-5} A_E^{1.25} = 2.38 \text{ l/s}$$

(d) Check effect of gutter length

$$L = 12\,500 \text{ mm} \quad ; \quad W = 75 \text{ mm}$$

$$\therefore \frac{L}{W} = \frac{12\,500}{75} = 167$$

Use Table 6 in BS EN 12056-3 or Eqn (6.8) in manual:

$$F_L = 1.0 - \frac{0.2}{150} \left[\frac{L}{W} - 50 \right] = 0.844$$

(e) Calculate design flow capacity from Eqn (6.7) in manual:

$$Q_C = 0.9 F_L Q_N = 0.9 \times 0.844 \times 2.38 = 1.81 \text{ l/s}$$

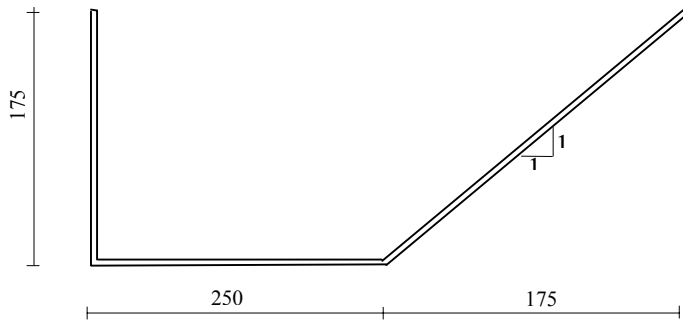
This just exceeds design flow load of $Q = 1.75 \text{ l/s}$

\therefore 150 mm half-round gutter is suitable.

Example 3

Design of valley gutter

Example 3 Design of valley gutter



Cross-section of gutter V (see Fig A1 for layout, all units)

A3.1 Design flow load (see Chapter 5)

From A1.3 : total flow load to gutter along 60 m length of building = 41.8 l/s

2 No. outlets at ends of gutter, 1 No outlet at mid-point

\therefore Gutter length $L = 15$ m

Flow load in each gutter length = $41.8 \times \frac{15}{60}$

\therefore $Q = 10.4$ l/s.

A3.2 Flow capacity of gutter (see Chapter 6)

Assume free discharge

Use procedure in Section 6.2.3 of manual:

(a) Gutter geometry as above: overall depth of gutter $Z = 175$ mm

(b) Freeboard allowance: $Y = 0.3Z$

$$Y = 0.3 \times 175 = 52.5 \text{ mm } (< 75 \text{ mm})$$

(c) Maximum design flow depth:

$$W = Z - Y = 175 - 52.5 = 122$$

(d) Calculate cross-sectional area of flow corresponding to depth W :

$$A_w = 250 \times 122 + \frac{1}{2} \times 122 \times 122 = 3.79 \times 10^4 \text{ mm}^2$$

- (e) Find value of shape factor F_D

Surface width of flow corresponding to design flow depth W :

$$T = 250 + 122 = 372 \text{ mm}$$

$$\therefore \frac{W}{T} = \frac{122}{372} = 0.328$$

From Fig 5 in BS EN 12056-3 or Eqn (6.5) in manual: $F_D = \left(\frac{W}{T}\right)^{0.25} = 0.757$

- (f) Find value of shape factor F_S

Sole width of the gutter $S = 250 \text{ mm}$

$$\therefore \frac{S}{T} = \frac{250}{372} = 0.672$$

From Fig 6 in BS EN 12056-3 or Eqn 6.6 in manual:

$$F_S = 0.8943 + 0.2013\left(\frac{S}{T}\right) - 0.0965\left(\frac{S}{T}\right)^2 = 0.986$$

- (g) Calculate nominal flow capacity from Eqn (6.7) in manual:

$$\begin{aligned} Q_N &= 3.89 \times 10^{-5} F_D F_S A_W^{1.25} \\ &= 3.89 \times 10^{-5} \times 0.757 \times 0.986 \times (3.79 \times 10^4)^{1.25} = 15.3 \text{ l/s} \end{aligned}$$

