



Sanitary plumbing and drainage

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Design of sanitary pipework systems

A good sanitary pipework system should be designed and installed to provide the following attributes:

1. Prevent the transmission foul air into the building.
2. Minimise the frequency of any blockage and provided with adequate pipe access to enable the effective clearance of any such blockage.
3. Provide efficient conveyance of discharge from sanitary, kitchen, laundry and wash-down facilities, to enable the correct function of each appliance.
4. Where any sewer is likely to surcharge, minimise the risk of flooding to any part of a building where the floor level is located below normal ground level.

Sanitary discharge pipework should therefore be kept as short as possible, with few bends, and with adequate gradient.

Location

Discharge stacks and discharge branches should be installed inside buildings, although for buildings up to three storeys it is permissible to place them externally.

Design basis

The sanitary discharge system, terminology, and method of sizing previously used in BS 5572 has now been replaced by Part 2 of BS EN 12056. This section therefore incorporates these changes. The new harmonised Standard is designed to be applicable in all EN member countries. The design engineer has a choice of four system types, as shown in Table 1.

Table 1

System	Typical practice in
I	Germany, Austria, Switzerland, Belgium
II	Scandinavia
III	United Kingdom
IV	France

In addition to the generic System requirements, the design engineer must also comply with the relevant National Annexe, which each country is allowed to incorporate in their own published version. The content of this Section is based on System III, the UK National Annexe, and the 2002 edition of the Building Regulations Approved Document H.

Terminology

The term 'domestic wastewater' refers to all the water, solid particles, and urine, which may be conveyed by a sanitary discharge system. It includes condensate water, and (where permitted) rainwater.

'Black water' is wastewater containing faecal matter or urine.

The documented definition for 'grey water' is wastewater which excludes faecal matter and urine; although some design engineers may also wish to exclude any macerated solids, such as food.

Therefore, the effluent conveyed by a typical discharge stack in the UK is domestic wastewater. Some countries have retained the two-pipe system, where one stack is used for black water, and a second stack is used for grey water, this method is also used where recycling of grey water is required.

Discharge pipe systems

For the purpose of stack sizing, there are essentially two piping methods:

Primary ventilated stack; or Secondary ventilated stack.

Figures 1-4 show the typical configurations in diagrammatic form.

The primary ventilated system (previously known as the single stack system) is shown in Figure 1. Where any branch piping does not comply with the requirements for unventilated branches, branch vent piping would be required, as shown in Figure 2. For primary ventilated systems there are limits (see Figure 5) on the vertical distance between the invert of the drain connection and the centre line of the lowest discharge branch connection to the stack. A primary ventilated stack may require additional venting at the base of the stack where the sewer connection is likely to surcharge or where the stack is the only means of ventilating an interceptor trap.

The secondary ventilated system (previously known as the ventilated stack system) is used to increase the flow capacity of a given discharge stack size, (see Figure 3). The additional vent stack, incorporating a connection to the discharge piping on every storey, alleviates excessive pressure fluctuations by allowing air movement within the system. Where any branch piping does not comply with the requirements for unventilated branches, branch vent piping would also be required, as shown in Figure 4.

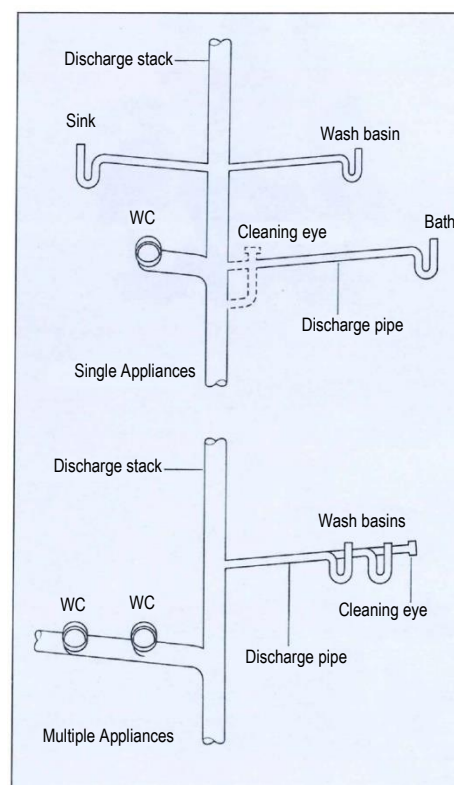


Figure 1 Primary ventilated system

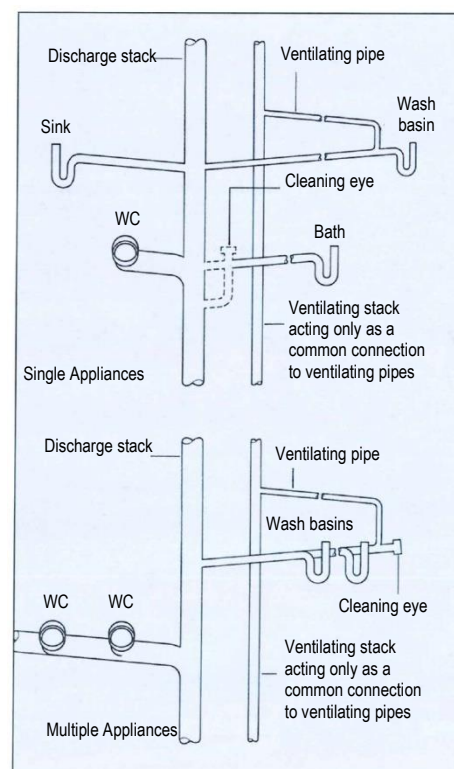


Figure 2 Modified primary ventilated system

At the base of any discharge stack, the drain connection should be achieved by using two 45° bends, or a single swept bend with a centre line radius of not less than 2 times the pipe bore, (see Figure 5).

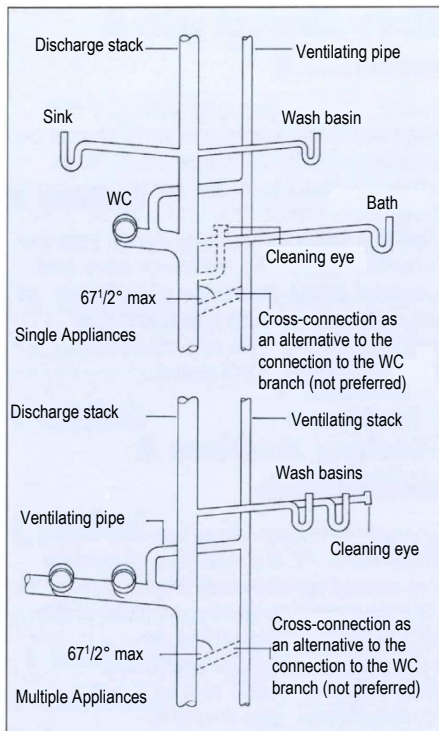


Figure 3 Secondary ventilated system

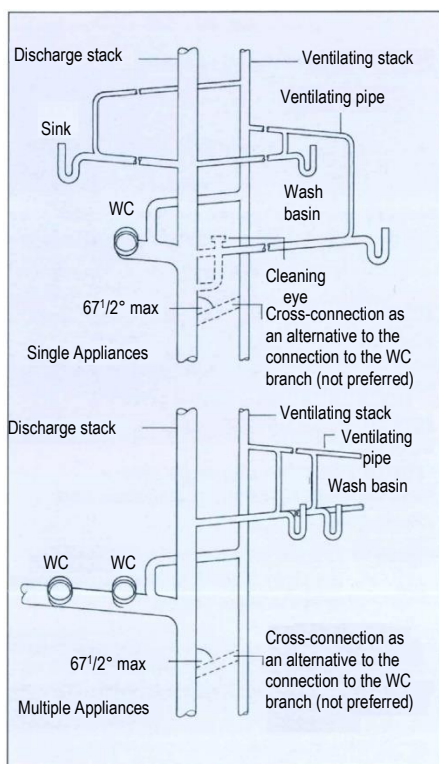


Figure 4 Modified secondary ventilated system

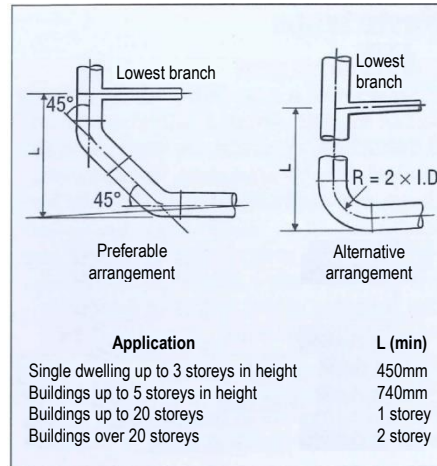
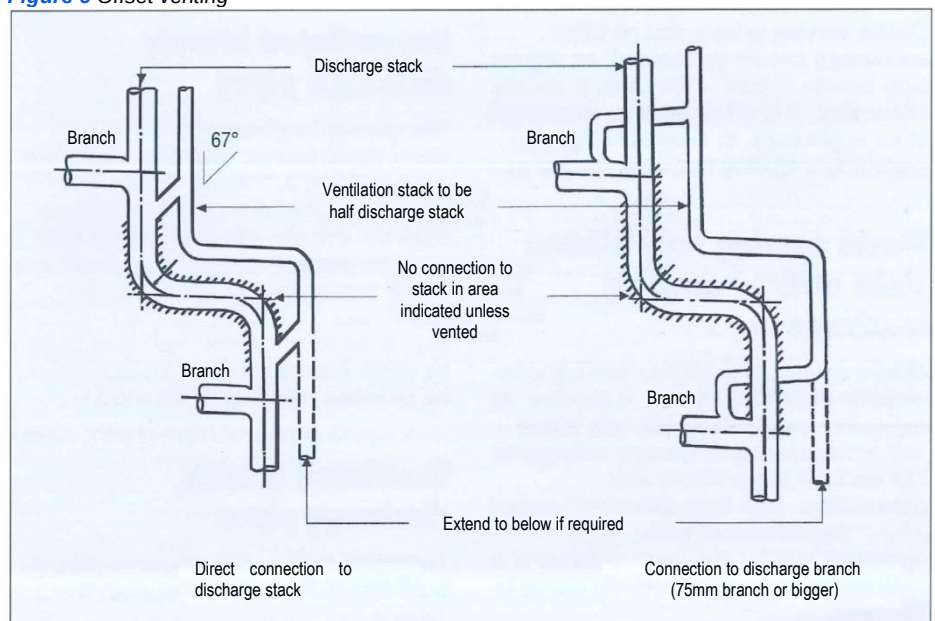


Figure 5 Requirements at the base of primary ventilated discharge stacks

Offsets

In large buildings, it is often necessary for the discharge stack to offset. Vent piping to relieve the offset pressure fluctuation would be required (see Figure 6) where systems are heavily loaded or serving more than three stories. The bore of the vent pipe should be not less than half the bore of the discharge stack. Where offsets are incorporated, the bends should have a centreline radius of not less than 2 times pipe bore, and no discharge branch connection should be made to the offset between the vent connection points. Where offset venting is used, the stack should still be sized as a primary ventilated system, unless vent connections to every storey are included. Offsets above the highest discharge connection to the stack do not require venting or the use of large radius bends.

Figure 6 Offset venting



Air admittance valves

Air admittance valves may be used in either primary or secondary ventilated systems, providing they are used within the application limits contained in the approval document issued by a European Technical Approvals body, such as the BBA and WIMLAS. These valves are available in a range of sizes and can be used to terminate stack vent pipes inside the building, and to prevent siphonage problems for branch discharge pipes or individual appliances. The valves open automatically on sensing negative air pressure within the system; thus, allowing air ingress only. They should not be used where positive pressure ventilation is required, such as when the stack connects to a septic tank, intercepting trap, or where a sewer is prone to surcharge.

Termination of ventilation pipes

At the top of a discharge stack, the vent pipe diameter should be equal to the stacks. However, on stacks serving 1 or 2 storey housing, the vent pipe may be reduced to 75mm diameter. Each pipe should be fitted with a durable and secure domical cage, which is resistant to bird nesting and movement by vermin. Ventilation pipes should terminate outside the building, positioned where the emission of foul air does not cause a nuisance. This is generally achieved, if the termination point is not less than 900mm above the top of any window or natural ventilation opening if within a horizontal distance of 3m. Consideration should also be made in relation to adjacent roof structures likely to cause wind based fluctuating pressure zones and mechanical ventilation inlets.

Stub stacks

Stub stacks may be used as a method to connect discharge branches from ground floor appliances to drain. They are essentially a short vertical extension from a 100mm drain, and there are limits on the height of branch connections, (see Figure 7). They can be used to connect the discharge from a group of appliances in a bathroom and kitchen, but should be limited to a cumulative load of 5 l/s. They may be installed either internally or outside the building, and should be terminated with an access cap. If the stub stack is located inside the building, and it is not possible to comply with the dimensional or flow limitations, then an air admittance valve should be used instead of an access cap. The length of the branch drain serving the stub stack should be limited as required for correct drainage accessibility, and should be connected to a drain, which is adequately ventilated.

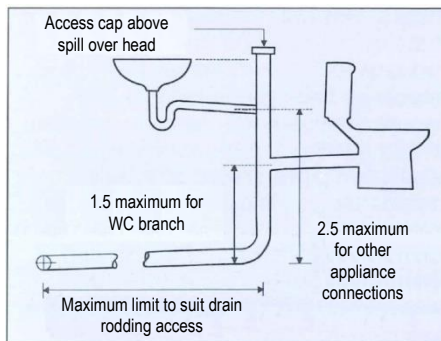


Figure 7 Stub stack vertical limits

Stacks serving only urinals

Stacks serving urinals and no other appliances should be avoided, as regular pipe access to clear deposition is usually necessary. It is advantageous to connect other appliances, to allow flushing, preferably including hot water discharge.

Stacks serving only kitchen sinks and/or washing machines

Stacks serving only kitchen sinks and/or washing machines should be avoided, as deposition (particularly with soft water) and problems due to foaming detergents can occur. If these stacks are unavoidable, then they should be located where regular access will not pose a threat to hygiene, and the avoidance of a stack connection on the bottom storey is desirable.

Waste traps

Every sanitary appliance should be provided with a trap, either as an integral part of the appliance, or attached directly to the appliance outlet, or fitted in close proximity to the appliance. On showers, for ease of maintenance, a trap may be positioned up to 750mm from the outlet. An alternative method to a trap is to use a proprietary valve (see Figures 22-26). The purpose of the trap is to provide a non-mechanical barrier to prevent the escape of foul air into the building, but in addition the water reservoir can act as a dilution feature and to intercept small accidentally dropped objects.

There are essentially two types of trap: tubular, and bottle. Kitchen sinks and macerators should only be fitted with tubular traps. Kitchen sinks with two or three bowls may be provided with an outlet manifold and a single trap. There should not be more than one trap on the discharge pipework from any appliance. The minimum depth of trap seal for various applications is given in Table 2. Resealing traps and anti-vacuum traps are available where self-siphonage may be a problem; some types are noisy in use.

Table 2 Minimum depth of trap seal

Use	Seal
Baths & showers which discharge to a stack	50mm
Baths & showers located at ground floor level which discharge to a gully having a grating	38mm
Wash basins with spray taps, and no outlet plugs	50mm
Appliances with an outlet bore of 50mm or larger	50mm
All other appliances	75mm

Unventilated branch discharge pipes

The general requirements for unventilated branch discharge pipes are given in Table 3. If the configuration of a discharge pipe from a single appliance does not comply with the requirements for unventilated branches, then there is a risk of self-siphonage of the trap. In which case a resealing trap, anti-vacuum trap, or small air admittance valve should be used. Alternatively, a vent pipe should be provided (see Figure 20 and 21).

Ventilated branch discharge pipes

The general requirements for ventilated branch discharge pipes are given in Table 4.

Waste disposal units & macerators

Branch discharge pipes serving waste disposal units and macerators should be connected to a discharge stack, stub stack, or direct to drain, not to a trapped gully. Only tubular traps should be used, and any bends should be swept (not the 'knuckle' type). The minimum bore and gradient of the discharge pipe should be as recommended by the appliance manufacturer, but in any event not less than given in Table 3 and 4.

Washing machines & dishwashers

Branch discharge pipes serving washing machines and dishwashers should be connected as shown in Figure 8, 9 or 10. The minimum bore, and gradient of the discharge pipe should be as recommended by the appliance manufacturer, but in any event not less than given in Table 3 and 4.

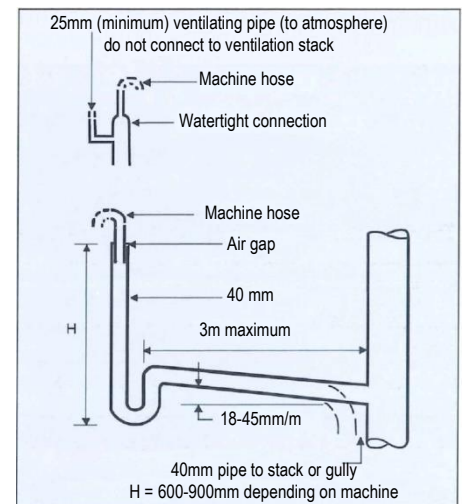


Figure 8 Upstand discharge pipe arrangements for washing machines and dishwashers

Figure 9 Discharge pipe arrangements for washing machines and dishwashers with low level outlets

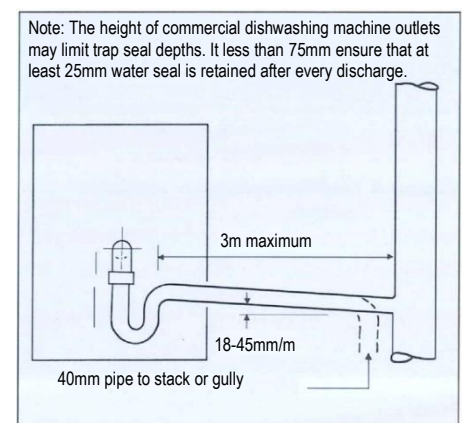


Table 3 Limitations for unventilated branches

Appliance (See Figures 11,12, 13 and 14)	Diameter (mm)	Max. pipe length (m)	Pipe gradient mm per m run	Max. number of bends	Max. drop (m) vertical pipe
Wash basin or bidet	32	1.7	18 to 22	None ¹	None
	32	1.1	18 to 44	None ¹	None
	32	0.7	18 to 87	None ¹	None
	40	3.0	18 to 44	2 ¹	None
Bath or shower	40	3.0 ²	18 to 90	No limit	1.5
Kitchen sink	40	3.0 ²	18 to 90	No limit	1.5
Domestic washing machine or dishwashing machine	40	3.0	18 to 44	No limit	1.5
WC with outlet up to 80mm dia.	75	No limit	18 min.	No limit ⁴	1.5
WC with outlet over 80mm dia.	100	No limit	18 min.	No limit ⁴	1.5
Bowl urinal ⁴	40	3.0 ³	18 to 90	No limit ⁴	1.5
Trough urinal	50	3.0 ³	18 to 90	No limit ⁴	1.5
Slab urinal ⁵	65	3.0 ³	18 to 90	No limit ⁴	1.5
Food waste disposal unit ⁶	40 min.	3.0 ³	135 min.	No limit ⁴	1.5
Sanitary towel disposal unit	40 min.	3.0 ³	54 min.	No limit ⁴	1.5
Floor drain	50 to 100	3.0 ³	18 min.	No limit	1.5
Branch serving 2 to 4 wash basins	50	4.0	18 to 44 0	None	None
Branch serving several bowl urinals ⁴	50	3.0 ³	18 to 90	No limit ⁴	1.5
Branch serving 2 to 8 WC's	100	15.0	9 to 90 2 1.5	2	1.5
Up to 5 wash basins with spray taps ⁷	32	4.5 ³	18 to 44	No limit ⁴	None

1. Excluding the 'connecting bend' fitted directly or close to the trap outlet.
2. If longer than 3m, this may result in noisy discharge, and there will be an increased risk of blockage.
3. Should ideally be as short as possible to limit deposition problems.
4. Swept bends should be used; not 'knuckle' bends.
5. For up to 7 people; longer slabs should have more than one outlet.
6. Includes small potato-peeling machines
7. Wash basins must not be fitted with outlet plugs.

Table 4 Limitations for ventilated branches

Appliance (See Figures 12,13, 14, 20 and 21)	Diameter (mm)	Max. pipe length (m)	Pipe gradient mm per m run	Max. num ber of bends	Max. drop (m) vertical pipe
Wash basin or bidet	32	3.0	18 min.	2 ¹	3.0
	40	3.0	18 min.	No limit	3.0
Bath or shower	40	3.0 ²	18 min.	No limit	No limit
Kitchen sink	40	3.0 ²	18 min.	No limit	No limit
Domestic washing machine or dishwashing machine	40	No limit ³	18 min.	No limit	No limit
WC with outlet up to 80mm dia.	75	No limit	18 min.	No limit ⁴	1.5
WC with outlet over 80mm dia.	100	No limit	18 min.	No limit ⁴	1.5
Bowl urinal ⁴	40	3.0 ³	18 min.	No limit ⁴	3.0
Trough urinal	50	3.0 ³	18 min.	No limit ⁴	3.0
Slab urinal ⁵	65	3.0 ³	18 min.	No limit ⁴	3.0
Food waste disposal unit ⁶	40 min.	3.0 ³	135 min.	No limit ⁴	3.0
Sanitary towel disposal unit	40 min.	3.0 ³	54 min.	No limit ⁴	3.0
Floor drain	50 to 100	3.0 ³	18 min.	No limit	No limit
Branch serving 2 to 5 wash basins	50	7.0	18 to 44	No limit	None
Branch serving 6 to 10 wash basins ⁸	50	10.0	18 to 44	No limit	None
Branch serving several bowl urinals ⁴	50	3.0 ³	18 min.	No limit ⁴	No limit
Branch serving 2 or more WC's	100	No limit	9 min.	No limit	No limit
Up to 5 wash basins with spray taps ⁷	32	No limit ³	18 to 44	No limit ⁴	None

1. Excluding the 'connecting bend' fitted directly or close to the trap outlet.
2. If longer than 3m, this may result in noisy discharge, and there will be an increased risk of blockage.
3. Should ideally be as short as possible to limit deposition problems.
4. Swept bends should be used; not 'knuckle' bends.
5. For up to 7 people; longer slabs should have more than one outlet.
6. Includes small potato-peeling machines.
7. Wash basins must not be fitted with outlet plugs.