- (h) Check effect of gutter length:

$$L = 15\,000 \text{ mm} ; W = 122 \text{ mm}$$

$$\therefore \frac{L}{W} = \frac{15\,000}{122} = 123$$

Use Table 6 in BS EN 12056-3 or Eqn (6.8) in manual:

$$F_L = 1.0 - \frac{0.2}{150} \left[\frac{L}{W} - 50 \right] = 0.903$$

- (i) Calculate design flow capacity from Eqn (6.7) in manual:

$$Q_C = 0.9 F_L Q_N = 0.9 \times 0.903 \times 15.3 = 12.4 \text{ l/s}$$

Design flow capacity of gutter $Q_C = 12.4 \text{ l/s}$

This exceeds flow load of $Q = 10.4 \text{ l/s}$

\therefore The selected valley gutter provides a safety margin of 20% (assuming that the outlets are large enough to allow free discharge).

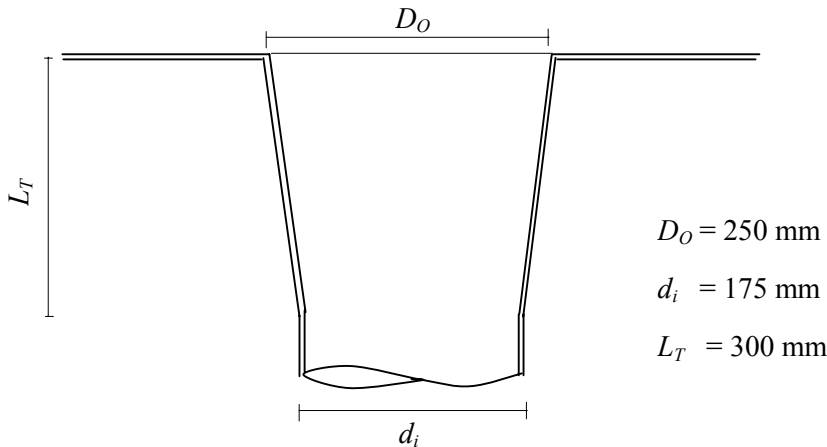
Example 4

Design of outlets in valley gutter

Example 4 Design of outlets in valley gutter

A4.1 Details of outlet

Check whether this design of tapered outlet will allow gutter V in Figure A1 to discharge freely (see Chapter 7).



Does outlet meet geometric requirements in Fig 9 of BS EN 12056-3 ?

$$d_i \geq \frac{2}{3} D_O = 167 \text{ mm?} ; L_T \geq D_O = 250 \text{ mm?} \quad - \quad \underline{\text{YES IT DOES}}$$

\therefore Effective diameter $D = 250 \text{ mm}$.

A4.2 End outlets A and C (see Figure A1)

Design the end outlets to allow free discharge for the maximum design flow capacity of each gutter length.

(a) From A3.2 : design flow capacity of gutter length $Q_C = 12.4 \text{ l/s}$ (from step (i) in A3.2)

Only one gutter length discharges to outlet

$$\therefore \text{ Total flow rate entering outlet } Q_T = 12.4 \text{ l/s}$$

(b) Find limiting head, h_L , from Fig 10 in BS EN 12056-3 or Eqn (7.9) in manual:

$$\text{From step (f) in A3.2: } \frac{S}{T} = 0.672$$

$$F_h = 0.6459 - 0.3084 \left(\frac{S}{T} \right) + 0.1415 \left(\frac{S}{T} \right)^2 = 0.503$$

Maximum design flow depth: $W = 122 \text{ mm}$

Limiting flow depth in gutter for free discharge:

$$\text{From Eqn (7.8): } h_L = F_h W = 61.4 \text{ mm}$$

(c) Calculate flow rate that the outlet can discharge at this value of head

$$D = 250 \text{ mm}$$

$$h = h_L = 61.4 \text{ mm}$$

Is $h > D/2$? – NO

∴ Use Eqn (7.1) in manual: outlet does not have a grating ∴ $k_O = 1.0$

$$Q_O = \frac{k_O D h^{1.5}}{7500} = 16.0 \text{ l/s}$$

This exceeds the maximum design flow rate of $Q_T = 12.4$ l/s entering the outlet

∴ Outlet is satisfactory and will allow free discharge.