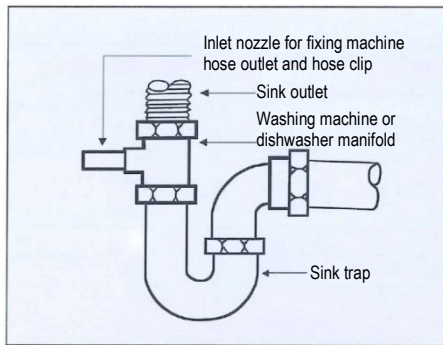


Figure 10 Sink manifold connection for washing machines and dishwashers

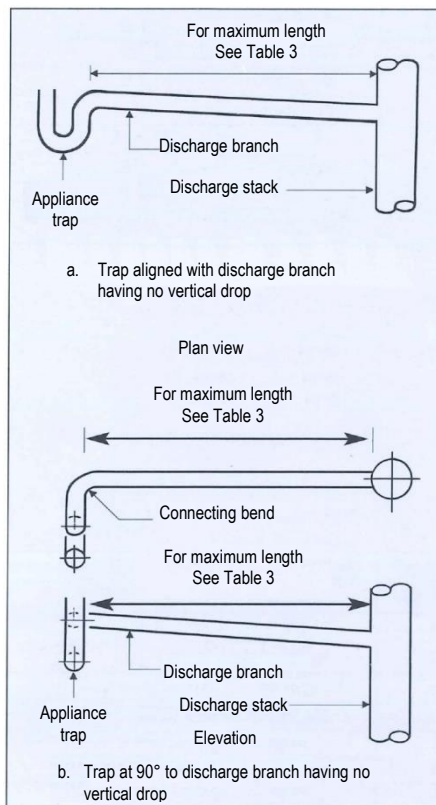


Figure 11 Branch limitations for unventilated branches where no vertical drop is permitted

Prevention of cross flow - small diameter pipes

Opposed small diameter branch discharge connections to stacks (without swept entries) should be arranged so that risk of the flow from one branch affecting another branch is avoided. See Figures 15 to 18.

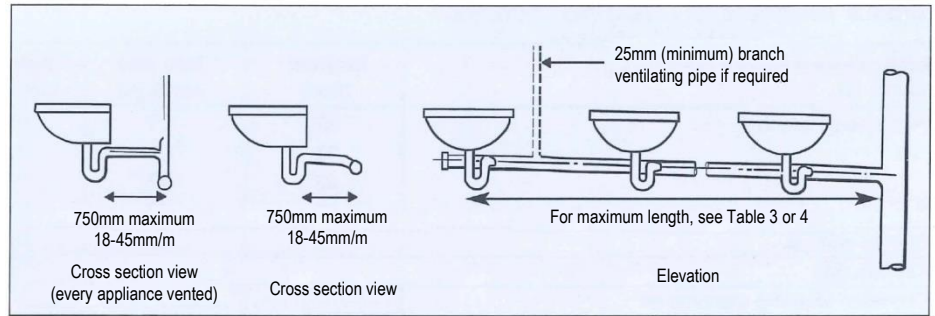


Figure 12 Combined discharge branch for a group of wash basins (or urinals)

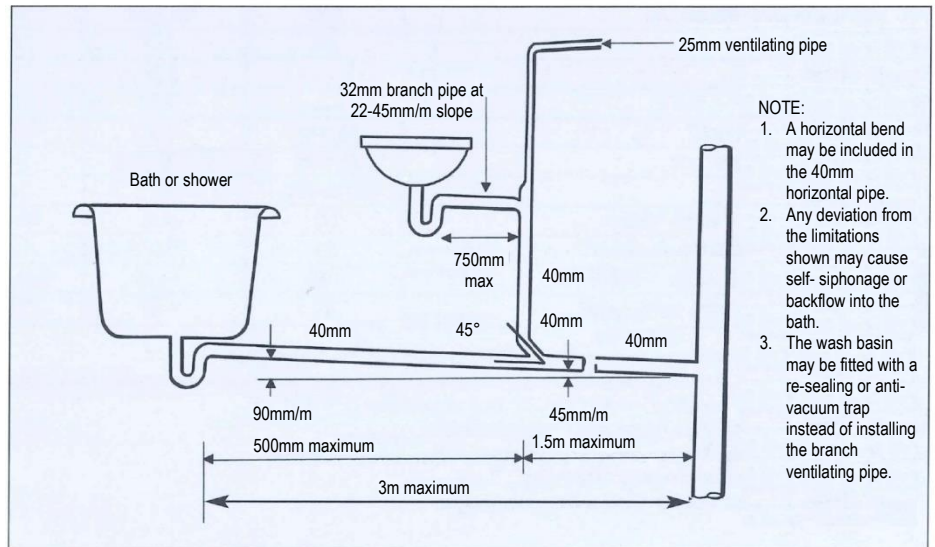


Figure 13 Combined discharge branch for a bath and wash basin

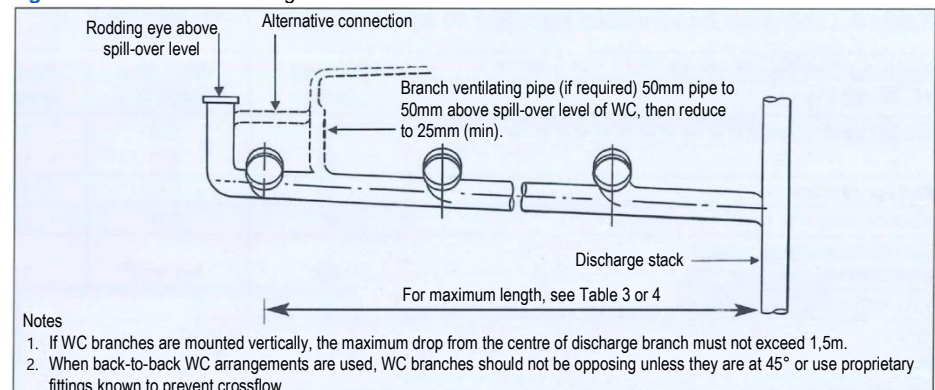
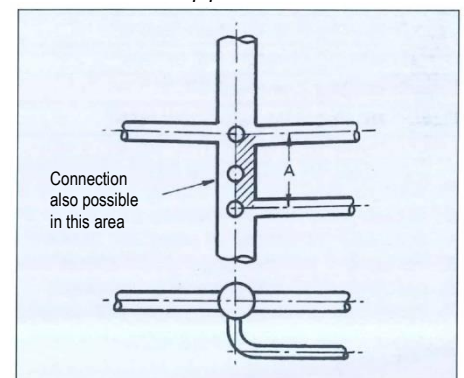


Figure 14 Combined discharge branch for a group of WC's

Prevention of cross flow - large diameter pipes

To prevent the discharge from a large branch (e.g., WC) from affecting a smaller opposed discharge branch connection, the latter should not be connected to the stack within a vertical height of 200mm below the larger branch, (see Figure 18). Where this cannot be achieved, a parallel branch can be used, (see Figure 16), or a proprietary 'Collar Boss' could be used, (see Figure 19).

Figure 15 Example of permitted stack connection for small diameter branch pipes



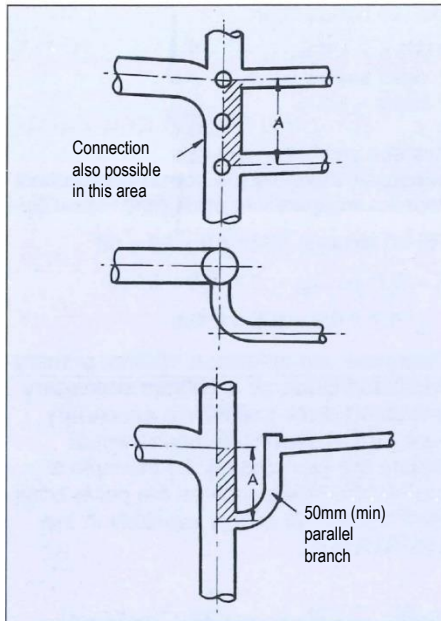


Figure 16 Example of permitted stack connections for adjacent small & large diameter branch pipes

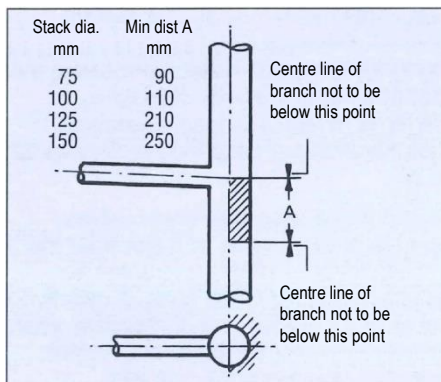


Figure 17 Restricted stack connections for small diameter branch pipes

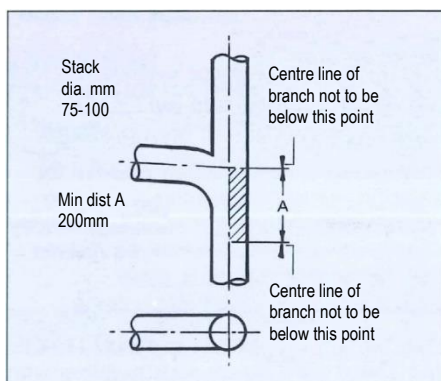


Figure 18 Restricted stack connections for adjacent small & large diameter branch pipes

Collar Boss' system

The 'Collar Boss' (see Figure 19) was specifically designed to overcome the installation difficulty imposed by the 200mm restricted zone, and to allow multiple low level discharge pipes to be connected to the stack above floor level. The boss inlets can be adapted for 32, 40 and 50mm connections. Crossflow is prevented as the annular chamber protects the small diameter connections from the WC discharge, allowing wastewater to flow freely and merge below the critical zone.

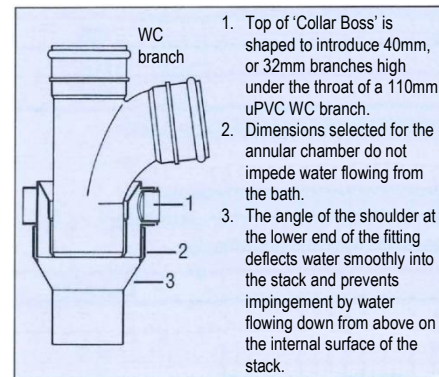


Figure 19 'Collar Boss' fitting

Ventilating pipes

The purpose of ventilating pipes is to maintain equilibrium of pressure within the sanitary discharge system, and thus prevent the depletion of trap seals by siphonage, or compression. They should be connected to the discharge pipe no further than 750mm from the trap, (see Figure 20). They should be provided with a continuous back fall towards the branch discharge connection pipe, in order to prevent any trapped condensation interfering with the free air movement. Alternatively, a 'loop vent' arrangement could be used (see Figure 21), and the ventilating pipe sloped downwards towards the ventilating stack.

Except where forming a secondary ventilated system, or used for offset venting, pipes should have a bore of not less than 25mm, but if longer than 15m or include more than 5 bends, the pipe size should be increased to 32mm. To reduce the risk of blockage, vent pipe connections to WC branches should be not less than 50mm and extend upwards not less than 50mm above the spill over level of the WC pan before reducing in size.

The top end of a ventilating stack may connect to the discharge stack above the spill over level of the highest appliance, fitted with an air admittance valve, or extended outside the building to form a vent terminal.

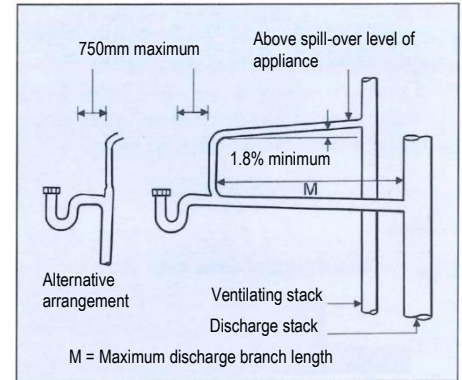


Figure 20 Branch ventilation

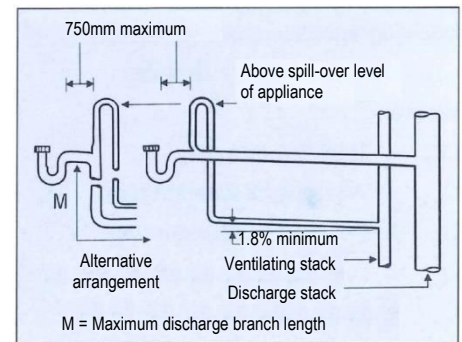


Figure 21 Branch 'Loop Vent'

Capacities of stacks

The maximum capacity of a discharge stack is normally limited to about one quarter full. The purpose of this is to allow space for a core of air within the centre of the stack, whilst the discharge falls downwards around the internal surface of the vertical pipe. The movement of air keeps pressure fluctuations to a minimum. The size of a discharge stack, and decision on whether a secondary ventilation stack is required depends on the peak design flow from the connected appliances.

Table 5 gives the discharge unit values (DU), in litres per second, for common appliances, and is valid for System III. The values for WC's are dependent on the design of the appliance, and the relevant manufacturer should be consulted. Where the type of WC is unknown at the design stage, or likely to change, the maximum rating should be assumed. The first task is to add up all the discharge units applicable to a discharge stack. Where a shower mixer is located over a bath, the shower should be ignored, and only the bath DU should be included in the total. Readers familiar with the 'domestic group unit' included in BS 5572 will notice that this approach has been discontinued. However, for most practical applications the method explained in this Section will yield similar results.

Not all sanitary appliances will be in simultaneous use. The peak design flow can be assessed by applying a frequency of use K factor (see Table 6) to the total sum of the discharge units, and by using the following equation:

$$Q_{ww} = K \sqrt{\sum DU}$$

Where:

Q_{ww} = Wastewater flow rate (l/s)

K = Frequency of use

$\sum DU$ = Sum of discharge units

Before the stack selection can be made, any other continuous or fixed flow must be added to the Q_{ww} value. The following equation explains further:

$$Q_{tot} = Q_{ww} + Q_c + Q_p$$

Where:

Q_{tot} = Total flowrate (l/s)

Q_{ww} = Wastewater flowrate (l/s)

Q_c = Continuous flowrate (l/s)

Q_p = Pumped flowrate (l/s)

Once the Q_{tot} value has been obtained, a decision about the stack size, and ventilation principle can be made by referring to Table 7 and 8. The pipe sizes relate to the pipe bores which have traditionally been used in the UK. The theoretical minimum bore for 50, 75, 100 and 150 sizes are 44, 75, 96, and 146mm respectively. Both Table 4 and 5 are based on 'swept entry' equal branches, which are required in the UK.

Table 5

Appliance	DU (L/s)
Wash basin or bidet	0.3
Shower without plug	0.4
Shower with plug	1.3
Single urinal with cistern	0.4
Slab urinal (per person)	0.2
Bath	1.3
Kitchen sink	1.3
Dishwasher (household)	0.2
Washing machine (6kg)	0.6
Washing machine (12kg)	1.2
WC with 6 l cistern	1.2 - 1.7
WC with 7.5 l cistern	1.4 - 1.8
WC with 9 l cistern	1.6 - 2.0

The Water Regulations & Byelaws in the UK do not allow the use of 7.5 or 9 litre WC flushing cisterns on new installations, the information is provided for use in connection with existing systems.

Table 6

Usage of appliances	K
Intermittent use, e.g. dwelling, guesthouse, office	0.5
Frequent use, e.g. hotel, restaurant, school, hospital	0.7
Congested use, e.g. toilets and/or showers open to the public	1.0
Special use, e.g. laboratory	1.2

Table 7 Maximum capacity of PRIMARY ventilated discharge stacks

Min. stack & vent I.D.	Litres/sec
75mm*	2.6
100mm	5.2
150mm	12.4

No WC's allowed on 75mm stacks

Table 8 Maximum capacity of SECONDARY ventilated discharge stacks

discharge stacks

Min. stack & vent I.D.		Litres/sec
Stack & vent	Vent	
75mm*	50mm	3.4
100mm	50mm	7.3
150mm	50mm	18.3

No WC's allowed on 75mm stacks

Example 1

Determine total design flowrate and stack requirements for an 11-storey block of apartments. Each stack will serve one apartment per floor, comprising of bathroom, en-suite shower room and fully fitted kitchen. DU per flat:

2 WC's x 1.7 =	3.4
2 wash basins x 0.3 =	0.6
1 bath =	1.3
1 shower =	0.4
1 kitchen sink =	1.3
1 washing machine =	0.6
1 dishwasher =	0.2
	7.8

Assume a primary ventilated stack is adequate; therefore, the bottom storey must connect separately to drain (see Figure 5).

For 10 storeys, $\sum DU: 7.8 \times 10 = 78$

$K = 0.5$, so $Q_{ww} = 0.5 \sqrt{78} = 4.42 \text{ l/s}$

Q_c & Q_p = zero, so $Q_{tot} = 4.42 \text{ l/s}$

From Table 7, a 100mm primary ventilated stack has a limit of 5.2 l/s, so this size is adequate. Secondary ventilation is not required.

Example 2

Determine total design flowrate and stack requirements for an 11-storey hotel. The stack will serve two en-suite bathrooms on each floor; there will be air conditioning units on the roof with a peak discharge of 0.2 l/s, and laundry equipment on the 5th floor with a peak discharge of 0.5 l/s.

DU per typical floor:

2 WC's x 1.7 =	3.4
2 wash basins x 0.3 =	0.6
2 baths x 1.3 =	2.6
	6.6

Assume a primary ventilated stack is adequate; therefore, the bottom storey must connect separately to drain (see Figure 5).

For 10 storeys, $\sum DU: 6.6 \times 10 = 66$

$K = 0.7$, so $Q_{ww} = 0.7 \sqrt{66} = 5.7 \text{ l/s}$

$Q_{tot}: 5.7 + 0.2 + 0.5 = 6.4 \text{ l/s}$

There are two options: a 150mm primary ventilated stack, or a 100mm secondary ventilated stack and 50mm secondary vent. Practical considerations would dictate the best choice, for example a proprietary fitting such as the collar boss (see Figure 19) is only available in the 100mm size.

Self-sealing waste valves

The recent introduction to the plumbing market of waste valves to replace the water seal trap offers the installer an opportunity to reconsider his system design, often reducing the amount of pipework required, whilst still meeting the mandatory requirement of Building Regulation ADH.1. These valves and their function are described in Figures 22 to 26.

As the name suggests, these valves open to allow the flow of water from the appliance, or to allow air to enter the pipework system in the case of negative pressure, then closes automatically when the flow stops, or the pipework system pressure reaches equilibrium with atmosphere.

This means that a system fitted with valves in place of water seal traps would be self-ventilating.

The valves are designed to open between 3 and 6mb and will remain sealed against 400+mb back pressure.

These valves are particularly useful for situations where water seals would be lost by evaporation - for example, holiday homes, condensate drains from chillers and air conditioning units. (See manufacturers' detailed instructions.)

The valves are available in 32mm (1¼") and 40mm (1½") body size, together with 87½° knuckle elbow and running adaptor. Universal compression outlets are used for making connections to either push fit BS 5254 or solvent weld BS 5255 waste systems.

Testing of waste valves

Because these devices do not depend on a water seal in a trap, many of the guidelines related to prevention of seal loss contained in the previous pages need not be applied, typically:

- Performance testing for retention of water seal on applications fitted with the valve is of course irrelevant.
- Performance test for WC water seal retention should be carried out.
- Soundness testing - First flush the appliances to ensure free flow of water through the valves and clearance of possible site debris, then carry out a 38mm (50mm Scotland) water test.

Standards

As these valves are not covered by British Standards, it is important that they carry performance certification by a third-party approvals body acceptable to Building Regulations, e.g., WIMLAS or BBA.

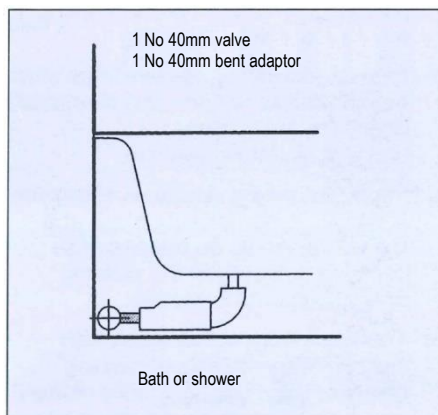


Figure 22 Bath or shower

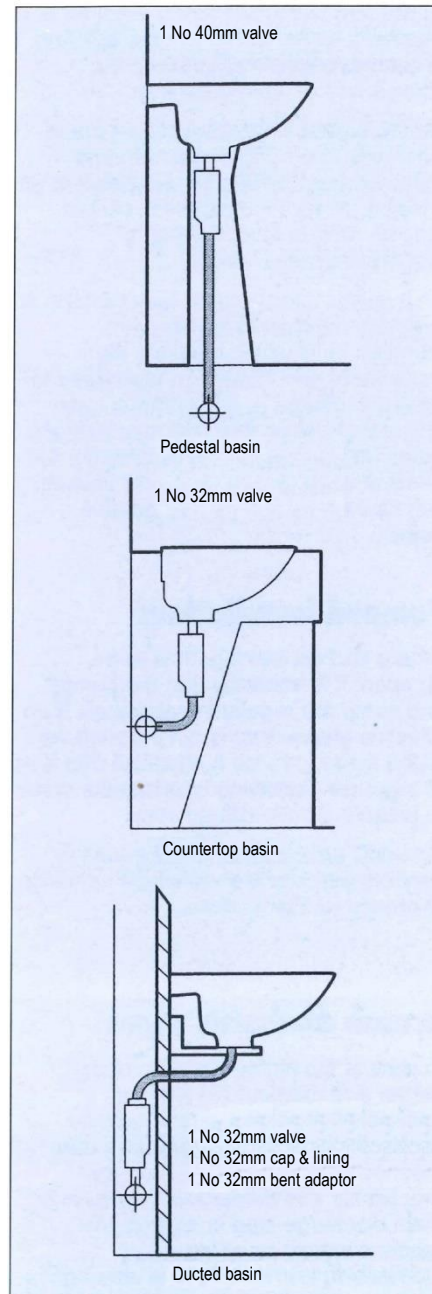


Figure 24 Single wash basin

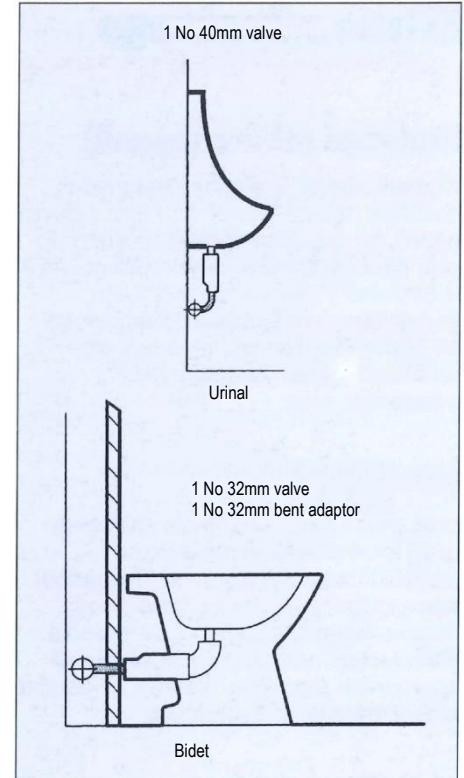


Figure 25 Urinal & bidet

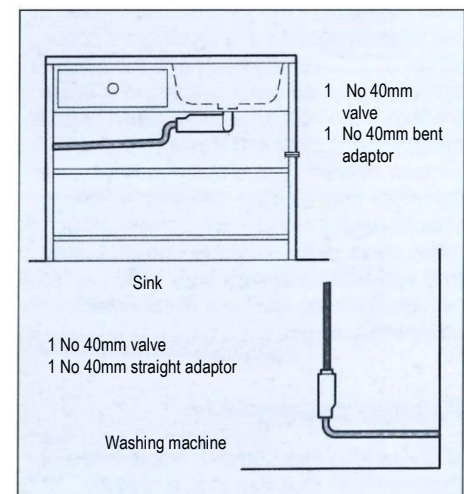
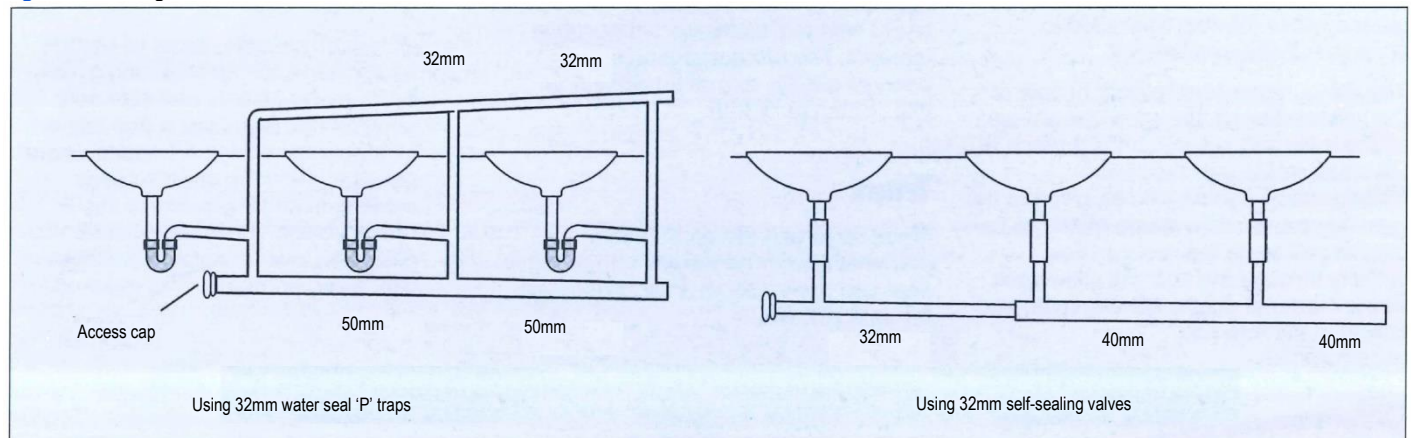


Figure 26 Sink & washing machine

Figure 23 A range of wash basins



Kitchen Drainage

Drainage (above ground)

Kitchens are of necessity, designed to ensure a natural flow of work and seldom permit the grouping of the appliances to give the best conditions of drainage. As it is of primary importance that there should be no loss of water seal in traps on kitchen appliances, an adequate ventilated system of drainage is necessary.