A4.3 Central outlet B (see Figure A1)

(a) From A3.2 : discharge capacity of gutter length = 12.4 l/s

Two gutter lengths discharge to outlet B

∴ Total flow rate entering outlet $Q_T = 24.8$ l/s

(b) Limiting head for free discharge is same as for the end outlet in A4.2

∴ Flow capacity is same: $Q_O = 16.0$ l/s

∴ Outlet will not allow free discharge and flow capacity of gutter will be reduced.

A4.4 Size of rainwater pipes

The proposed outlets are connected to rainwater pipes of internal diameter $d_i = 175$ mm. The maximum flow load occurs at outlet B (see A4.3).

∴ Design flow rate in rainwater pipe = $Q_T = 24.8$ l/s

The limiting flow rate in the pipe is given by the Wyly-Eaton equation. From Table 8 in BS EN 12056-3 (p. 26) or Eqn 10.2 in this manual:

$$Q_{RWP} = 5.0 \times 10^{-5} d_i^{2.667} = 48.0 \text{ l/s}$$

This exceeds the design flow rate of $Q_T = 24.8$ l/s.

∴ The proposed size of rainwater pipe is satisfactory.

Example 5

Gutter with restricted discharge

Example 5 Gutter with restricted discharge

A5.1 Design problem

Assume that the 250mm×150 mm tapered outlet considered in Section A4.1 is used at position B in valley gutter V (see Figure A1).

The calculations in Section A4.3 showed that this outlet will restrict the discharge from the gutter.

Check whether the gutter and outlet combination at position B has sufficient flow capacity to cater for the design rainfall intensity of 0.041 l/s per m².

A5.2 Calculation procedure (see Chapter 8, Section 8.2)

- (a) Assume value of $r = 0.041$ l/s per m²
- (b) From A3.1, design flow load in each gutter length :

$$Q = 41.8 \times \frac{15}{60} = 10.4 \text{ l/s}$$

Total flow rate entering outlet:

$$Q_T = 2 \times 10.4 = 20.8 \text{ l/s}$$

- (c) Find the required head at outlet to pass this flow rate:

Effective diameter of outlet: $D = 250$ mm

$$\text{Eqn (8.2): } h = \left(\frac{7500 \times Q_T}{D} \right)^{0.67} = \left(\frac{7500 \times 20.8}{250} \right)^{0.67}$$

$$h = 74.6 \text{ mm}$$

Note: this exceeds the limiting head of $h_L = 61.4$ mm (see A4.2), and confirms that the outlet will restrict the discharge and reduce the flow capacity of the gutter.

- (c) Flow capacity of gutter if it were unrestricted:

From step (i) of A3.2: $Q_C = 12.4$ l/s

- (d) Use procedure in Section ND.3.3 in BS EN 12056-3 (p. 68) to find flow capacity for restricted discharge. Note the two gutter lengths draining to the outlet are of equal length and have equal flow loads.

Check whether the gutter will have sufficient flow capacity if the required head over the outlet of $h = 74.6$ mm (see step (b)) is allowed.

\therefore Assume $h_R = 74.6$ mm

(e) Calculate flow restriction factor:

$$F_R = \left(\frac{h_L}{h_R} \right) \left(\frac{W - h_R}{W - h_L} \right) = \left(\frac{61.4}{74.6} \right) \left(\frac{122 - 74.6}{122 - 61.4} \right) = 0.644$$

From Fig ND.2 in BS EN 12056-3 or Eqn (8.1) in manual:

$$\frac{Q_R}{Q_C} = 1.000 + 0.500 \log_{10} F_R = 0.904$$

$$Q_R = 0.904 \times 12.4 = 11.2 \text{ l/s}$$

∴ The outlet reduces the flow capacity of each gutter length to $Q_R = 11.2 \text{ l/s}$.

This still exceeds the required flow load in each gutter length of $Q = 10.4 \text{ l/s}$

∴ The proposed combination of gutter and outlet meets the design requirements.