Materials

Only smooth bore materials should be used for any system of drainage pipework but particular care is required when selecting materials for drainage from restaurant kitchens. It is essential that pipework should be robust and, in appropriate situations, suitable to receive high temperature discharges.

Backflow problems

Backflow can occur and manifest itself in the kitchen system if a blockage occurs downstream at a point where the kitchen system joins the main system in a large complex or if effluents pass down stacks from floors above and through the kitchen system. It is recommended therefore that kitchen drainage systems should not be closely linked with those of other parts of the building complex and that separate drainage stacks be provided where kitchens are located other than on ground floors.

Grease separators

The Building Regulations Approved Document H requires that a grease separator is provided for kitchens in commercial hot food premises. The grease separator (or grease trap) should be designed and located to promote cooling, coagulation and retention of the grease within the trap and sized to achieve maximum efficiency. The temperature and velocity of flow of the wastewater should allow the grease to separate and collect on the surface of the water in the trap reservoir. Consideration should also be given to the general nature of the waste matter to be discharged since the reduced flow velocity through the trap will allow solid waste matter in suspension to settle and collect in the trap reservoir. Provision should be made to facilitate the hygienic removal and disposal of the grease. Provision should also be made for the trap to be completely emptied and cleaned periodically to limit the build-up of settled matter which inhibits the effectiveness of the grease trap.

Ideally, grease traps should be located externally and siting of grease traps within kitchens should be avoided if at all possible. In no circumstances should they be sited in food storage or preparation areas.

An hygienic alternative to grease traps is a grease removal unit. These are retention units which maintain the wastewater at sufficient temperatures to allow the grease to rise to the surface and remain liquid. The unit automatically skims off the grease into a container for removal and recycling. Strainer baskets can be included to retain vegetable matter.

Pumped installations

Where kitchen drainage has to be pumped, it is essential that the pumps and sump are regularly maintained. If an effective grease trap is not installed prior to the sump, provide a chemical drip feed of a grease dissolving type into the sump to prevent grease coagulating. Similarly, coating of any electrodes or controls with silicone will inhibit adhesion of grease to their surface.

Branch discharge pipes

In view of the high proportion of solid matter and grease from kitchen appliances, 'flat' gradients should be avoided. Branch discharge pipes from macerators should be as short as practicable and connected directly to a main discharge pipe or stacks. The gradient should be at least $7\frac{1}{2}^{\circ}$ (135mm/m) to the horizontal although steeper gradients are advisable, and any bends should be of a large radius. It is an advantage if other appliances can be connected to the discharge pipe upstream of the macerator connection, to assist with the discharge of the waste material. The discharge pipe should connect directly to a drain without an intervening gully trap.

Traps

Traps up to and including 50mm diameter should be tubular with a 75mm seal and preferably of a two piece type for easy access.

Access

Access points should be above spill-over level of the appliances at risk and located in positions permitting effective use without nuisance.

Floor drainage

Floor channels, open gullies and gratings in kitchens, food preparation and wash-up rooms harbour dirt and grease and if not properly fitted can be hazardous to pedestrian traffic. This form of drainage is unhygienic and should be avoided. However, an open top gully with sediment bucket should be provided for discharge from mobile sinks where these are to be used in vegetable preparation areas.

Specific requirements

- a. Drain-off valves on food containers should be of the full way plug-cock type with quick release bodies for easy cleaning. These valves must not be connected to a common waste pipe or drain without an intervening air break.
- b. Sinks and washing up machines must be individually trapped and connected directly to the building drainage/plumbing system.
- c. Vegetable paring machines should be fitted with a waste dilution unit and the waste should be trapped and connected directly to the building drainage/plumbing system.
- d. The pipes from appliances which discharge wastewater containing heavy concentrations of solid matter, e.g. vegetable paring machines and waste disposal macerators, should not be connected to the head of long runs of horizontal waste pipes. They should be connected as close as is practicable to the main drain or discharge stack so as to gain the maximum flushing advantage from appliances with high wastewater discharge rates.
- e. Where practicable, items of kitchen equipment such as steaming ovens, bains marie, boilers and cafe sets should discharge over a drip tray or fixed tundish having a trapped waste pipe connected to the discharge system. In situations where this is impracticable, the waste should discharge over a suitable container which can be emptied as required.

- f. Boiling pans should be drained separately over removable tundishes into trapped gullies. The trapped gully should be fitted with a solid hinged flap set flush with the floor and kept closed when not in use.

Laboratory drainage

General

At the outset of any design of a laboratory waste system it is imperative to ascertain and receive written confirmation from the client as to the type and probable quantities of effluents that will be discharged. It is also important to know whether any allowance for future alterations or extensions is to be made.

Design of stack layout

There is divided opinion of the relative advantages and disadvantages of either horizontal or vertical stack layout but the latter is to be preferred for discharge systems and will generally permit a large degree of planning flexibility.

Vertical distribution is ideal for laboratory premises with repetitive planning on successive floors and also when dealing with alterations, as their effect is invariably confined to the laboratory concerned.

Replacement

Due to the nature of discharges from laboratories, despite the fact that the best material for the job should be selected, the life expectancy may well be less than for ordinary discharge systems. The design must therefore take into consideration ease of replacement.

Dilution

The greater the dilution of laboratory waste obtained, the better, so as to minimise possible damage to final drains and sewers. Dilution may be achieved by individual dilution recovery traps (catchpots), by similar fittings serving groups of appliances or by dilution chambers constructed below ground level as part of the drainage system.

Incompatible wastes

The designer should always bear in mind that chemical wastes may be incompatible e.g. chemicals each producing few problems on their own, but which, if combined in a common branch discharge pipe, may have a tendency to gel or produce an undesirable chemical effect and therefore will need to be kept separate until sufficient dilution has occurred in the system.

As a general rule it is preferable for each laboratory to have its own connection(s) to the main stack(s), and not to combine wastes by continuous branch discharge pipes passing through a number of laboratories. Obviously this will be easier where vertical stack layout has been adopted. For most practical purposes, once the wastes discharge into a main stack, sufficient dilution will occur, but each instance must be considered on its own merits.

Sanitary/laboratory appliances should be easy to clean. Discharge pipes must be sealed throughout their run to the sewer which should be as short as possible.

The routing of pipes must take into account areas which might be put in hazard by leakage, and should be freely accessible for inspection and repair. A secondary system of containment may be considered necessary.

Radioactive pipe runs must be labelled at points of access.

The designer should consult the user about the pattern of usage and monitoring procedures. Any small or intermittent radioactive discharges should be well flushed out to main drainage, by other flow and allowed to dry out along the pipe line. The character of any added discharge should however be taken into account, particularly to avoid the risk of blockage; discharges carrying a high proportion of paper or macerated materials should be kept separate. If a holding tank is installed for monitoring purposes, matter likely to turn septic must be excluded.

Materials for above ground drainage systems

General

For a well designed above ground drainage system it is essential to have considerable knowledge of the materials that are available and their fixing and jointing techniques.

Types of materials

- a. Cast iron
- b. Copper
- c. Galvanised steel
- d. ABS (Acrylonitrile butadiene styrene)
- e. FIDPE (High density polyethylene)
- f. MUPVC (Modified unplasticized polyvinyl chloride)
- g. UPVC (Unplasticized polyvinyl chloride)
- h. PP (Polypropylene)
- i. Borosilicate glass (primarily for laboratory waste)
- j. Heavy duty polyethylene (primarily for laboratory use)
- k. Heavy duty polypropylene (primarily for laboratory use).

Selection

When designing a laboratory drainage system the following factors require consideration:

- a. The type, quantity, dilution strength, and temperature of chemicals, also the disposal position
- b. Whether the effluent may be conveyed direct to the sewer, or whether treatment is required
- c. Whether the pipe material and pipe jointing method can withstand the chemicals and/or temperature involved
- d. Whether the pipe jointing process requires any specialist knowledge or equipment
- e. Ease of future alteration and repair.
- f. Properties of piping, e.g. expansion, flammability, weight, etc.
- g. Cost and availability of any nonstandard products.

NOTES:

When considering the chemical effects on any piping, it is advisable to seek written confirmation from the manufacturer. For plastics and rubber seal rings, ISO/TR 10358 and ISO/TR 7620 may be consulted respectively.

Inspection and testing of discharge pipes

Work should be inspected and tested during installation; care being taken that all work which is to be concealed is tested before it is finally enclosed. Final tests should be applied on completion of the installation both for soundness and performance. Normally, the air test is used for soundness, but if the water test is applied, it should be used only up to the level of the lowest sanitary appliance connected to the system, and then only in new systems.

When testing old systems, it may be necessary to limit the pressure applied because of shallow trap seals; the water test should not be used. Any defects revealed by the test should be made good and the test repeated until a satisfactory result is obtained.

Reference should be made to Local Authority and other enforcing authority requirements, particularly where pipework passes through areas where blockages and leaks cannot be detected. In general, sufficient access should be provided to enable complete systems to be tested.

Access points should be carefully sited to allow the entry of cleaning and testing equipment and consideration also be given to adjacent services. Traps and joints that are easily disconnected can be an advantage so additional access is required only under exceptional circumstances.

The discharge from urinals can give rise to heavy deposits, especially in hard water areas. Regular maintenance is therefore required, and access should be provided so that all parts of the stack, branch, discharge pipe and trap can be readily cleaned. Where the vertical discharge pipe has a long connection to a manhole, access should be provided at ground floor near the foot of the stack.

In multi-storey domestic buildings, access should be provided at 3 storey intervals or less. In public and commercial buildings and more complex drainage systems, access should be provided at each floor level.

Air test

An air test should apply a pressure equal to 3.8mbar (38mm) water gauge and should remain constant for a period of not less than three minutes. The water seals of all sanitary appliances which are installed should be fully charged and a test plug inserted into open ends of the pipework to be tested, each plug being sealed with a small quantity of water. One testing plug should be fitted with a tee-piece, with a valve on each branch, one branch being connected by a flexible tube to a manometer.

Table 9 Number of sanitary appliances to be discharged for performance testing

Type of use	Number of appliances of each kind on the stack	Number of appliances to be discharged simultaneously		
		WC	Wash basin	Kitchen sink
Domestic	1 to 9	1	1	1
	10 to 24	1	1	2
	25 to 35	1	2	3
	36 to 50	2	2	3
	51 to 65	2	2	4
Commercial or public	1 to 9	1	1	-
	10 to 18	1	2	-
	19 to 26	2	2	-
	27 to 32	2	3	-
	53 to 78	3	4	-
	79 to 100	3	5	-
Congested	1 to 4	1	1	-
	5 to 9	1	2	-
	10 to 13	2	2	-
	14 to 26	2	3	-
	27 to 39	3	4	-
	40 to 50	3	5	-
	51 to 55	4	5	-
	56 to 7	4	6	-
	71 to 78	4	7	-
	79 to 90	5	7	-
	91 to 100	5	8	-

These figures are based on a criterion of satisfactory service of 99%. In practice, for systems serving mixed appliances, this slightly overestimates the probable hydraulic loading. The flow load from urinals, spray tap basins and showers is usually small in most mixed systems, hence these appliances need not normally be discharged.

To apply the test, air is introduced into the system through the other branch of the tee-piece until the desired pressure is shown on the manometer scale. Alternatively, the pressure may be applied by passing a flexible tube from a tee-piece attached to a manometer through the water seal of the trap of a sanitary appliance, the test then being carried out as previously described.

Defects revealed by an air test may be located by the following:

- Soap solution can be applied to the pipes and joints, under test, leakage can be detected by the formation of bubbles.
- A smoke producing machine may be used which will introduce smoke under pressure into the defective pipework. Leakage can be observed as the smoke escapes. Smoke producing equipment should not be used where plastic piping has been installed.
- A proprietary aerosol leak detection spray. Leakage can be detected by foaming.

Performance of testing systems

In addition to a test for air or watertightness, every discharge pipe installation should be tested for stability of the trap seals on the system. When subjected to the appropriate discharge tests, every trap must retain not less than 25mm of water seal. Each test should be repeated three times, traps being recharged before each test and the maximum loss of seal in any one test should be taken as the significant result.

To test for the effect of self-siphonage, waste appliances should be filled to overflowing level and discharged in the normal way. The seal remaining in the trap should be measured when the discharge is finished.

To test for the effects of probable maximum simultaneous discharges of sanitary appliances, the number of appliances to be discharged together is given in Table 9. For the purpose of this test, baths are ignored as their use is spread over a period and they do not normally add materially to the peak flow.

Where a stack services baths only, the number to be discharged simultaneously in a test should be the same as for sinks. The worst conditions occur when appliances on the upper floors are discharged. A reasonable test therefore is to discharge up to one WC, one basin and one sink from the top floor of the building with any other appliances to be discharged on the floor immediately below.

Methods of waste collection

1. Refuse chutes provide an economic solution in multi-storey and similar type buildings. Adequate precautions must be taken to prevent entry of rodents into the bin storage area and also to minimise the entry of flies.
2. Kitchen waste disposal units are a means of disposal of food waste and for commercial and industrial use. It is advisable to consult specialist suppliers.
3. Sanitary towel disposal can be carried out by incineration, maceration or by collecting bins for storing and bulk disposal.
4. Owing to its varied nature, hospital refuse should be disposed of by maceration (near as possible to the disposal source) or by incineration.
5. Compression systems are available which reduce the volume to between 1/3rd to 1/12th.
6. Composting refuse in agricultural areas is considered the most economic method of disposal. Refuse collection and disposal methods used should be determined in consultation with the Local Authority.

Sanitary accommodation

1. The planning in most instances is performed by the Architect, who should be advised of special requirements and where an alteration to the layout, within structural limitations, can affect economies and performance.
2. Hand drying facilities can either be
 - i. disposable paper
 - ii. roller towel
 - iii. warm air electric.
3. Soap solution dispensers, fed from local reservoirs provide a ready alternative to the provision of bar soap.
4. Hand rinse basins have found a ready use in general toilet accommodation. Operation other than by hand can lead to removal of taps completely from basins and this can lead to a reduction of cross-infection.
5. Spray mixer taps produce savings in water consumption, economies in pipework and fuel costs. However, in some hard water areas the spray nozzles rapidly become blocked with lime scale and in some soft water areas, gelling of soap residues occurs in branch discharge pipes. The additional maintenance costs may outweigh any savings made in water and fuel costs.
6. The use of wall hung or concealed outlet type WC pans makes for easier cleaning.

7. Automatic water flow for hand washing, flushing etc. can be achieved (i) hydraulically (ii) pneumatically (iii) electrically.

Reference should also be made to BS 6465: Part 1.

Table 10 Dwellings

Type of dwelling	Appliances	Number per dwelling	Remarks
Dwellings on one level e.g. bungalows & flats	WC	1 for up to 5 persons 2 for 6 or more	Except for single persons accommodation, where 1 WC is provided, the WC should be in a separate compartment. Where 2 WC's are provided, 1 may be in the bathroom
	Bath/shower	1	
	Wash basin	1	
	Sink	1	
Dwellings on one or more levels e.g. houses and maisonettes	WC	1 for up to 4 persons 2 for 5 or more	Except for single persons accommodation, where 1 WC is provided, the WC should be in a separate compartment. Where 2 WC's are provided, 1 may be in the bathroom.
	Bath/shower	1	
	Wash basin	1	
	Sink	1	

NOTE 1 Where en-suite facilities are provided there should be additional provision of toilets for visitors & staff.

Table 11 Accommodation for elderly people and sheltered accommodation

Type of accommodation	Appliances	Number per dwelling	Remarks
Self-contained for 1 or 2 elderly persons, or grouped apartments for 2 less-active elderly persons	wc	1	An additional WC May be provided in the bathroom.
	Bath/shower	1	
	Wash basin	1	
	Sink	1	
Grouped apartments for less-active elderly persons	WC	1	
	Wash basin	1	
	Sink	1	
	Bath/shower	Not less than 1 per 4 apartments	Some may be Sitz baths or level access showers
Additional provisions for communal facilities			
Common room for self-contained or grouped	WC	1	Minimum number required. Should be available for use by Visitors.
	Wash basin	1	
The pan try or kitchen for self-contained or grouped apartments	Sink	1	Adjacent to common room
Laundry room for grouped apartment schemes	Sink	1	
	Washing machine	1	
	Tumble drier	1	
Cleaner's room	Bucket/cleaner's sink		1 in each cleaner's room

NOTE 1 Many persons using this type of accommodation may have disabilities therefore the layout of rooms, approaches and accesses should be capable of being used by disabled persons.

Table 12 Residential homes and nursing homes for elderly people. Type of accommodation

Type of accommodation	Appliances	Number recommended	Remarks
Residents	WC	1 per 4 persons	An adjacent wash basin is also required
	Bath	1 per 10 persons ¹	
	Wash basin	1 to each bedsitting room	
Staff	WC	At least 2 for non-residential staff ²	
	Wash basin	1	In WC compartment
Visitors	WC	1	
	Wash basin	1	In WC compartment
Kitchen	Sink	As appropriate	
Cleaner's room	Bucket/cleaner's sink	1	In each cleaner's room
Other	Bed pan cleaning/disposal	As appropriate	Service area
	Wash basin	1	In each medical room, hairdressing, chiropodist, non-residential staff toilets and kitchen areas.

NOTE 1 Where en-suite facilities are provided, toilets for visitors and staff should also be provided.

NOTE 2 Attention is drawn to the Workplace (health, Safety and Welfare) Regulations.

NOTE 3 Attention is drawn to the Department of Health and Social Security Local Authority Building Note No. 2 and the National Assistance Regulations 1962.

¹ Sitz baths with hand showers (not fixed overhead) and/or shower units suitable for use by residents in wheelchairs or sani-chairs, may be suitable alternatives. The number may vary in different parts of the country.

² Where residential accommodation is provided for staff, sanitary appliances should be in accordance with table 11

Table 13 Staff toilets in offices, shops, factories and other non-domestic premises used as place of work

Sanitary appliances for any group of staff

Number of persons at work	Number of WC's	Number of washing stations
1 to 5	1	1
6 to 25	2	2
26 to 50	3	3
51 to 75	4	4
76 to 100	5	5
Above 100	One additional WC and washing station for every unit or fraction of a unit of 25 persons	

Alternative scale of provision of sanitary appliances for use by male staff only

Number of men at work	Number of WC's	Number of urinals
1 to 15	1	1
16 to 30	2	1
31 to 45	2	2
46 to 60	3	2
61 to 75	3	3
76 to 90	4	3
92 to 100	4	4
Above 100	One additional WC for every unit or fraction of a unit of 50 men provided at least an equal number of additional urinals are provided.	

NOTE 1 Where work activities result in the heavy soiling of hands and forearms washing stations should be provided for staff as follows:

1 per 10 people at work (or fraction of 10) up to 50 people
1 additional washing station for every further 20 people (or fraction of 20)

NOTE 2 For facilities for disabled workers and visitors, attention is drawn to the building regulations

NOTE 3 Where sanitary conveniences provided for staff are also used by the public the number of conveniences specified should be increased by at least one, for each sex as necessary to ensure that staff can use the facilities without undue delay

NOTE 4 In certain situations where security necessitates separate provision for visitors, this should be sited in or adjacent to the public area.

Table 14 Facilities for customers in shops and shopping malls

Sales area of shop	Appliances	Male	Female
1000m ² to 2000m ²	WC	1	2
	Urinal	1	Nil
	Wash basin	1	2
Toilet for disabled people 1			
2001m ² to 4000m ²	WC	1	4
	Urinal	2	Nil
	Wash basin	2	4
Toilet for disabled people 1			
Greater than 4000m ²	In proportion to the size of the net sales area		

NOTE 1 This table of recommendation scale of provision for customers applies to shops having a net sales area in excess of 1000m²

NOTE 2 In this table it has been assumed that the customers will be 50% male and 50% female. For different proportions the accommodation levels will have to be adjusted proportionally.

NOTE 3 For shopping malls the sum of the floor areas of the shops should be calculated and used with the above table.

Table 15 Schools

Type of school	Appliances	Number recommended	Remarks
Special	Fittings	1/10 of the number of pupils rounded up to the next nearest whole number	
	WC only	Girls: all fittings	
	Urinals and WC	Boys: not more than 2/3 of fittings should be urinals	
	Wash basin	As for secondary school	
	Shower	Although not required by statute, it is suggested that sufficient showers should be provided for physical education	
	Bucket/cleaner's sink/slop hopper	At least one per floor	
Primary	Fittings	Aggregate of 1/10 of the number of pupils under 5 years old and 1/20 of the number of others. Not less than 4. Rounded up to the nearest whole number	
	WC only	Girls: All fittings	
	Urinal and WC	Boys: not more than 2/3 of fittings should be urinals	
	Wash basin	As for secondary school	
	Shower	Although not required by statute, it is suggested that sufficient showers should be provided for physical education	
	Bucket/cleaner's sink/slop hopper	At least one per floor	
Secondary	Fittings	1/20 of the number of pupils. Not less than 4. Rounded up to the nearest whole number	
	WC only	Girls: All fittings	
	Wash basin	1 in each washroom. At least 2 basins per 3 fittings	
	Shower	As for primary school	
	Bucket/cleaner's sink/slop hopper	At least one per floor	
Nursery and play	WC	1 per 10 pupils (not less than 4)	
	Wash basins	1 per WC	
	Sink	1 per 40 pupils	
Boarding	WC	1 per 5 boarding pupils	Where sanitary accommodation for day pupils is accessible to and suitable for the needs of boarders, these requirements may be reduced to such an extent as may be approved in each case.
	Wash basin	1 per 3 pupils for the first 60 boarding pupils: 1 per 4 pupils for the next 40 boarding pupils; 1 for every additional 5 boarding pupils;	
	Bath	1 per 10 boarding pupils	
	Shower	May be provided as alternative to not more than 1/3 of the minimum number of baths	

NOTE 1 For the purpose of this table 'fittings' is the sum of WC's and urinals.

NOTE 2 Attention is drawn to the Workplace (Health, Safety and Welfare) Regulations 1992.

NOTE 3 Attention is drawn to the need for facilities for the disposal of sanitary dressings.

NOTE 4 For educational establishments not mentioned above, advice should be sought for the Department of Education

NOTE 5 For Scotland attention is drawn to the School Premises (Scotland) Regulations 1967, 1973 and 1979

NOTE 6 For Northern Ireland attention is drawn to the statutory requirements of the Department of Education (Northern Ireland).

NOTE 7 Attention is drawn to the Education (School Premises) Regulations, 1981 and 1989, upon which this table is based

NOTE 8 Changing accommodation and showers should be provided for staff engaged in PE where pupils have achieved the age of 8 years.

NOTE 9 Medical accommodation should be provided centrally in all schools, to include a wash basin sited near to a WC. For boarding schools, attention is drawn to the Education (School Premises) Regulations 1981 and 1989.

NOTE 10 For toilets for disabled people attention is drawn to the Department of the Environment Design Note 18 1984 (12)

Table 16 Buildings used for public entertainment

Appliances	Males	Females
WC	In single-screen cinemas, theatres, concert halls and similar premises without licensed bars: 1 for up to 250 males plus 1 for every additional 500 males or part thereof	For single-screen cinemas, theatres, concert halls and similar premises without licensed bars: 2 for up to 40 females 3 for 41 to 70 females 4 for 71 to 100 females plus 1 for every additional 40 females or part thereof
Urinal	In single-screen cinemas, theatres, concert halls and similar premises without licensed bars: 2 for up to 100 males plus 1 for every additional 80 males or part thereof	
Wash basins	1 per WC and in addition 1 per 5 urinals or part thereof	1, plus 1 per 2 WCs or part thereof
Bucket/cleaner's sink	Adequate provision should be made for cleaning facilities including at least one cleaner's sink	

NOTE 1 In the absence of more reliable information it should be assumed that the audience will be 50% male and 50% female

NOTE 2 In cinema-multiplexes and similar premises where the use of facilities will be spread through the opening hours the level of provision should normally be based upon 75% of total capacity and the assumption of equal proportions of male and female customers. (For single-screen cinema 100% occupancy is assumed).

NOTE 3 Where buildings for public entertainment have licensed bars, facilities should also be provided in accordance with Table 19, based upon the capacity of the bar(s) and assuming equal proportions of male and female customers.

NOTE 4 Attention is drawn to the necessity to provide facilities for the disposal of sanitary dressings.

NOTE 5 Attention is drawn to the Workplace (Health, Safety and Welfare) Regulations 1992.

Table 17 Hotels

Type of accommodation	Appliances/facilities	Number required	Remarks
Hotel with en-suite Accommodation	En-suite	1 per residential guest bedroom	Containing bath/shower, WC and wash basin
	Staff bathroom	1 per 9 residential staff	
	Bucket/cleaners' sink	1 per 30 bedrooms	At least 1 on every floor
Hotels and guest houses without en-suite accommodation	WC	1 per 9 guests	
	Wash basin	1 per bedroom	
	Bathroom	1 per 9 guests	Containing: Bath/shower, wash basin and additional WC
	Bucket/cleaners' sink	1 per floor	
Tourist hostels	WC	1 per 9 guests	
	Wash basin	1 per bedroom or 1 for every 9 guests in a dormitory	
	Bathroom	1 per 9 guests	Containing bath/shower, wash basin and additional WC
	Bucket/cleaners' sink	1 per floor	

NOTE 1 For staff toilets attention is drawn to the Workplace (Health, Safety and Welfare) Regulations 1992.

NOTE 2 Attention is drawn to the necessity to provide facilities for the disposal of sanitary dressings.

NOTE 3 For provision of facilities associated with buildings used for public entertainment, restaurants and licensed bars see Tables 16, 18 and 19.

Table 18 Restaurants, cafes, canteens and fast food outlets

Appliances	For male customers	For female customers
WC	1 per 100 up to 400 males. For over 400 males, add at the rate of 1 per 250 males or part thereof	2 per 50 up to 200 females. For over 200, add at the rate of 1 per 100 females or part thereof
Urinal	1 per 50 males	
Wash basins	1 per WC and in addition 1 per 5 urinals or part thereof	1 per WC
Bucket/cleaner's sink	Adequate provision should be made for cleaning facilities including at least one cleaner's sink	

NOTE 1 In the absence of more reliable information it should be assumed that the customers will be 50% male and 50% female. **NOTE 2** Attention is drawn to the Workplace (Health, Safety and Welfare) Regulations 1992.

NOTE 3 Attention is drawn to the necessity to provide facilities for the disposal of sanitary dressings.

NOTE 4 For establishments with licensed bars see also Table 19.

Table 19 Public houses and licensed bars

Appliances	For male customers	For female customers
WC	1 for up to 150 males plus 2 for every additional 150 males or part thereof	1 for up to 12 females plus 1 for 13 to 30 females plus 1 for every additional 25 females or part thereof
Urinal	2 for up to 75 males plus 1 for every additional 75 males or part thereof	
Wash basins	1 per WC and in addition 1 per 5 urinals or part thereof	1 per 2 WC's
Bucket/cleaner's sink	Adequate provision should be made for cleaning facilities including at least one bucket/cleaner's sink	

NOTE 1 Occupancy should be calculated at the rate of 4 persons per 3m² of effective drinking area (EDA)

NOTE 2 In public houses a ratio of 3 male customers to 1 female customers may be assumed. In many other situations a ratio of 1 male to 1 female may be appropriate.

NOTE 3 For provision of toilets for employees and staff see table 13

NOTE 4 Public houses with restaurants should provide facilities as for licensed bars but restaurants should have additional separate toilets in accordance with table 18.

NOTE 5 Public houses with public music, singing and dancing licences should be as for licensed bars. The licensed area for public music, singing and dancing should be separated for calculation of occupancy and the provision of toilets should be in accordance with Table 16.

Table 20 Swimming pools

Appliances	For male bathers	For female bathers
WC	2 for up to 100 males plus 1 for every additional 100 males or part thereof	1 per 5 females for up to 50 females plus 1 for every additional 10 females or part thereof
Urinal	1 per 20 males	
Wash basins	1 per WC and in addition 1 per 5 urinals or part thereof	1, plus 1 per 2 WC's or part thereof
Shower	1 per 10 males	1 per 10 females

NOTE 1 Toilets should be provided for staff in accordance with table 13

NOTE 2 Toilets should be provided for spectators in accordance with table 16

NOTE 3 Attention is drawn to the need to provide facilities for the disposal of sanitary dressings

NOTE 4 In this table it has been assumed that the ratio of swimmers using the pool(s) will be 50% male and 50% female.

Tables 10-20 are extracts from BS 6465 Part 1: 1994 reproduced with the kind permission of BSI under licence number 2002SK/0140.

The design of building drainage systems

The scope of this section is to provide guidance for the design of foul and surface water systems constructed in the ground under and around buildings, together with some general commentary regarding larger drainage systems beyond those directly associated with a building development.

All drainage systems should be designed to be as simple and direct as possible. All vertical stacks should terminate with long radius bends, and changes in direction and gradient should be minimised and as easy as practicable. Access points should be provided only if blockages could not be cleared without them and drain runs between access points should be laid in straight lines, both in the horizontal and vertical planes. However, where it is unavoidable drains may be laid to slight curves in the horizontal plane, if these can still be cleared of blockages. All changes in gradient should be at an inspection chamber or manhole. The drain soffit should invariably be level, to facilitate ventilation of the system, thus minimising the problems associated with foul smells, gases and the creation of positive and negative pressures.

Historically, installation required that all manhole branch inverts should be joined level with the horizontal centreline of the mainstream drain. However, this is not relevant to one-piece chamber branches or chamber bases that are factory formed.

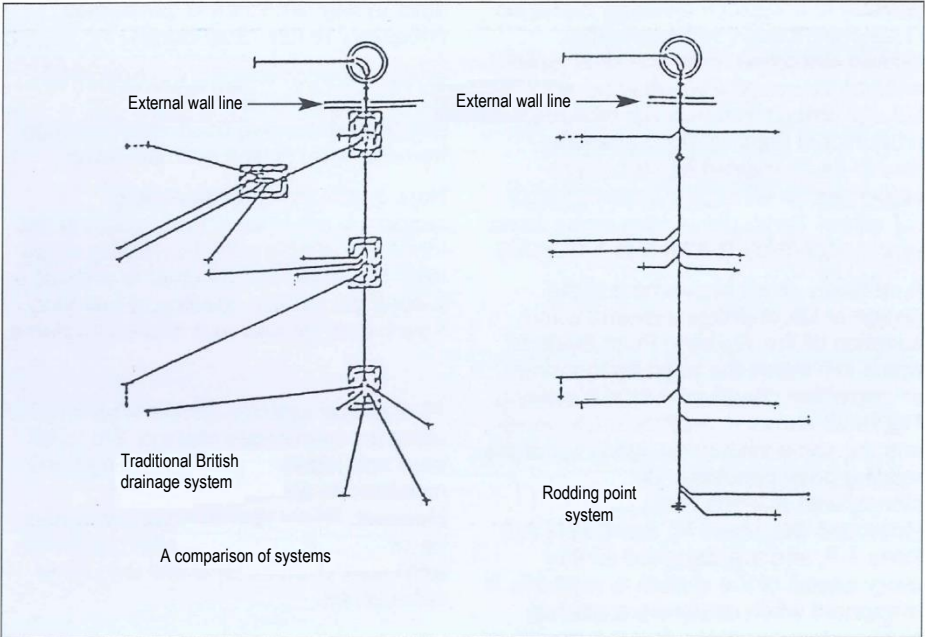
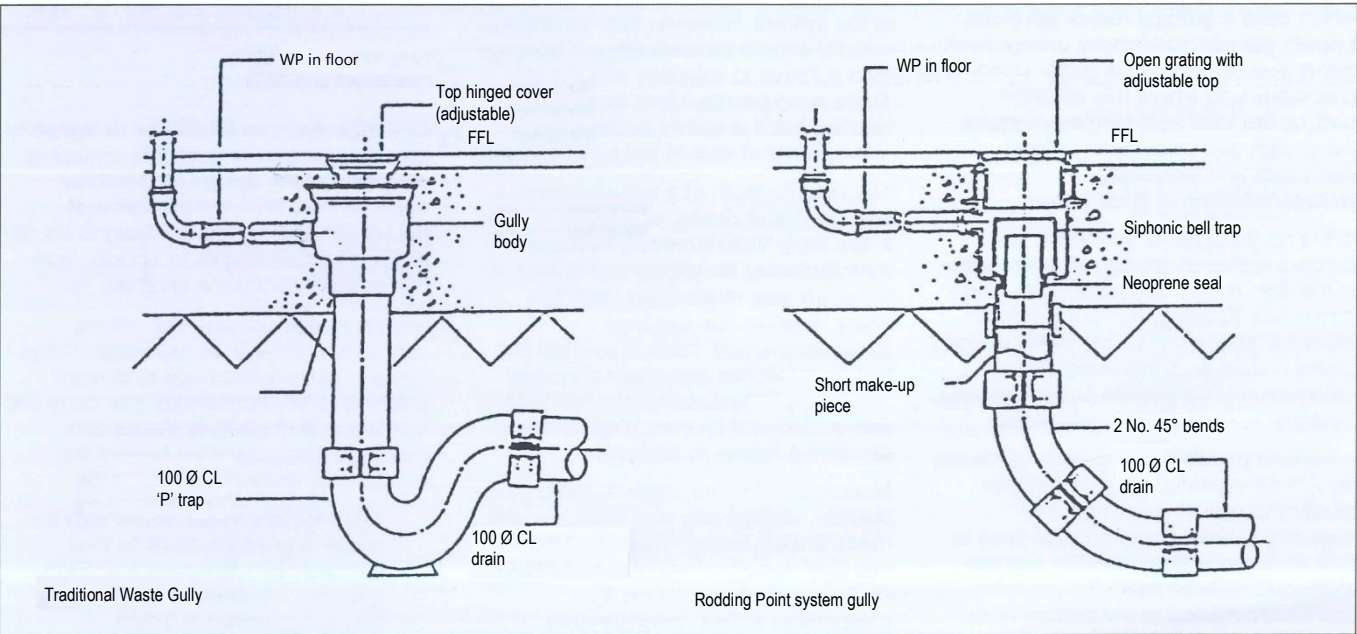


Figure 27 Rodding Point

Table 21 Maximum of access points

Distance to	From access fitting		From junction or branch (m)	From inspection (m)	From manhole (m)
	1 (m)	2 (m)			
Start of external drain	12	12	-	22	45
Rodding eye	22	22	22	45	45
Access fitting (1) min. 150mm x 100mm or 159mm dia	-	-	12	22	22
Access fitting (2) min. 225mm x 100mm	-	-	22	45	45
Inspection chamber	22	45	22	45	45
Manhole	22	45	45	45	90

Figure 28 Rodding Point Gully



Branches from individual gullies and sanitary appliances may be square, but any branch that may run more than a proportional depth of 0.3 (30% full) should be connected into the mainstream with a 45-degree baron bend or 3/4 slipper bend, plus a long radius bend where necessary to minimise turbulence.

A relatively new development in the design of UK drainage systems is the adoption of the 'Rodding Point System', which minimises the need for manholes or inspection chambers within a building. Figure 27 shows a 'traditional' UK design, and the same system designed using the rodding point principles. Both systems comply with Building Regulations (approved Document H) and BSEN 752 Parts 1-7, and are designed so that every aspect of the system is roddable. It is important when designing a rodding point system to ensure that the maximum spacings of access points as given in the Building Regulations (Approved Document H) and BSEN 752 Parts 1-7 are observed, and also that a roddable gully is used. Table 21 shows the maximum spacing of access points. Figure 28 shows a rodding point system gully against a traditional UK waste gully, which is not truly roddable. The rodding point system gully, commonly known as a syphon bell gully is becoming more commonly available within the UK from both European and British manufacturers.

All drainage systems should be designed to flow at a constant velocity. Where this cannot be achieved, the method of dealing with the problem will depend upon the capacity of the downstream receiving sewer under flood conditions.

Some sewers have spare capacity, in which case a gradual rise or fall in the system velocity is relatively unimportant. Some sewers surcharge under storm conditions and where this situation occurs, the local authority may require the design and installation of flow restrictors and temporary storage/retention of flood waters.

If it is not possible or economic to achieve sufficient storage of storm water in the drain system, then suitable areas for surface flooding, (for surface water drainage only) such as car parks or flood plains should be considered. For guidance on Sustainable Urban Drainage Systems, refer to CIRIA guidelines.

Wherever possible, steep drain gradients should be avoided. Most difficult site conditions can be overcome with backdrops, allow the horizontal drain to flow at an acceptable velocity and the increased velocity down the backdrop can be attenuated at the bottom of the drop. In hilly districts it is sometimes necessary to use ramp drains.

Under storm conditions, the bottom of the sloping drain may become surcharged causing flood water to issue from low level gullies and manholes.

Here again, flow restrictors and temporary retention of flood water at the top of the ramp/s plus the sealing of low-level manholes can be used to prevent or reduce the surface flooding of low-lying areas, both for new and existing systems.

All drainage systems should be designed using an appropriate method. For small sites and individual buildings long hand calculations are invariably used.

However, larger drainage schemes may be calculated using computer programs and cross checked by a few long hand calculations.

Pipe gradients

The maximum flow rate in a drain occurs at a proportional depth of 82 to 83%. Any rise in water level above this figure will cause increased frictional resistance, a hydraulic jump and a reduced flow rate, which will tend to maintain the full surcharge condition.

The maximum depth of flow for stormwater in estate drainage generally should not exceed 75%. This will allow for changes in site development, the ingress of ground water, and a margin to allow the free ventilation of the system and spare capacity for infrequent peak storms.

Gradients and velocities should be kept low or reduced over the total length, and this will tend to increase the drain sizes, volume and transitional capacity/storage of the system. However, any continuous velocity should theoretically not be lower than 0.75m/s to maintain self-cleansing. There is no practical limit to maximum velocity, but it is widely accepted that 3.6 metres/second should not be exceeded.

The popular myth of a self-cleansing velocity in foul drains, was arbitrarily set in the early Victorian era, when the manufacturing standards and quality of materials was much lower than it is today. National standards of workmanship and supervision had not been established and much drainage work was being done for the first time, with limited and less accurate hand calculated hydraulic formula.

Modern drainpipes, manufactured from plastics, vitrified clay and spun iron are made in long straight lengths. All have true and smooth bores, which provide a considerable improvement by comparison to their predecessors, manufactured prior to the 1950's.

This improvement in standards and quality allow drain gradients to be reduced whilst still maintaining an adequate velocity at the calculated depth of flow.

Discharges in branch drains are intermittent and normally start in the form of a short wave, close to the bottom of the stack or appliance, such as from a WC. As the wave travels down the branch drain, the initial vertical discharge energy is lost and the depth of flow flattens out, this attenuation occurs because at all normal gradients, the top of the wave travels faster than the water in contact with the invert, thus levelling out the flow. Unless there is a continuous discharge of water to maintain the hydraulic depth of flow, it is not possible to achieve a constant velocity. As the numbers of discharges from branches and buildings increase, so does the diversity of use. This, together with an extended time of travel, creates the average and peak dry weather flows found in the main public sewers.

Table 22 which is taken from the Approved Document H to the Building Regulations 2002 for England and Wales, shows a very simple way of sizing a scheme for small drainage systems, provided the maximum capacities are not exceeded.

Table 22 Recommended minimum gradients for foul drains

Peak flow (litres/sec)	Pipe size (mm)	Minimum gradient (1 in...)	Maximum capacity (litres/sec)
<1	75	1:40	4.1
	100	1:40	9.2
>1	75	1:80	2.8
	100	1:80*	6.3
	150	1:150 [§]	15.0

* Minimum of 1 WC

[§] Minimum of 5 WCs

Drainage systems should be designed to provide constant or gradually changing velocities at the design proportional depth of flow. With the exception of backdrops and ramps, all designs should avoid marked changes in velocity from one section of drain to another.

Branch drains carrying low volume intermittent flows from individual fittings and stacks should be laid to steeper gradients than main drains that carry the discharge from multiple stacks and buildings. The reasoning behind this approach is extended as follows:

1. Main surface water drains may be laid at a gradient equal to their diameter in millimetres e.g., 100% gradient = 300mm diameter drain laid at a gradient of 1:300.

Table 23

Diameter (mm)	Surface water drains		Foul drains	
	Main drain 100% gradient	Branch drain 50% gradient	Main drain 80% gradient	Branch drain 40% gradient
75	1:75	1:35	1:60	1:30
100	1:100	1:50	1:80	1:40
150	1:150	1:75	1:120	1:60
225	1:225	1:110	1:180	1:90
300	1:300	1:150	1:240	1:120

- alternatively, main foul drains may be laid at a gradient equal to 80% of their diameter, e.g., 300mm diameter, drain laid at a gradient of 1:240.
- Branch drains with low flow rates may be laid at 50% of their respective main drain gradients as follows in Table 23.

The above schedules are an example of what may be applied to a relatively flat site; other percentage values may be usefully applied to suit different site surface slopes.

Discharge units

The Water Regulations make provision for water savings in the UK particularly with WCs and urinals.

A number of other countries, such as the USA, Germany, Japan, Mexico, Africa, Asia and some Scandinavian countries have for some years, been using 3 and 4 litre low volume designs for matched pans and cisterns. The UK now has a maximum flush volume of 6 litres for any new WC suite. Metered water supplies are also required for all new connections and there is a general move towards compulsory metering for all premises as a result of the water shortages experienced in recent years.

The general trend in the volume of water used by appliances both in the UK and abroad has been downwards and it is now more important not to oversize foul drains.

The new less wasteful low volume flush designs will make it possible to utilise the capacity of existing drainage systems more efficiently and the demand for new sewerage treatment works may be reduced. The overall effect should make substantial savings to water supply, treatment and disposal.

Surface water flows

The method adopted for the assessment of the peak discharge flowrate of surface water from a building development will vary according to the area and type of development. For areas which require a main surface water drain up to 200m in length, a uniform rate of rainfall intensity may be adopted. A rate of 50mm/h is commonly used for such areas, but higher rates may be applicable in specific circumstances and reference should be made to BS EN 12056 in these cases.

The whole of the rainfall on impervious areas should be assumed to reach the drains. The impervious areas should include the horizontal projection of the roof areas, paved areas connected to the drainage system and half the area of the exposed vertical face of tower buildings. Unpaved areas are generally assumed not to contribute.

For larger areas when a design based on a uniform rate of rainfall intensity is not appropriate, the use of the 'Wallingford Rational' method for the design of storm sewers is recommended and reference should be made to BS EN 752 Parts 1-7 and BS EN 12056-3 for further guidance.

For surface water drains where larger quantities of grit are liable to be carried into the drain or sewer, the minimum velocity of flow should be 0.75m/s as for foul drains and sewers.

However, as a guide for systems where grit is not anticipated to be a problem, then an absolute minimum flow rate of 0.3m/s should be allowed for in order to avoid possible obstruction due to the build-up of solid matter not being carried along by the water, particularly at low depths of flow.

Drainage pipe sizing calculations

In calculating pipe sizes for drainage installations, it is essential to record in a clear and concise manner all factors which determine the selected pipe size for the section of the drainage installation under consideration. The calculations should be recorded in an orderly manner, so that arithmetical checks can be easily made at the completion of the pipe sizing exercise, to enable the implication of subsequent site variations to be assessed, and modifications to the drainage design made where necessary; and finally, to provide a source of design information for the designer or the building user, which can be filed for future reference.

Design information which it is necessary to record, includes gradients, maximum and minimum flow rates, velocities and depths of flow together with the invert levels at predetermined points.

Gravity flow pipe design charts

Charts for the design of circular pipes have been available from various sources for many years and have been used, with varying degrees of success to design pipes running part full under gravity. Graphs can overcome the difficulties encountered with the older style charts, making it possible to read velocity and flow rate directly from a single chart, for all depths of flow.

Theory

Each chart has been prepared for a particular combination of pipe diameter (D) and roughness (K) and is composed of two families of curves (S and Q) superimposed on a pair of orthogonal axes. The intersection of these curves represents the relationship between flow rate (Q), pipe gradient (S), proportional depth of flow (d/D) and flow velocity.

The Colebrook-White equation has been selected to represent gradient (S) curves because of its sound basis in both theory and experimentation.

$$V = -2\sqrt{(2gs\psi D)} \log \left[\frac{K_s}{3.7\psi D} + \frac{\sqrt{2.51\nu}}{\psi D\sqrt{(2gs\psi D)}} \right]$$

where ν = kinematic viscosity and g = gravitational acceleration

In this form of the equation, D has been modified by a correction factor (i)/ to account for depths of flow less than full. This factor is only dependent on the geometry of flow, and is defined in terms of the angle (θ) subtended at the pipe centre by the free water surface.

$$\psi^2 \frac{\theta - \sin \theta}{\theta} \quad \text{where} \quad \theta = 2 \cos^{-1} \left(\frac{1-2d}{D} \right)$$

The continuity equation forms the basis of the flow (Q-) curves which, when modified for gravity flow, can be written as:

$$v = \frac{8Q}{\sqrt{\theta} D^2}$$

Example 1

It is estimated that a new housing development will produce daily peak foul sewage flow of 521/sec. Determine the pipe size and minimum gradient required to carry this flow whilst ensuring that a velocity of 0.76m/sec is achieved and that a proportional depth of 0.75 is not exceeded. Site conditions dictate that the maximum grade available is 1:40 and the ground surface falls at 1:240. Confirm that a satisfactory velocity is also achieved before completion of the development when the flow is 10 l/sec.

Assume $K_s = 1.5\text{mm}$ Step 1

Select a design chart by choosing:

- A pipe roughness (e.g. $K_s = 1.5\text{mm}$) relevant to this application
- A pipe diameter (e.g. $D=250\text{mm}$) which can carry the design flow (Q). Q must lie within the range of flows on the right hand side of the chart.

Step 2

Sketch on the limiting factors:

- Minimum self-cleansing velocity (V) e.g. 0.76m/sec.
- Maximum proportional depth of flow (d/D) e.g. 0.75
- Maximum available fall (e.g. 1:40)
- Minimum available fall (e.g. 1:240).

This will define the allowable gradient 'window' (shown shaded in Graph 5) within which all combinations of flow and gradient satisfy the constraints listed above.

Step 3

Locate the actual design flow Q-curve (e.g. 52 l/sec) and verify that it passes through the 'window'. If it does not change the pipe diameter and go to Step (1).

Step 4

Read along the Q-curve and:

- Note the point where it leaves the 'window'
- Locate the gradient S-curve which intersects it at this point (e.g. 1:110). This value represents the minimum gradient at which the pipe can be laid whilst satisfying the velocity and proportional depth constraints given in Step (2).

Also read-off for this flow and grade:

- Proportional depth (e.g. 0.75)
- Velocity (e.g. 1.32m/sec).

Step 5

For other flows in a pipe laid at the gradient found in Step (4ii) (e.g. 1:110).

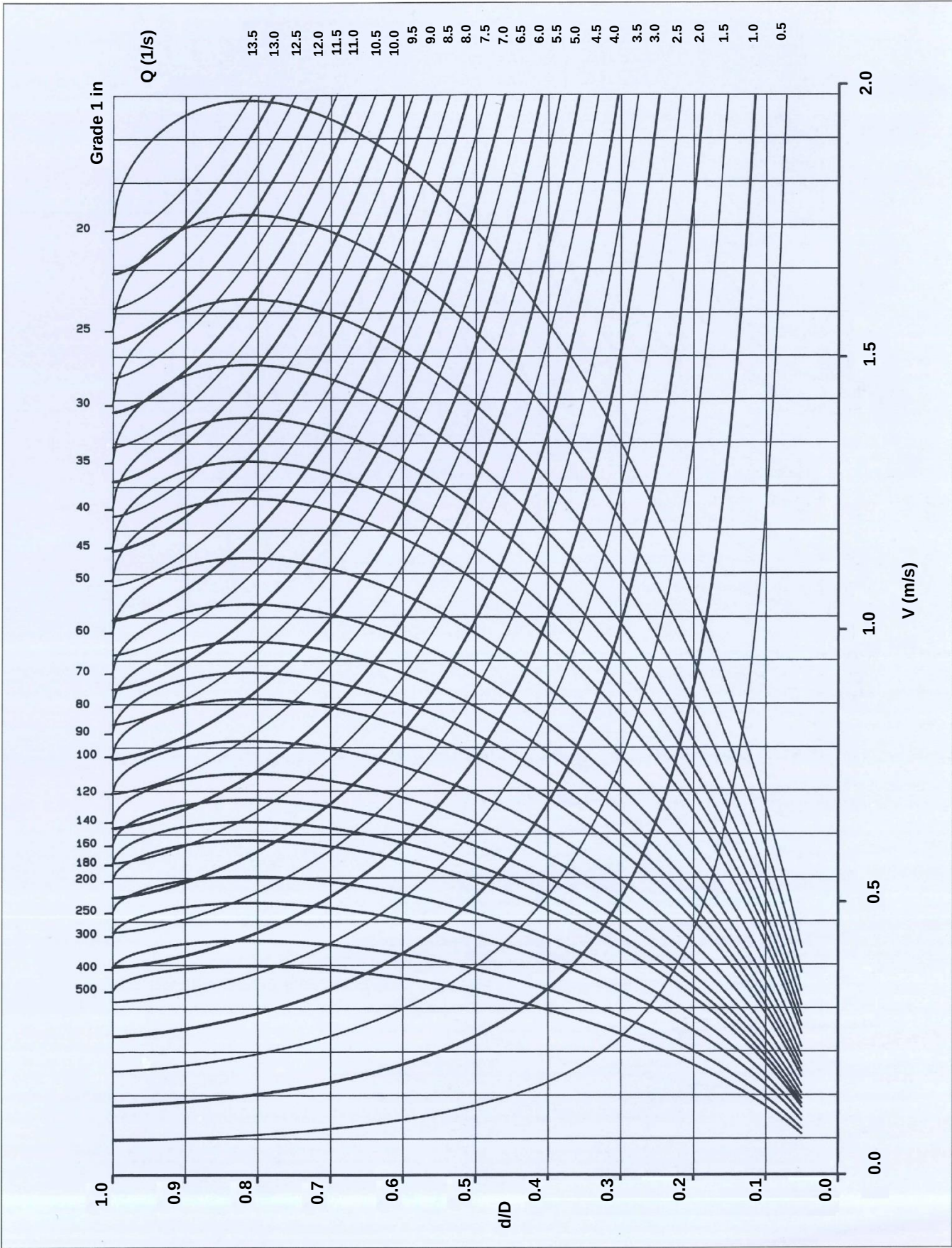
- Locate and read along the new Q-curve (e.g. 101/sec) to the intersection with the chosen S-curve
Read off:
- Proportional depth (e.g. 0.28)
- Velocity (e.g. 0.89).

NOTES

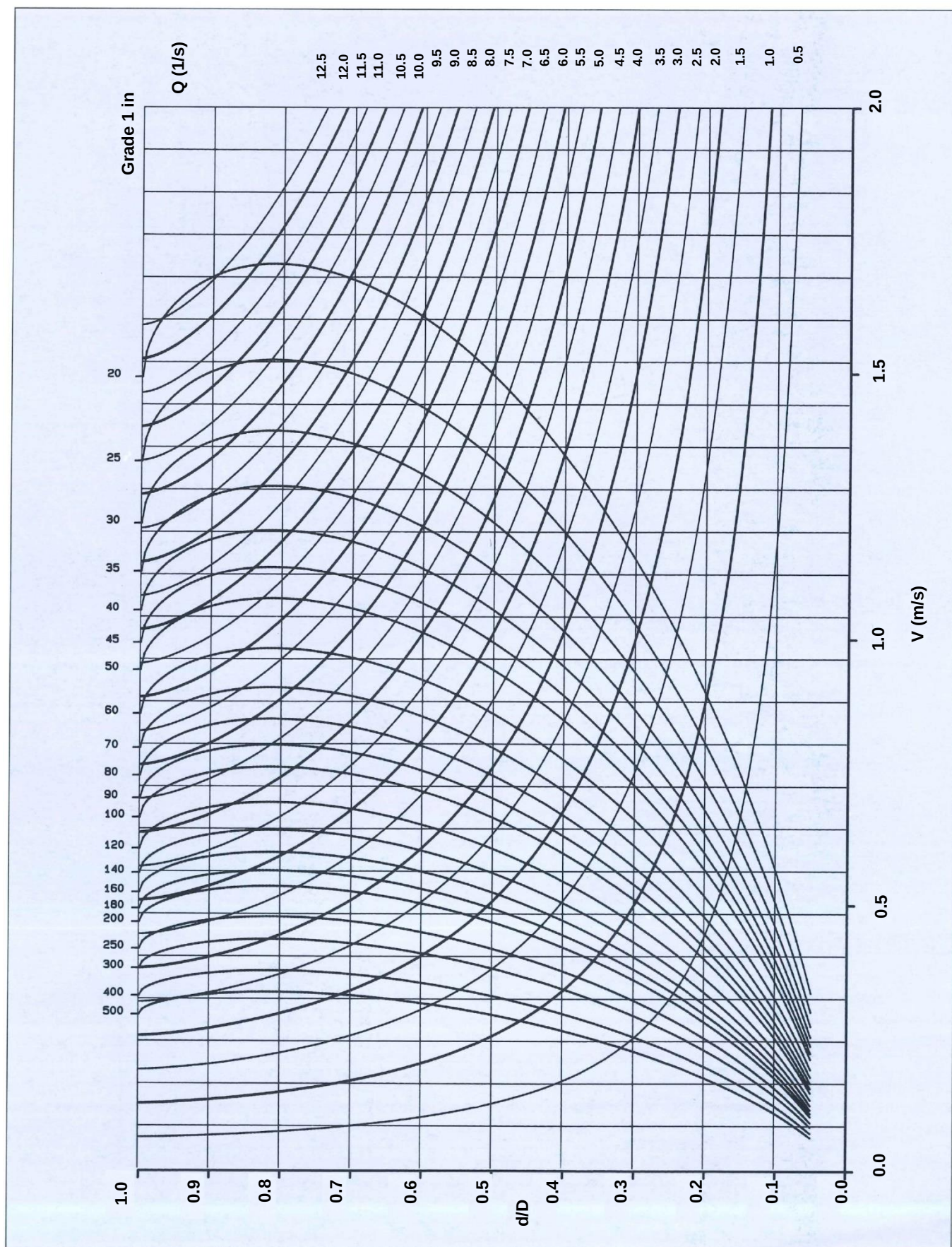
It is recommended that a value of $K = 0.6$ is used when designing stormwater drains and $K = 1.5$ is used for foul drains.

For a fuller account of the theory, more examples and a range of forty-four different two colour charts, the reader is referred to the reference below. Graphs 1 to 5 have been reproduced by permission of the authors and publishers; Butler D and Pinkerton B.R.C. 'Gravity flow pipe design charts', Thomas Telford Limited 1987.

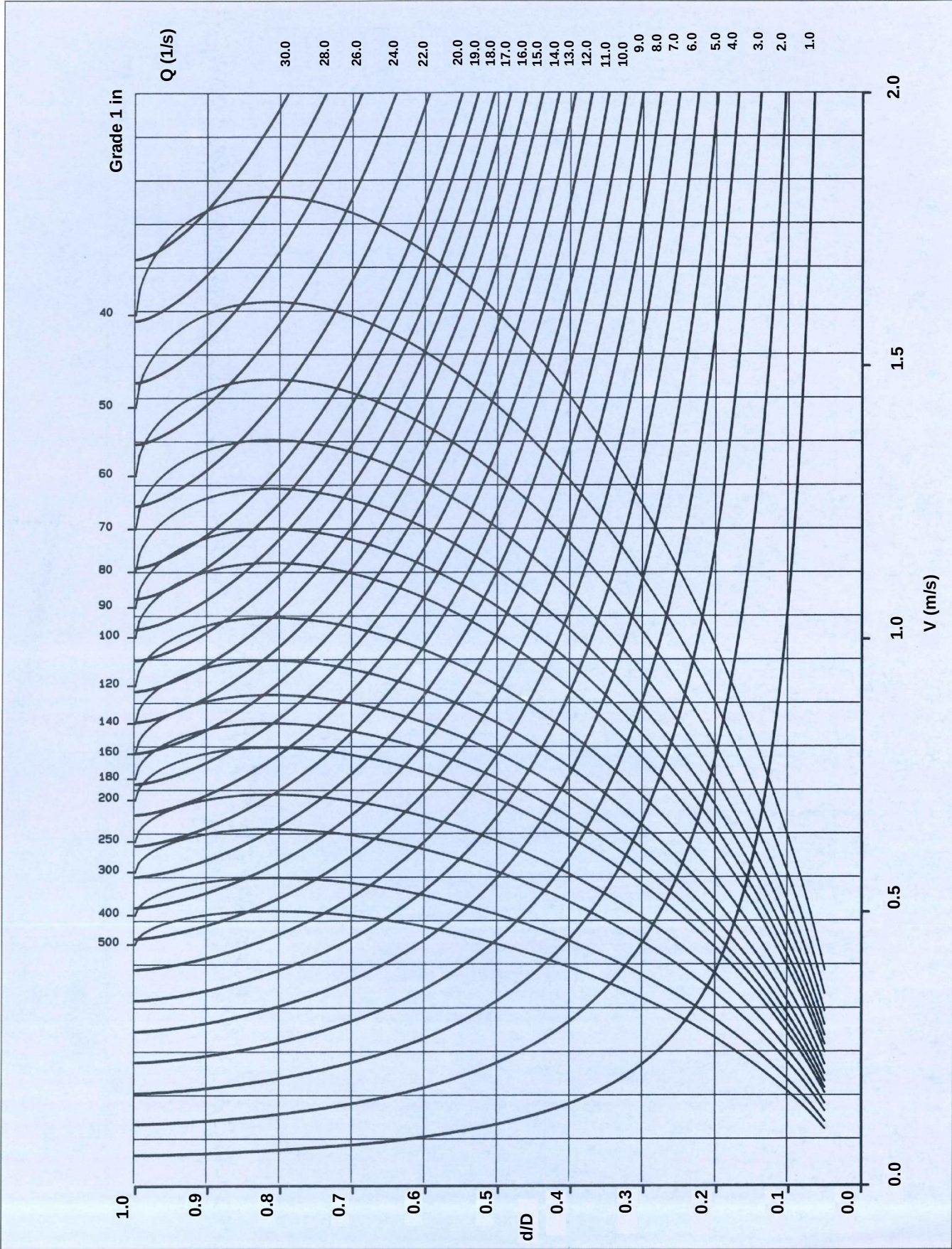
Graph 1 100mm diameter pipe - gravity flow ($K_2 = 0.6$)



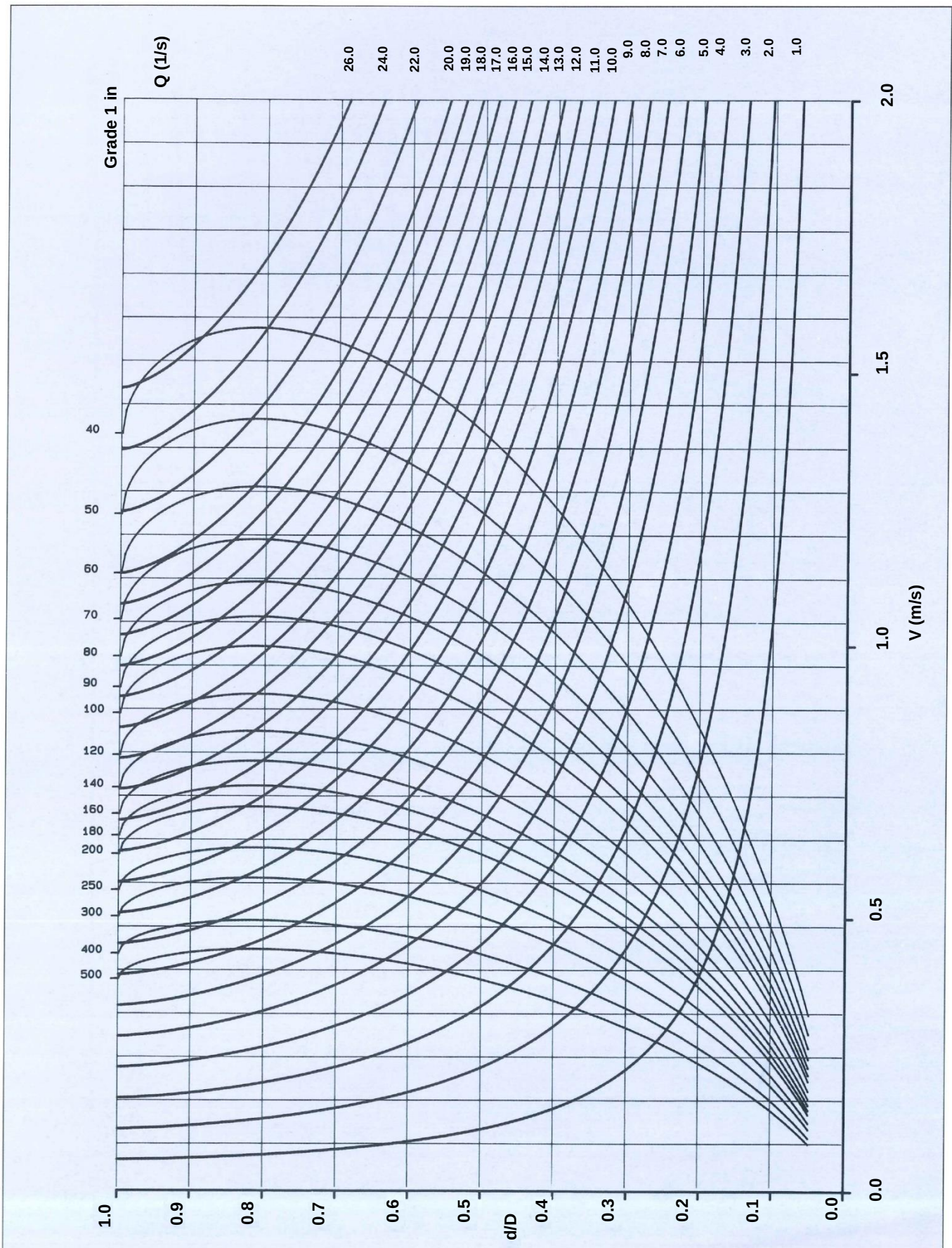
Graph 2 100mm diameter pipe - gravity flow ($K_2 = 1.5$)



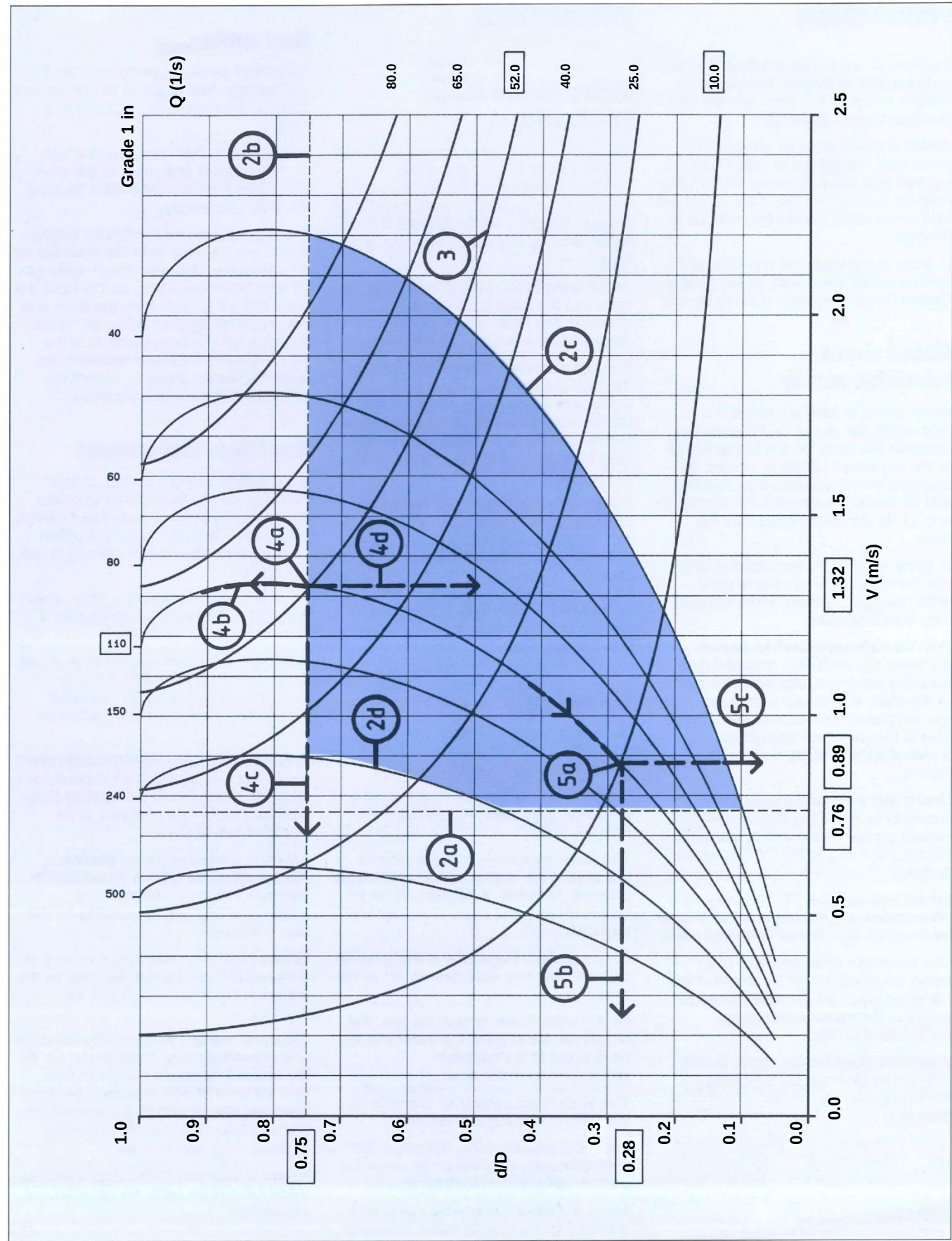
Graph 3 150mm diameter pipe - gravity flow ($K_p = 0.6$)



Graph 4 150mm diameter pipe - gravity flow ($K_z = 1.5$)



Graph 5 250mm diameter pipe - gravity flow ($K_2 = 1.5$)



Below ground drain renovation

The type of renovation will be dependent on the extent of defects, the means of access, usage of the drain and the type of effluent being discharged.

Where a drain has been cracked for some time, the egress of water from the cracked pipe will wash away the bedding material surrounding the drain, creating a void which could lead to the collapse of the pipe.

In order to ascertain the condition of a drain, it will be necessary to carry out a Closed Circuit Television (CCTV) Survey.

Closed circuit television survey

Although not in itself a method of renovation, the use of CCTV is vital to establish the need for and to monitor all of the renovation works, to ensure, for example, that the pressure jet cleaning and de-scaling has been fully completed and all the debris removed from the drain.

In some operations, such as root cutting and lining, a CCTV camera is used within the drain to monitor the works as they are carried out.

With drains from 100mm to 300mm diameter, the camera is mounted on a stainless steel skid, aligned in the centre of the drain, to produce a clear view of the complete circumference of the pipe. This is then winched through the drain at a rate of approximately 6 metres per minute.

Drains with a larger diameter are surveyed by mounting the camera on a remote controlled electrically operated tractor unit linked to the CCTV camera operator.

Where required, the CCTV survey can be recorded on video tape, which should be in colour VHS format (standard play).

The meterage, date, time and drain being surveyed should be recorded on the video tape and the tape should be stored in a purpose made folder, numbered and titled.

A detailed typed survey report should also accompany the CCTV survey identifying the position and extent of all defects.

Methods of renovation

High pressure water jet-cleaning

Water is pumped under pressure through a flexible hose to a steel nozzle, producing a backwards umbrella-shaped jet. This has the effect of pulling the hose through the drain and forcing the flow of water carrying any debris back along the pipe.

Jet cleaning is carried out by feeding the hose into the drain in an upstream direction. The hose is then pulled back in stages and the resulting debris removed.

For pipes between 100mm and 300mm, the high pressure water jetting equipment will be trailer-mounted with a 20mm hose delivering water at pressure. Pressures should be dependent on the type of jet and the material and condition of the sewer.

Larger diameter drains and those that are heavily silted or blocked with solid debris require a larger volume of water. This cannot be provided by a trailer-mounted unit and so a lorry tanker unit is required. The hose would be larger - up to 30mm diameter and would deliver 140 bar - 750 bar with volumes of 0.5-1.5 l/sec.

De-scaling

In vitrified clay drains, scale can form, particularly at joints, creating a rough surface where blockages can occur.

Cast iron drains develop heavy scale and corrosion, particularly where there are only low flows.

The same equipment and procedures are used in de-scaling as for pressure jet cleaning. However, a different shape jet nozzle is used and lower flow rates are required.

For de-scaling, the nozzle is designed to produce very fine water jets at 90° to the hose.

As the water flows through the jets, the nozzle rotates to allow the water jets to be directed to the complete circumference of the pipe.

The scale is cut away from the walls of the drain by the water pressure.

Following the de-scaling operation, it is then necessary to pressure jet clean the drain to remove the resulting debris.

There is electro mechanical equipment available for de-scaling works.

However, it is not commonly used on below ground drainage pipework.

Root cutting

A common problem, particularly in older vitrified clay drains with sand and cement joints, is the ingress of plant and tree roots.

The roots can enter the drain through very fine cracks and, once in the drain, can expand and multiply, often blocking the drain completely.

The process and equipment for cutting and removing roots from the drain are as for de-scaling. However, the process can be very time consuming, as the roots are often difficult to clear from the drain and only small sections of drain can be cut and cleared at a time. Once all of the roots have been cut and removed, the drain will require lining to prevent the roots growing back into the drain.

Trenchless replacement

This method, using a system of 'pipe bursting', can be considered when the condition of a drain is such that it cannot be repaired, but the cost or disruption caused by traditional replacement is not acceptable.

For example, a vitrified clay drain, which has partly collapsed, passing under a busy access way or road.

Because of its condition, the drain could not be internally lined and the cost and disruption associated with traditional excavation and replacement would be prohibitive.

In this situation, the defective drain can be replaced by inserting an expanding mandrill, which forces the existing pipe outwards allowing a new pipe to be threaded into position.

Although termed as being 'trenchless', this system does require an excavation between 1000mm x 800mm and 2500mm x 1500mm, depending on the size of the pipe.

Where there is an available manhole, an excavation is not always required, as the equipment can be located with the manhole.

The steel mandrill is forced into the drain and expanded using compressed air. As the mandrill is moved along the drain, new sections of pipe manufactured from concrete, clay or plastic are pushed into place to follow the line of the existing drain.

Where a drain has connecting branches, these have to be replaced by traditional excavation.

Lining

There are several types of liner, all of which reduce the bore of the existing drain.

The minor reduction in bore, between 10mm and 25mm depending on the size of the pipe and type of liner, does not adversely affect the flow characteristics, which are greatly improved by the smooth bore of the liner.

Each lining method has advantages and disadvantages, which must be considered for the application at hand.

Cement lining

This is the oldest form of drain lining and has been used successfully for about 40 years.

Originally used with ordinary Portland cement, applications today are more common using a range of specially produced quick drying resin-based cement compounds.

This type of lining is only suitable for rigid drain installations where there is no anticipated movement.

The method of application is by pulling two loose rubber pistons, slightly smaller in diameter than the drain, filled with the mixed cement through the drain. The pressure exerted by the piston at the front pushes the cement in the pipe and leaves a thin lining all around the pipe.

To provide a smooth internal lining with all cracks etc. filled, it is usually necessary to repeat this process 3 or 4 times.

Where there are branches connecting to the drain being lined, these will have to be thoroughly cleaned following this type of lining operation to ensure they are clear of any cement debris.

Rigid plastic liners

Made from high density polyethylene or polyolefin polymer-based materials, with screw and socketed joints.

These liners are winched into the drain, providing a new smooth bore, although of reduced diameter.

In order to pull this type of liner through a drain, a tolerance should be allowed in sizing to ensure that the liner can pass through the drain without becoming stuck on open joints or in a section of slightly non-uniform pipe.

Once in place, the annular space between the new liner and the drain has to be sealed to prevent movement. This is carried out by pumping a weak cement grout.

Where the existing drain is found to be oversized, for example where the use of a building has changed, this type of lining system is very effective and there is a range of liner diameters from 75mm to 600mm.

This type of lining system is ideally suited where flexibility is required and where aggressive discharges are anticipated.

Where there are connecting branches, these have to be excavated and connected to the new liner with a purpose made branch section.

Grouting

This is the term used for sealing cracks or open joints in a drain with an aqueous compound.

There are a number of different products on the market. However, there are two main types of grout:

Cement

This is applied in the same way as the cement lining, using larger pistons so that the cracks and gaps are filled, but a lining is not left in the pipe.

Any movement in the pipe will result on the repaired cracks opening up. Therefore, this system should only be considered where no possible movement is anticipated.

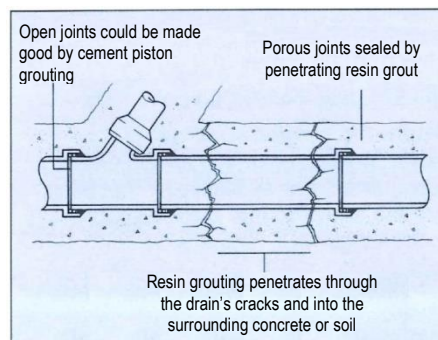
This system does have a good resistance to chemical attack. However, branch connections cannot be repaired by this method, as access is required from both ends of the drain.

Resin

Resin compounds used for grouting in drain renovation works were originally developed for use in stabilising ground in mining and excavations and in controlling the flow of ground water.

The use of these resins has been adapted and they have been in use for drain renovation works for over 20 years.

Figure 29 Cement and resin grouting



There is a wide range of products available, each with a slightly different chemical make-up.

However, there are two main generic types, both of which have the same qualities are widely used in grouting defective drains.

The resin produced with a mixture of polyphenolic vegetable extract and paraformaldehyde or from other organic monomers is delivered to site in a dry powder form.

This is then mixed with water at a concentration of 20-22% depending on the type of product used and the ambient temperature.

The drain to be grouted is thoroughly cleaned and sealed at its lowest point and the aqueous resin grout is pumped into the drain and filled through a standpipe to produce a static head pressure of 1.5m above the highest point.

Under pressure, the aqueous resin grout is forced into any cracks or open joints in the drain.

Due to its viscosity, the resin grout passes through any crack and permeates the surrounding ground.

As the resin grout passes through any cracks, voids in the surrounding bedding material are filled and replaced with the grout.

When the level in the standpipe has stabilised, the grout is left to cure for between 30 minutes and 90 minutes depending on the resin product and the ground temperature.

When fully cured, the resin forms a solid flexible gel, which is impervious to water.

Before the resin becomes fully cured, which takes between 2 and 3 hours, the drain plug should be taken out and the surplus resin within the pipe pumped out and disposed of.

After allowing the remaining resin to cure fully, the drain should then be pressure jet cleaned to remove any surplus resin gel from the walls of the pipe.

Being flexible, the grouted drain is not adversely affected by movement. However, where the drain carries aggressive or chemical waste, the selection of the resin material must be carefully considered.

The life of the resin grout for drainage renovation is not guaranteed beyond 15 years, as tests beyond this period have not yet been carried out.

However, from the research carried out on these resin materials where they have been used to stabilise ground water, no deterioration has been found after periods of 20-30 years.

Continuous fibre liners

These consist of a felt or polyester sleeve which is impregnated with a hardening resin.

The sleeve, which is sized to suit the diameter of the drain, is winched into the drain and filled with water, pushing the liner out to the wall of the drain.

Some types of liner require the water to be heated to allow the resin to harden. However, this has always been difficult and time consuming and, with the advent of more advanced resin formulae, this system is not as often used.

Once in position and filled with water to a static head of between 3m and 6m, the liner is left to cure for between 1 and 2 hours depending on the weather conditions.

When the liner is set, the ends are trimmed and sealed.

This type of liner provides a smooth solid wall to the drain and reduces the bore by only 10-15mm.

Being completely flexible when installed, the liner can be used in drains that are not true to line or bore.

The liner adheres to the wall of the drain and is very secure. Once fully cured, the drain will remain relatively flexible, with a tolerance of $\pm 2^\circ$ per metre.

This type of system is resistant to a large range of chemicals. However, a detailed check of the manufacturer's chemical resistance chart for the type of liner considered should be made where the discharge is aggressive or likely to contain high levels of chemical waste.

Although it is possible to use this type of system to line a drain and reduce the bore, great care is required in the installation to avoid undulation of the invert and flotation during grouting.

Figure 30 Insertion of continuous fibre liner

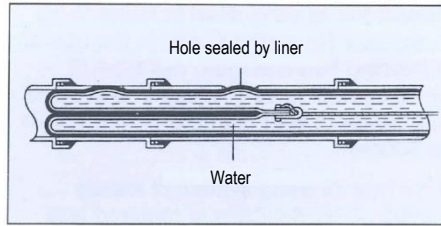
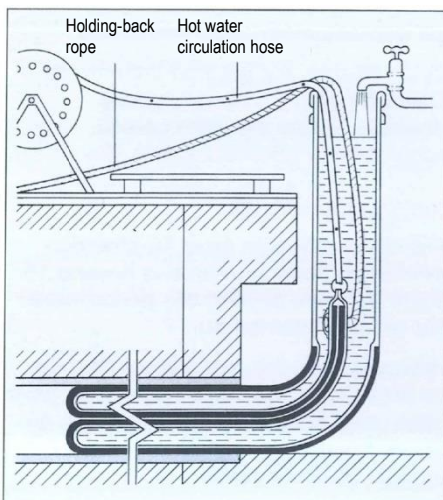


Figure 31 Typical fibre liner

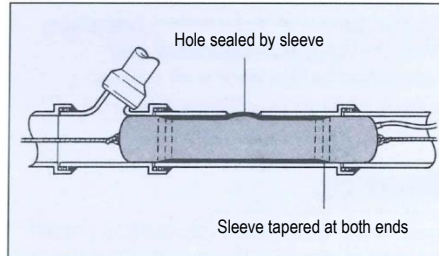


Figure 32 Continuous fibre liner

Where this type of liner is used to provide a considerably reduced bore to the drain, the installation should be as before. However, prior to releasing the water, the annular space should be filled by pumping with grout. Due to the high temperatures created by cement based grouting materials due to exothermic reaction, a resin or clay-based compound should be used.

Where there are connecting branches, the liner has to be cut internally after curing by a remote-controlled tractor unit.

Sectional fibre liners

These are of the same material as the continuous fibre liners above. However, they are used in short lengths of 300mm to 1500mm to deal with isolated defects in a drain where a continuous liner is not required.

The liner is winched into position on an inflatable carrier tube and its location confirmed by CCTV.

The carrier tube is then inflated, pushing the liner onto the wall of the pipe.

Once cured, the carrier tube is deflated and removed, leaving the liner in place.

To improve the sewers hydraulic gradient, a vitrified channel is bedded onto the existing brick invert and benched both sides would provide a new clean, efficient, self-cleansing sewer invert.

Where the general condition of a brick sewer is poor, glass reinforced plastic sewer liners are available for installing into the sewer in one-piece sections, up to 6m long.

The annular gap between the new section and existing brickwork is pressure grouted to complete the job.

Rainwater systems

This section has been produced using charts and tables as an alternative to the British Standards. Although most of the data used is from BS 6367, similar results will be obtained by using BS 12056-3.

The flow chart (See Figure 33) is designed to suggest appropriate routes for the various situations.

Method of design

The method of design is based on the following assumptions:

- The gutter is normally level
- The gutter has a uniform cross-sectional shape
- The outlets are large enough to allow the gutter to discharge freely.

An alternative is the Wyly-Eaton equation in BS EN 12056.

Sources of data

- Data and formulae for rainfall intensities are from BS 6367
- Formulae used for production of gutter sizing nomograms are from BS 6367
- Actual flow rates for grated roof outlets should be obtained from the manufacturers
- Flow rates for ungrated outlets are based on Weir formula
- The rainwater downpipe sizing chart is based on the formula:

$$q = Kd^{8/3}$$

resulting from work carried out by BRE and the US National Standards Bureau, where:

q = discharge capacity in litres/sec

d = stack diameter in mm

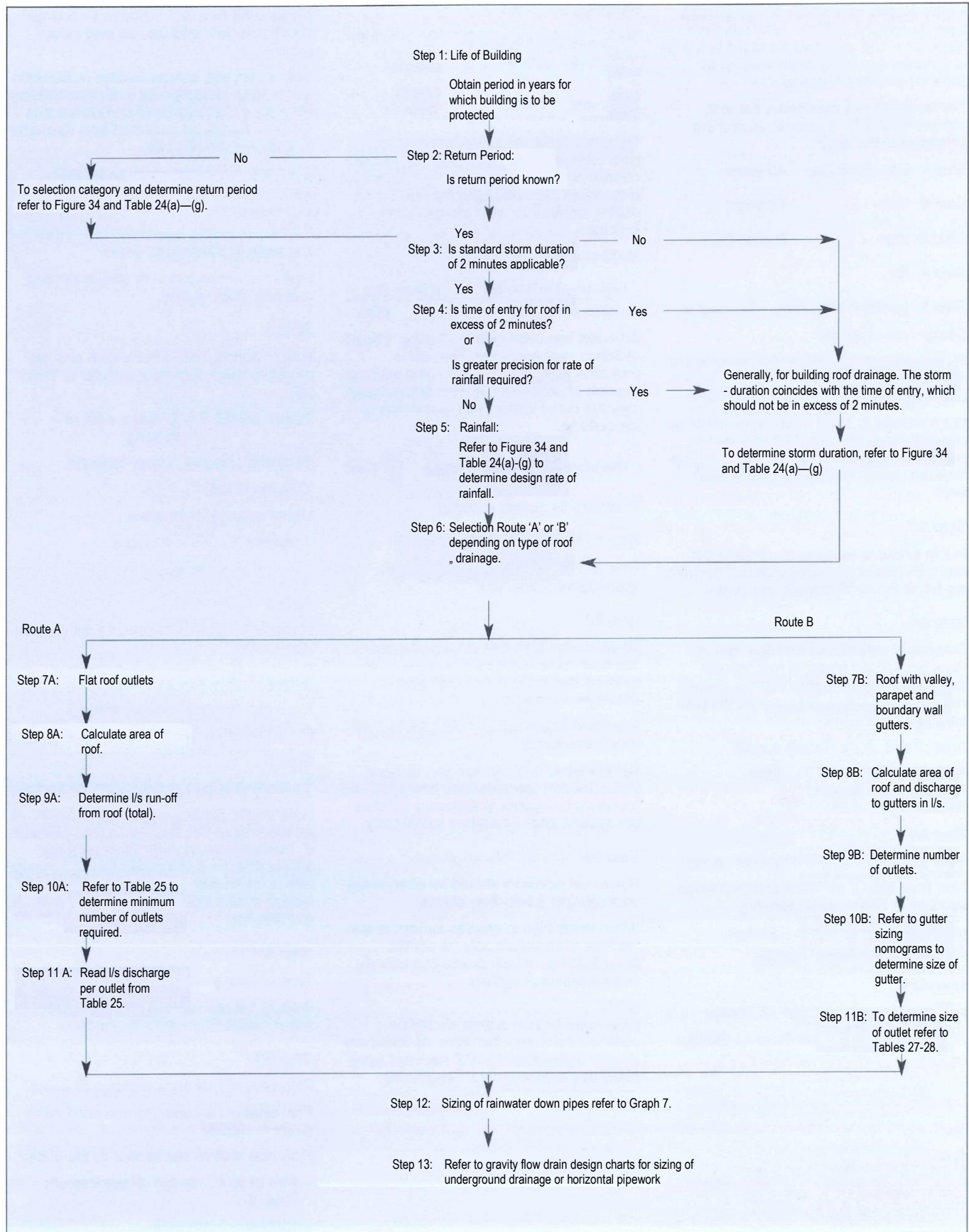
$$K (1/5 \text{ full}) = 2.1 \times 10^{-5}$$

$$K (1/4 \text{ full}) = 3.2 \times 10^{-5}$$

$$K (1/3 \text{ full}) = 5.2 \times 10^{-5}$$

The following two examples are for information purposes only, giving a step-by-step guide through the calculation procedure.

Figure 33 Flow chart showing calculation procedure



Example 1: Route A - flat roof

A typical spec office block of approximate plan dimensions of 50m x 20m sited in Newcastle. The expected life of the building is 40 years, and it has been decided to allow for a 60-year period.

The Architect has specified a flat roof, asphalt finish with a parapet around the perimeter of the roof.

Step 1: Life of building 40 years

Step 2: Yes 60 years

Step 3: Yes 2 min M5

Step 4: No

Step 5: Location of building - Newcastle

Design rate of rainfall

By reference to the UK rainfall map. Figure 34, we can see that the site of our building (Newcastle) is adjacent to contour line D.

We now refer to Table 24(d), from which we can determine that, for a 60-year return period with a 2-minute duration rainfall, the required design intensity is 150mm per hour.

Step 6/7

In this example we have an upstand flat roof with grated rainwater outlets. Therefore, we follow Route 'A' through the guide.

Step 8A

Determine area of roof and flow rate in litres per second from the roof. We are assuming in this example that the area of roof to be drained is the same as the plan area. i.e., no overhangs.

Area of roof A = length x width

Therefore A = 50m x 20m
= 1000m²

Step 9A

Total run off from roof in litres per second.

Now from Step 5 we know that the design intensity is 150mm/hr (0.15m/hr).

So flow rate = Area x intensity
(in metres)

Therefore,

flow rate = 1000m² x 0.15m/hr
= 150m³/hr or 41.66l/sec

Step 10A

Select type of outlet

For installation reasons a 100mm diameter vertical grated type outlet Type 17B is selected.

Details of this outlet are to be found in Table 25.

From this Table we can determine the discharge rate in litres per second that the chosen outlet is capable of receiving at a given head. So, calculating the number of outlets required to drain the roof of the building:

Number of outlets =

Total run-off in litres per second (from step 9)
litres per second discharge per outlet

An outlet has been chosen, having a head of 30mm over the outlet. The roof is protected with an asphalt upstand which is capable of containing at least 60mm head over the outlet without risk of damage to the building.

Therefore, number of outlets = $\frac{41.66}{2.92}$ l/sec

Therefore 14 outlets required.

Step 11A

Flow rate per outlet is 2.92 litres per second (from Table 25)

Step 12

To determine diameter of rainwater pipes. We have assumed for the purpose of this exercise that there is one outlet per rainwater downpipe.

Therefore, flow down any one pipe is 2.92 litres per second.

By reference to Graph 8, it can be seen that a 100mm diameter pipe flowing 1/5 full (curve A) is capable of receiving 4.2 litres per second and is therefore satisfactory.

Step 13

Horizontal pipework should be sized using underground gravity flow charts.

When using high intensities for roof areas the flow rates should only be carried through to the branch drains immediately outside drainage system.

NOTE

Flow rates for roof outlets should be obtained from manufacturers, as these are usually higher than the BS standard types listed due to their type of design and construction.

Example 2: Route B - valley gutter

Design and size roof drainage for a large warehouse with pitched roof and valley gutters.

The warehouse is to be located in Swindon and is to be designed for a 40-year building life, with a high degree of confidence that the building will be protected from rainwater for the duration of its life.

The roof construction is to be steeply pitched roof with valley gutters.

Step 1

Life span of building: 40 years

Sensitive warehouse with steeply pitched roof and valley gutter.

Step 2

Return period. This is not known and has therefore to be determined. Refer to Table 26.

Return period, T = 'C' factor x life of building

Selecting category 3 from Table 26.

'C' factor is 4.5

Life of building is: 40 years

Therefore T = 4.5 x 40 years
= 180 years.

Step 3

Is standard storm duration of 2 minutes applicable?

Step 4

No: storm duration (time of entry) is required to be 1 minute.

Step 5

To determine the rainfall design intensity:

Referring to Figure 34, locating the building on the map of UK, Swindon lies on contour F. This corresponds with Table 24(f) and shows that, for a storm duration of 1 minute with a return period of 180 years, the design rainfall intensity is 275mm per hour (0.275m/hr).

Step 6/7

Type of roof drainage

Steeply pitched roof with valley gutters, follow Route 'B' (trapezoidal Gutter).

Step 8B

Plan area of roof and discharge to gutter.

Plan area of roof draining into each valley gutter = 1000m²

Flow rate in litres per second to the gutter:

= area of roof x design rainfall intensity (Step 3)

= 1000m² x 0.275 m/hr

= 275m³/hr

$$= \frac{275000}{3600} \text{ l/hour}$$

= 76 l/s (run-off per second per length of gutter)

Step 9B

Determine number of outlets and discharge in litres per second per outlet:

Number of outlets provisionally determined by potential stack location (one per outlet).

Therefore, number selected: 8

Therefore, flow rate per outlet

$$= \frac{\text{total flow rate}}{\text{number of outlets}}$$

$$= \frac{76}{8} \text{ l/s}$$

$$= 10 \text{ l/s}$$

approximately (5 l/s from each length of gutter)

Step 10B

Determine size of gutter:

Known criteria:

1. Gutter sole to be suitable for foot traffic, therefore minimum width of sole to be 300mm.
2. Drainage (Length of gutter 7.0 metres) (assuming equal outlet centres).

Now refer to respective nomogram; in this exercise we are using trapezoidal gutters with a 1:1 side slope.

Reading from gutter sizing nomogram, Graph 9 where:

yc = 29mm (critical depth)

yuf = 63mm (depth upstream of gutter - high point of water)

Freeboard must be added to yuf; this should be a minimum of 2/5ths of the maximum depth of flow (yuf) subject to a minimum of 25mm.

Therefore freeboard = 25mm (minimum)

So, total depth of gutter is, yuf + freeboard

$$= 63\text{mm} + 25\text{mm}$$

$$= 88\text{mm}$$

Details of roof construction and weathering might dictate that a greater overall depth of gutter is required.

For added safety overflow pipes or weirs should be installed at either end of the gutter as a minimum, preferably between each pair of outlets.

For the gutter to discharge freely, the outlet should be ungrated and of not less than three quarters of the width of the gutter. It may not be possible to select an outlet to conform with this, therefore we must alternatively construct a box receiver at the outlet. Box receivers should be the width of the gutter and the depth should not be less than H + 25mm, where H = head of water over outlet.

Step 11B

Size of rainwater outlet (and depth of box receiver). Having selected a circular ungrated outlet refer to Table 28.

Know criteria:

1. Flow rate per outlet
= approximately 10 l/s
2. Head of water cover outlet to be not more than yc or 29mm (from Step 10).

Referring to Table 28, a 250mm diameter outlet requires a head of water H of 45mm over the outlet to receive a flow rate of 10.06 l/s. It is not possible to select a standard outlet.

A smaller outlet could be chosen by using a box receiver to give a free discharge, as the outlet would then be less than three quarters of the width of the sole of the gutter.

Selecting a 150mm diameter outlet, the head of water over the outlet, H, is 65mm.

65 + 25mm = 90mm (minimum depth of box receiver)

Plan area of Box receiver would be made up as follows:

Width = Not less than the width of flow in the gutter.

Length = the length of the box for a flow of water from one direction should not be less than (0.75 x depth of gutter). If the flow of water is from both directions, the length of the box should be (1.5 x depth of gutter) minimum.

Step 12

Sizing of rainwater downpipes.

Refer to Graph 7.

Know criterion:

1. Flow rate = 10 l/s

A 150mm diameter rainwater downpipe flowing 1/5 full is capable of carrying 10 litres per second.

When using high intensities for roof areas the flow rates should only be carried through to the branch drains immediately outside the building.

Design flow rates should be reassessed based on the sensitivity of the underground drainage system.

Design rate of rainfall for varying storm durations and return periods

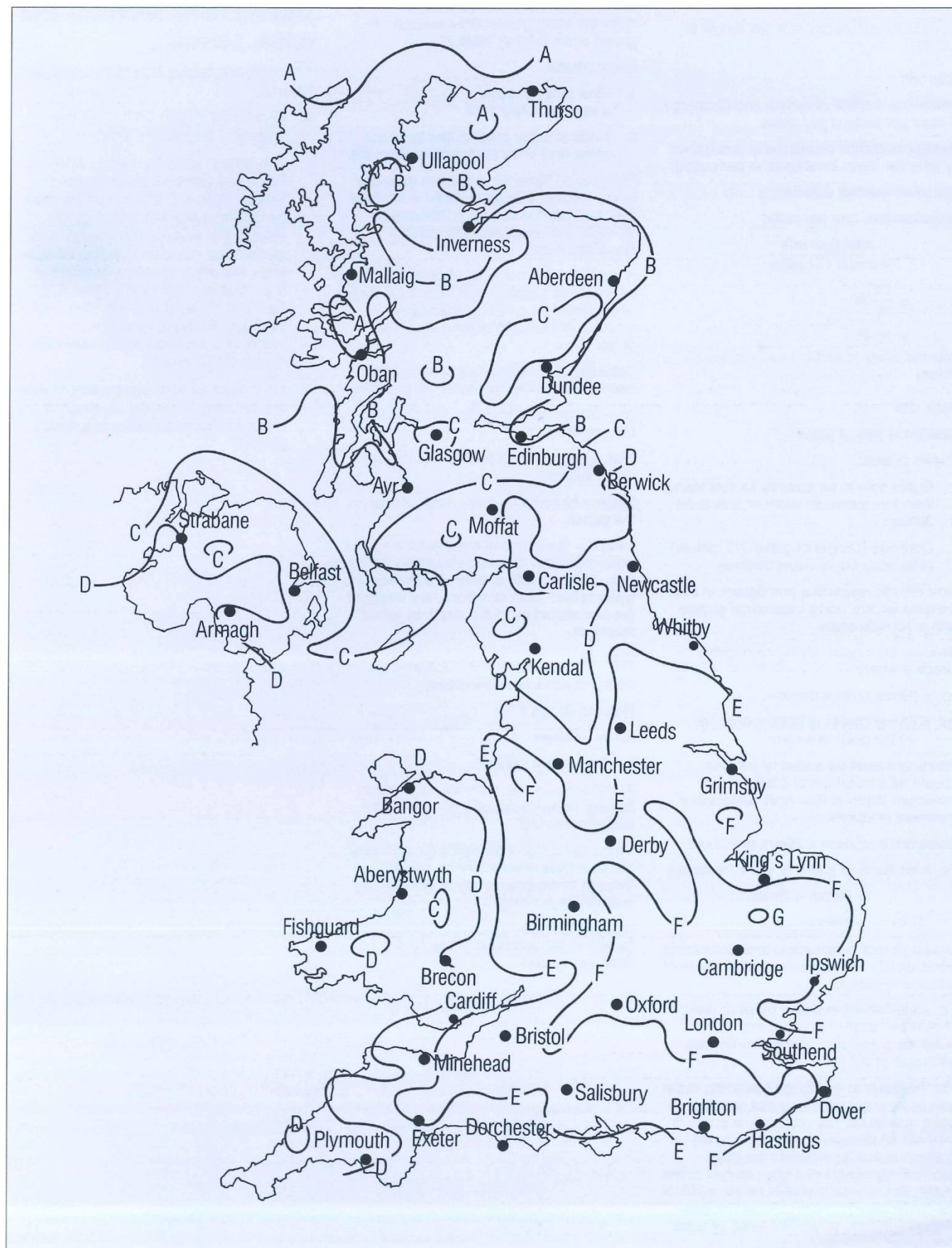
The following tables should be used as follows:

- a. Read from Figure 34 the contour reference for the site location.

The areas between contour lines on Figure 34 (which correspond with Tables 24(a)-(g)) should not be read as having a blanket coverage of rainfall, but as two extreme rates of rainfall that coincide with the contour lines, having a constant graduation from one contour to the other, e.g., Derby is situated midway between contours E and F, therefore a judgement must be made between Tables 24(e) and (f).

- b. Now read off from the selected table the intensity in mm/hr against the required storm duration and return period.

Figure 34 Key to rainfall Tables 24(a) to (g)



Series of tables relating rainfall intensity, duration and return period

Table 24(a) Rainfall amount 1.5mm in 2 minutes, occurring on average once in 5 years (2 min M5)

Duration (mins)	Intensity (mm/hr)				
	50mm	75mm	100mm	150mm	225mm
1	4.5	35	185	1800	-
2	5.5	55	300	3500	-
3	10	175	800	-	-
4	20	210	-	-	-
5	40	400	2000	-	-
10	300	300	-	-	-
Return period (years)					

Table 24(b) Rainfall amount 2mm in 2 minutes, occurring on average once in 5 years (2 min M5)

Duration (mins)	Intensity (mm/hr)				
	50mm	75mm	100mm	150mm	225mm
1	1.75	7	35	325	4000
2	2	18	60	850	-
3	4.5	35	175	1800	-
4	7	45	350	3000	-
5	8	60	750	4000	-
10	45	450	2500	-	-
Return period (years)					

Table 24(c) Rainfall amount 2.5mm in 2 minutes, occurring on average once in 5 years (2 min M5)

Duration (mins)	Intensity (mm/hr)				
	50mm	75mm	100mm	150mm	225mm
1	7 mths	3	8	90	1000
2	1.5	5	20	300	2500
3	2	7.5	40	500	-
4	3	15	60	800	-
5	4	20	100	1000	-
10	15	150	700	-	-
Return period (years)					

Table 24(d) Rainfall amount 3.0mm in 2 minutes, occurring on average once in 5 years (2 min M5)

Duration (mins)	Intensity (mm/hr)				
	50mm	75mm	100mm	150mm	225mm
1	6 mths	3	8	35	400
2	7 mths	5	20	60	750
3	8 mths	7.5	40	190	2000
4	9 mths	15	60	350	3000
5	2 yrs	20	100	-	-
10	7 yrs	150	700	-	-
Return period (years)					

Table 24(e) Rainfall amount 3.5mm in 2 minutes, occurring on average once in 5 years (2 min M5)

Duration (mins)	Intensity (mm/hr)				
	50mm	75mm	100mm	150mm	225mm
1	5 mths	1	2	20	180
2	6 mths	1.75	4.5	35	320
3	7 mths	2	10	60	700
4	9 mths	4	12	100	800
5	10 mths	4.5	18	185	1800
10	4 yrs	20	95	750	-
Return period (years)					

Table 24(f) Rainfall amount 4mm in 2 minutes, occurring on average once in 5 years (2 min M5)

Duration (mins)	Intensity (mm/hr)					
	50mm	75mm	100mm	150mm	225mm	275mm
1	4 mths	17 mths	1.5	7	50	180
2	5 mths	8 mths	2	18	110	450
3	5 mths	1.75	4	35	250	700
4	6 mths	1.75	6	40	350	1000
5	7 mths	2	7.5	50	650	-
10	2 yrs	7.5	40	300	3500	-
Return period (years)						

Table 24(g) Rainfall amount 4.5mm in 2 minutes, occurring on average once in 5 years (2 min M5)

Duration (mins)	Intensity (mm/hr)						
	50mm	75mm	100mm	150mm	225mm	275mm	300mm
1	3 mths	5 mths	2	7	55	190	350
2	3 mths	6 mths	2	7	55	190	750
3	4 mths	1	3	18	120	350	1100
4	6 mths	1.5	4.5	20	200	450	1600
5	6 mths	2	5	38	250	650	-
10	1 yr	6	50	200	1800	1900	-
Return period (years)							

For intensities of 225mm per hour and above, alternative means of protecting the building other than increasing the size of rainwater pipes etc. should be considered, such as the provision of overflows or additional freeboard.

The average roof should have a duration/run off time not exceeding two minutes. Periods of greater duration shown for information and completeness only.

Table 25 Estimated capacities of outlet for flat roofs

Outlet type	Table in BS416:1973	Outlet size (mm)	Area drained at rainfall intensity of 75mm/h at depth of water above outlet:					
			5mm (m ²)	10mm (m ²)	15mm (m ²)	20mm (m ²)	25mm (m ²)	30mm (m ²)
Square flat grating	17A	100	17	49	90	135	190	250
Circular flat grating	17B	50, 75	4.5	12	23	36	51	67
	17B	75, 90, 100	9.6	27	50	77	105	140
'D'-shaped flat grating	17C	65	5.2	14	27	42	58	77
	17C	75	5.4	15	28	43	61	80
	17C	90, 100	7.6	21	39	60	85	110
Circular flat grating with	17D	50	4.5	12	23	36	51	67
	17D	75, 100	7.1	20	37	57	80	105
			(l/s)	(l/s)	(l/s)	(l/s)	(l/s)	(l/s)
Square flat grating	17A	100	0.354	1.021	1.875	2.812	3.958	5.208
Circular flat grating	17B	50.65	0.093	0.250	0.479	0.750	1.062	1.396
Circular flat grating	17B	75, 90, 100	0.200	0.562	1.040	1.604	2.187	2.920
D shaped flat grating	17C	65	0.108	0.292	0.562	0.875	1.208	1.604
D-shaped flat grating	17C	75	0.112	0.312	0.583	0.896	1.270	1.667
D-shaped flat grating	17C	90, 100	0.158	0.437	0.812	1.250	1.771	2.292
Circular flat grating	17D	50	0.093	0.250	0.479	0.750	1.062	1.396
Circular flat grating	17D	75, 100	0.148	0.417	0.771	1.187	1.667	2.187

Procedure

- Determine type of outlet required.
- Refer to the Table for cast iron roof outlets as BS 416.

Actual flow rates for grated roof outlets should be obtained from the manufacturers.

Rainwater downpipes should be sized separately using

Graph 7 if vertical, or drain sizing data if horizontal.

Table 26

Type of Roof	Category	C Factor
Pitched roof with external eaves, gutters and flat roofs	1	1
Valley and parapet gutters	2	1.5
Valley gutters with higher security	3	4.5
Highest possible security	4	See BS EN 12056-3

Use of gutter sizing charts

The C factor is used when calculating the return period i.e. Return period, T = C factor x life of building.

The charts provide a unique method of selecting gutter sizes and produce results similar to BS 6367 and BS EN 12056-3.

A series of four charts cover four basic gutter profiles.

British Standard gutters are manufactured in a limited range of shapes and sizes, but with the aid of the charts it is possible to select a gutter to suit any application.

Procedure

- Calculate the flow of water (Q)
- Select the breadth (Bs) and length (Lg) to read off depth of water at point of discharge (Yc) and the upstream depth (yuf) to which a suitable freeboard depth must be added 2/5ths of yuf subject to a minimum of 25mm.

Example

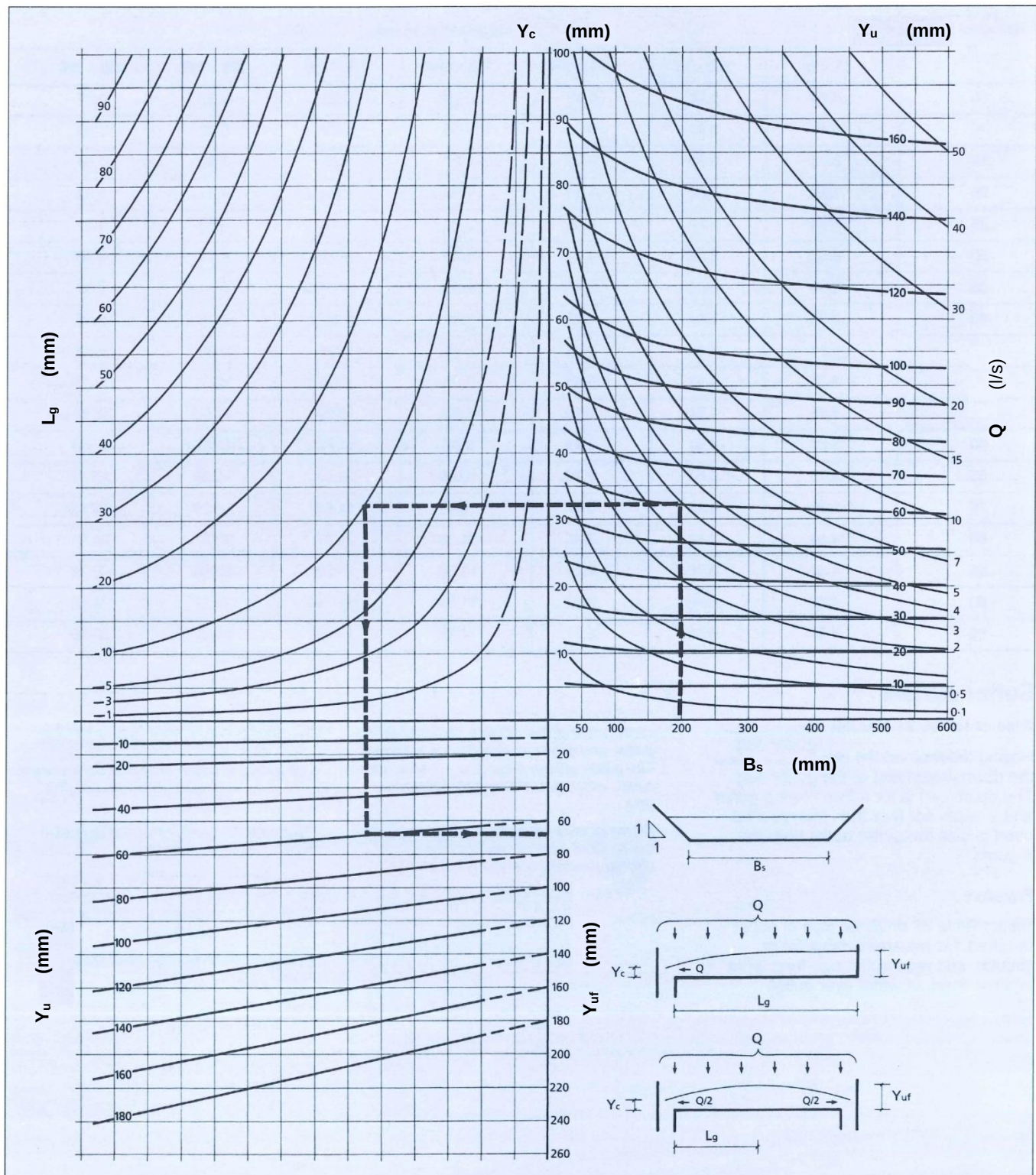
Roof size: 20 x 19.2 m = 384m²

(Refer to Graph 6)

Rainfall intensity = 75mm/hr

100% run off = 8 l/s

Graph 6 Gutter sizing nomogram showing worked example



The gutter runs off full length (20m) of the building and has one outlet at each end. Half of the water will discharge in each direction; ie. 4.0 l/s into 10m length of gutter. Select the appropriate nomogram for gutter profile required and range of sizes.

Starting at the bottom right-hand side of the chart select a gutter breadth (B), say 200mm, follow vertically up the nomogram to the flow rate curve of 4.00 l/s. Read off and note value of y_u , 60mm.

Read across to the centre axis noting the depth (y_c) at the outlet Of 32mm.

Continue to the left to the curve representing the gutter length (10m) and drop into the bottom left-hand section of the nomogram to the value of the depth (y_u) of 60mm previously established.

Follow right (horizontally) to the intercept with the y_{uf} axis and read off the value at y_{uf} . Add freeboard to y_{uf} .

Table 27 Flow rates, square/rectangular ungrated gutter outlets (litres per second)

Head of water over outlet in mm H	Size of rainwater outlets in mm						
	75x75	100x75	100x100	150x100	150x150	200 x 150	200 x 200
5	0.14	0.16	0.19	0.23	0.28	0.33	0.37
10	0.40	0.46	0.53	0.66	0.79	0.92	1.05
15	0.73	0.85	0.97	1.21	1.45	1.69	1.94
20	1.12	1.30	1.49	1.86	2.24	2.61	2.98
25	1.56	1.82	2.08	2.60	3.13	3.65	4.17
30	2.05	2.40	2.74	3.42	4.11	4.79	5.48
35	2.59	3.02	3.45	4.31	5.18	6.04	6.90
40	2.96	3.69	4.22	5.27	6.32	7.38	8.43
45	3.14	4.19	5.03	6.29	7.55	8.80	10.06
50	3.31	4.42	5.89	7.37	8.84	10.31	11.79
55	3.48	4.64	6.18	8.50	10.20	11.90	13.60
60	3.63	4.84	6.45	9.68	11.62	13.56	15.49
65	3.78	5.04	6.72	10.08	13.10	15.28	17.47
70	3.92	5.23	6.97	10.46	14.64	17.08	19.52
80	4.19	5.59	7.45	11.18	16.77	20.87	23.85
85	4.32	5.76	7.68	11.52	17.29	22.86	26.12
90	4.45	5.93	7.91	11.86	17.79	23.72	28.46
95	4.57	6.09	8.12	12.18	18.28	24.37	30.86

Gutter outlets

(Use of Tables 27 and 28)

Having determined the depth of water at the downstream end of the gutter (yc). The depth (yc) is for a free-flowing gutter and a depth not less than this must be used to size the gutter outlet from the Figures.

Procedure

Select Table 27 or 28 for type of outlet required, i.e., square/rectangular or circular, and read outlet size from table against depth of water over outlet.

NOTE

1. It is recommended that a box receiver is constructed at the outlet to be full width of gutter, and depth no less than $H + 25$ mm. The gutter will not otherwise act as a free outlet, which would invalidate previous data.
2. Diameter of outlet to be a minimum of $3/4$ the width of gutter to ensure free discharge where a sump is not used.

3. Bs (mm) = Sole width of gutter

Lg (m) = Length of gutter

Q (l/sec) = Discharge of flow in gutter

yc (mm) = Depth of flow at downstream end of gutter discharging freely

yu (mm) = Depth of flow at upstream end of gutter

yuf (mm) = Depth of flow at upstream end of gutter taking into account the affect of frictional resistance

yg (mm) = Overall depth of gutter

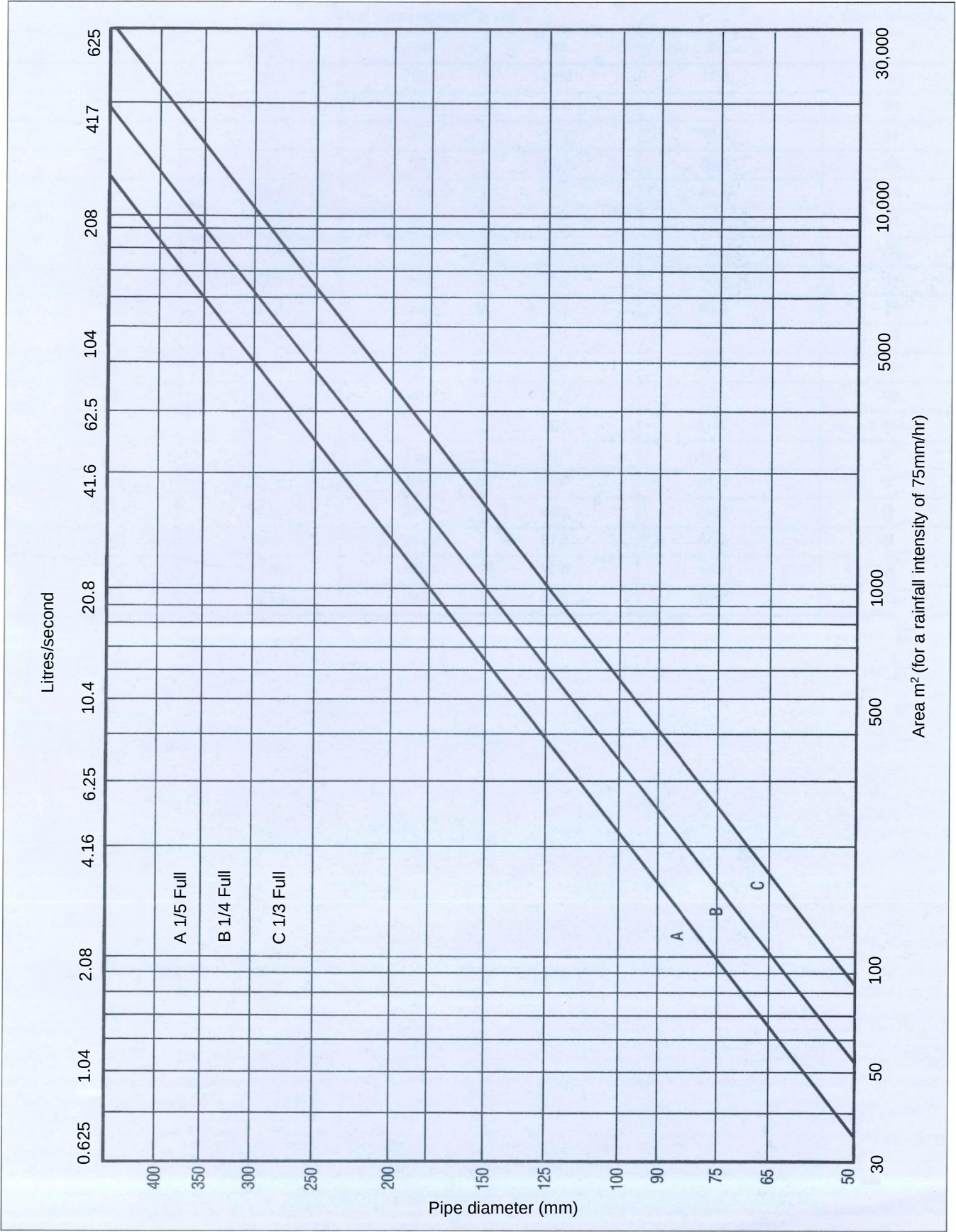
yg x1.5 = Length of sump

Table 28 Flow rates, circular ungrated gutter outlets (litres per second)

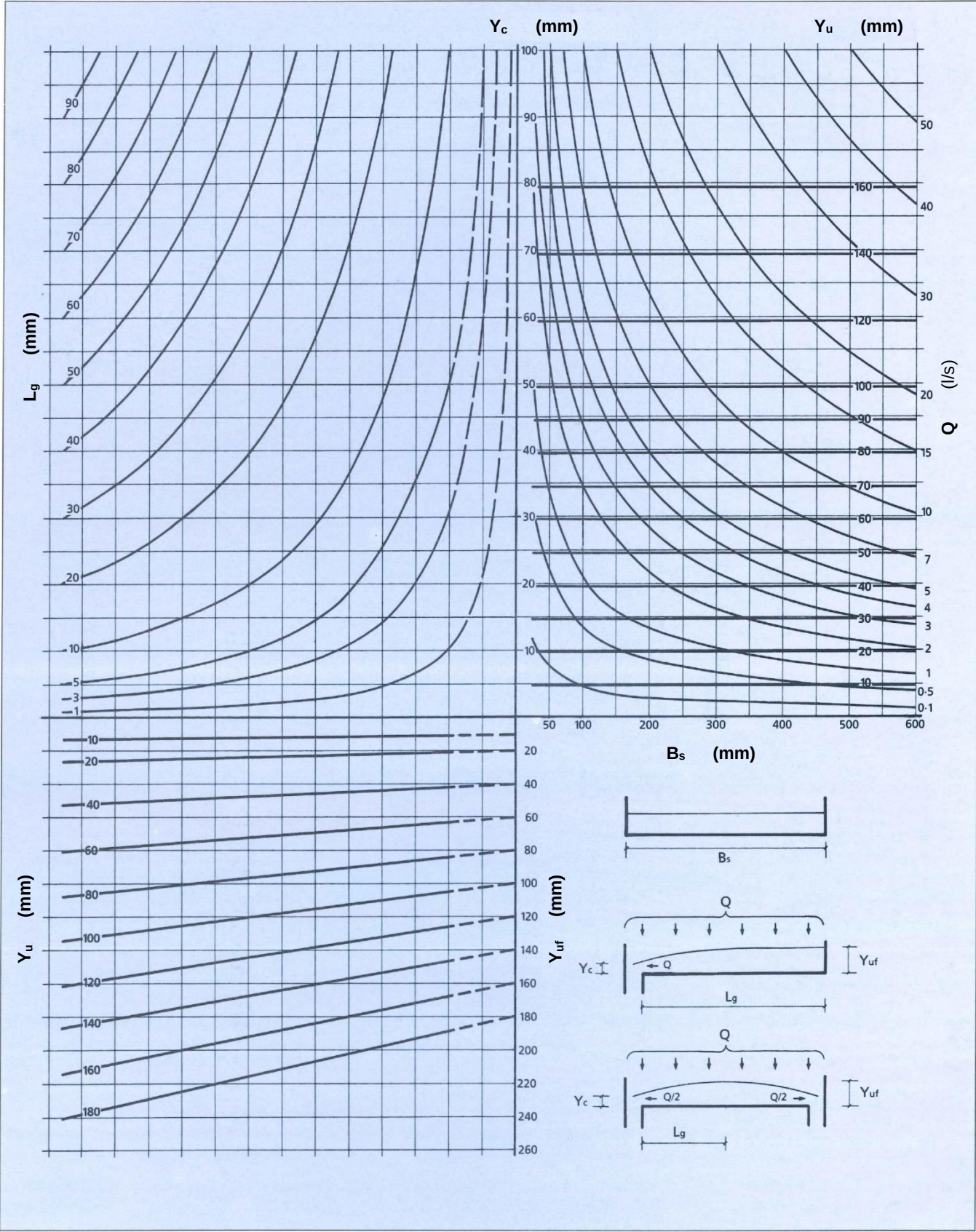
Head of water over outlet in mm H	Size of rainwater outlets in mm				
	75	100	150	200	250
5	0.11	0.15	0.22	0.30	0.37
10	0.32	0.42	0.63	0.84	1.05
15	0.58	0.77	1.16	1.55	1.94
20	0.89	1.19	1.79	2.39	2.98
25	1.25	1.67	2.50	3.33	4.17
30	1.64	2.19	3.29	4.38	5.48
35	2.07	2.76	4.14	5.52	6.90
40	2.37	3.37	5.06	6.75	8.43
45	2.52	4.02	6.04	8.05	10.06
50	2.65	4.71	7.07	9.43	11.79
55	2.78	4.94	8.16	10.88	13.60
60	2.90	5.16	9.30	12.39	15.49
65	3.02	5.37	10.48	13.97	17.47
70	3.14	5.58	11.71	15.62	19.52
75	3.25	5.77	12.99	17.32	21.65
80	3.35	5.96	13.42	19.08	23.85
85	3.46	6.15	13.83	20.90	26.12
90	3.56	6.32	14.23	22.77	28.46
95	3.66	6.50	14.62	24.69	30.86

Graph 7 Vertical rainwater pipe sizing chart

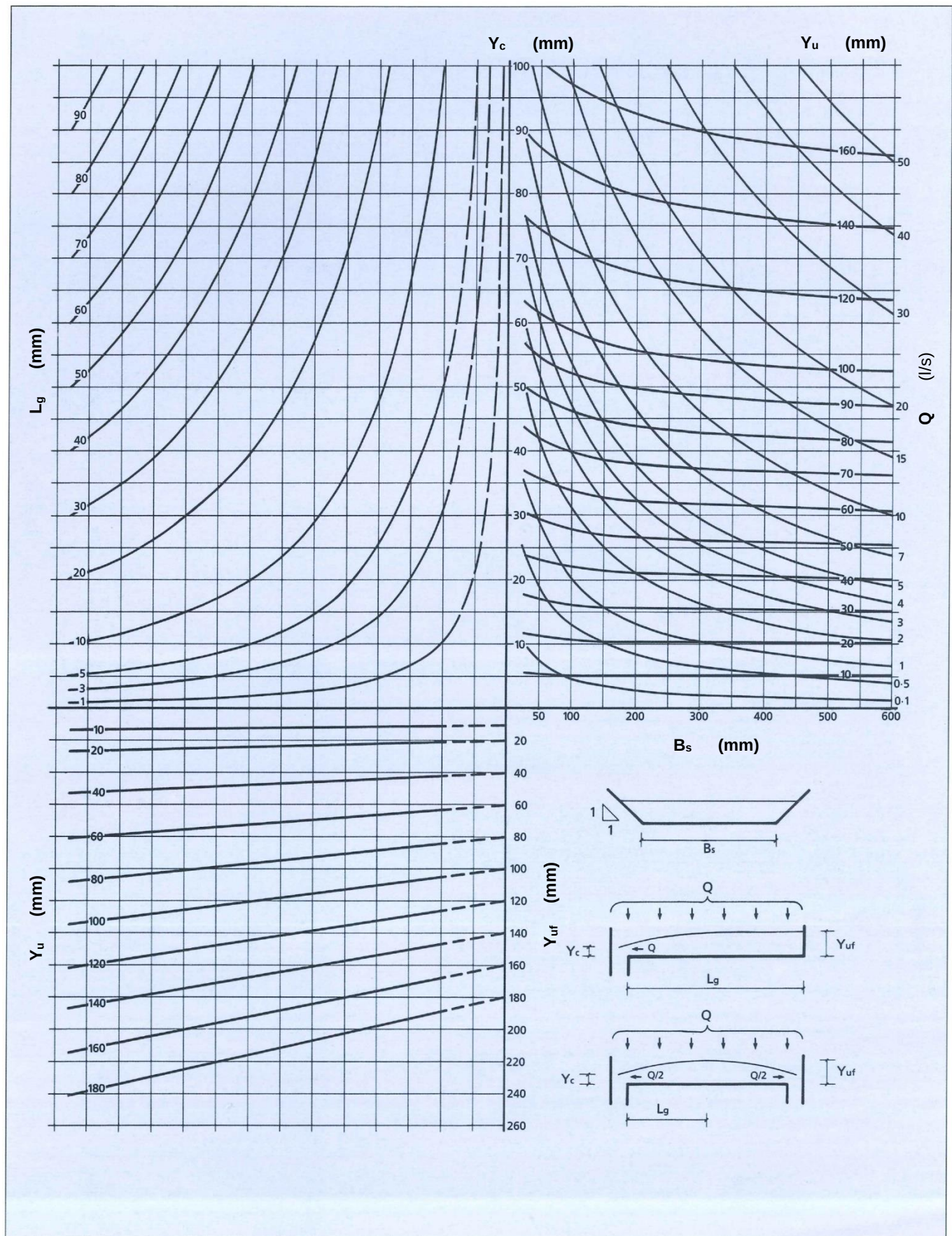
An alternative to this Graph is Table 8 from BS EN 12056



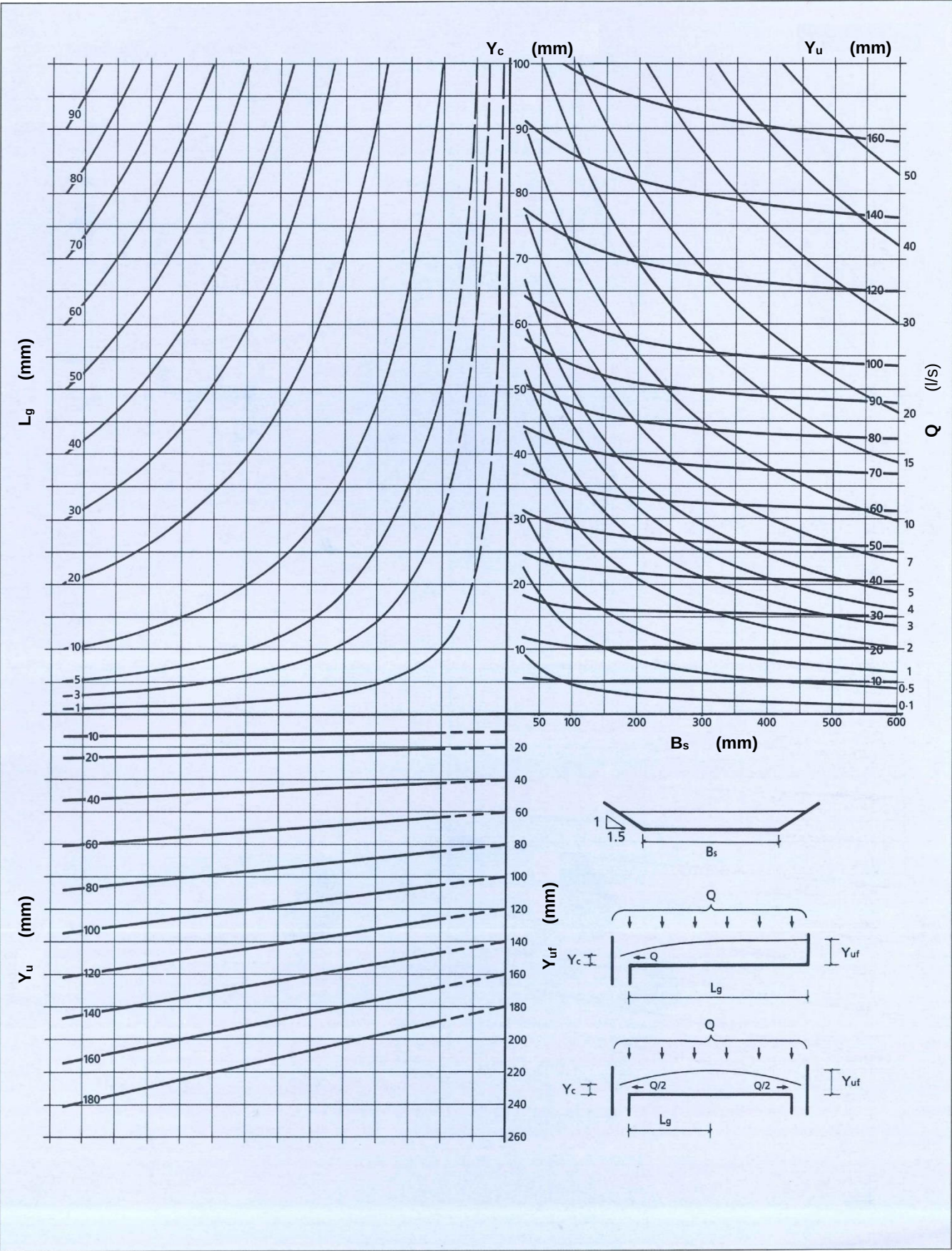
Graph 8 Rectangular Box Gutter



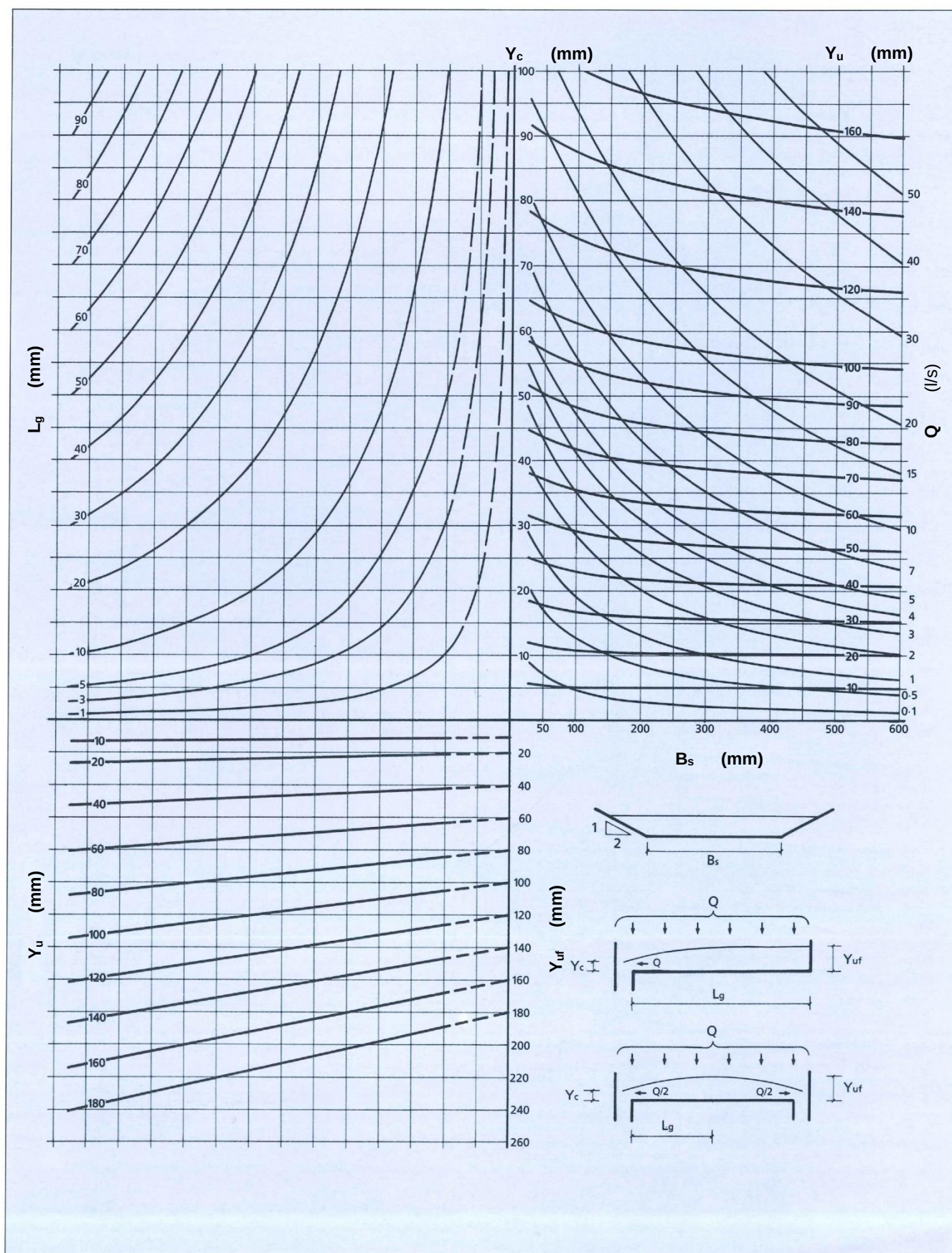
Graph 9 Trapezoidal gutter with 1 to 1 side slope



Graph 10 Trapezoidal gutter with 1 to 1.5 side slope



Graph 11 Trapezoidal gutter with 1 to 2 side slope



Siphonic rainwater systems

Introduction

A siphonic rainwater system is not truly siphonic according to the dictionary definition and should be seen as a full-bore system. The capacity of a full-bore system is dependent upon the size of the pipework and the available head from the water level over the outlet to the 'Velocity break' at the bottom of the system.

Specially designed roof outlets restrict air from entering the system allowing the pipework to be balanced using hydraulic principles. This allows the pipework to flow full bore under a head at the design rainfall intensity. Roof outlet manufacturers provide validated test data which indicate the minimum head of water required over outlets, to prevent air entrainment at given flow rates. It must be appreciated that this head requirement is to prevent air entrainment at the stated flow rate and not to force the water into the outlet as with a gravity system. The driving force in a siphonic system is the available head in the total system.

There are several space and cost advantages with a siphonic system:

- Pipework is smaller in diameter than a comparative gravity system and can be run level, occupying less space in ceiling voids making co-ordination of services easier.
- Vertical discharge pipes can be kept to a minimum reducing the number of connections to the underground stormwater drainage system. This minimises the amount of associated ground works to be implemented on site.
- Higher velocities generated in the pipework produce a self-cleaning flow, eliminating the need for rodding points.

The design must be carefully considered, or problems will be encountered due to:

- High negative pressures and possible cavitation
- High noise levels
- Excessive vibration
- Potential surcharging of gutters.

The rainwater pipework must not be designed in isolation but must form an integral design with the roof/gutter and the external drainage. The final balancing of the system head losses is critical and extremely sensitive to any variation in pipe lengths and fitting changes. For this reason, several balance checks may have to be made during installation if variations occur on site.

Design criteria and considerations

The roof area to be drained and the rainfall design intensity should be calculated as described elsewhere in this Guide.

Design of the system considers the building roof area to be drained together with the rainfall design intensity peculiar to the project location and building protection, in accordance with BS EN 12056-3. Where long term protection is required, the high rainfall intensity and consequent long return period, may conflict with the need to operate the siphonic system at full bore flow regularly to flush it through. In this situation consideration should be given to storing the higher intensity flows at roof level for a few minutes with the siphonic outlets operating as regulating valves. The additional head over the outlets will not noticeably increase the flow into the pipes. Due allowance must of course be made for the additional depth of water to build up without penetrating the waterproofing details.

Alternatively, provision must be made to discharge the water resulting from storms above the design intensity. The incorporation of weir or piped overflows at the end of long valley gutters is inadequate as they do not control the depth of water between outlets in the centre portion of the gutter. The use of a separate overflow system with overflows located between each outlet is necessary.

Alternatively, a system comprising siphonic outlets positioned at suitable intervals and heights along the gutter and connected to separate overflow siphonic pipework is another solution. The required hydraulic gradient and freeboard must of course be calculated from these higher outlets and added to the gutter depth. Such a system is not easy to detail or install and the additional depth of gutter is likely to make it impractical.

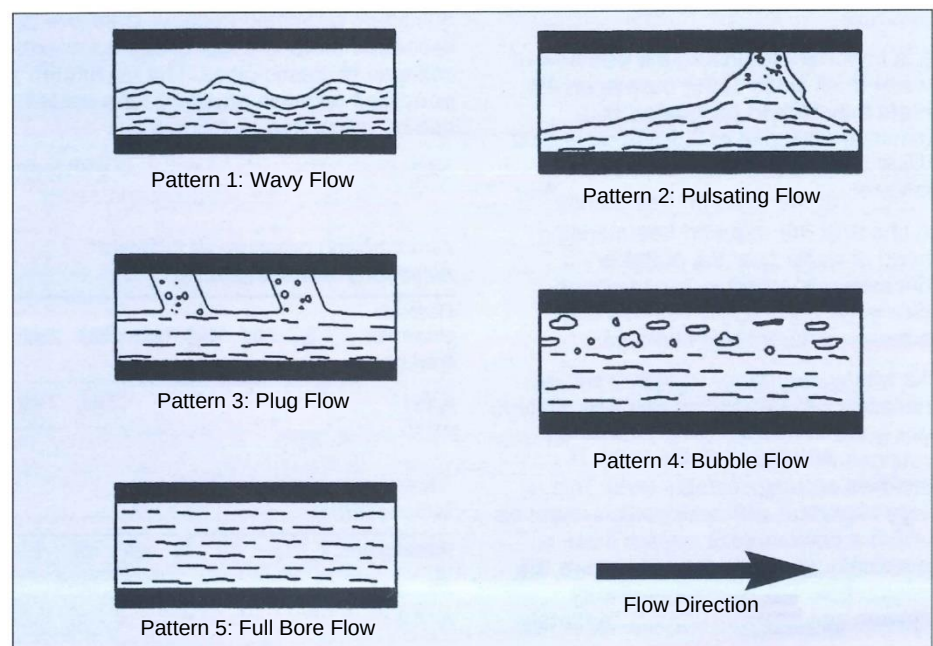
In order to maintain self-cleansing flows a minimum discharge capacity for individual outlets should not be less than 1 litre/sec, unless otherwise specified by the outlet manufacturer.

The roof outlets are specially designed to control the pattern of discharge from the roof. This is achieved by the use of a baffle which when submerged prevents air entrainment and the formation of a vortex.

The full design discharge will not occur instantaneously, sufficient rainwater is required to enter the pipework to prime the system. During this period a number of flow patterns occur with increasing flows until the flow rate to the outlet is exceeded and air enters the system. (Figure 35.)

Figures 35 and 36 illustrate the development of rainfall and roof drainage with approximate limits for the different flow patterns. It can be seen that with flows less than the design intensity the system will drain, and a wavy/pulsating flow occurs. As the water to air ratio increases then a plug flow occurs which leads to a bubble flow. The bubble flow can occur with flows as low as 50% water volume. Full bore flow occurs as the water volume increases and if the system is correctly balanced.

Figure 35 Flow patterns



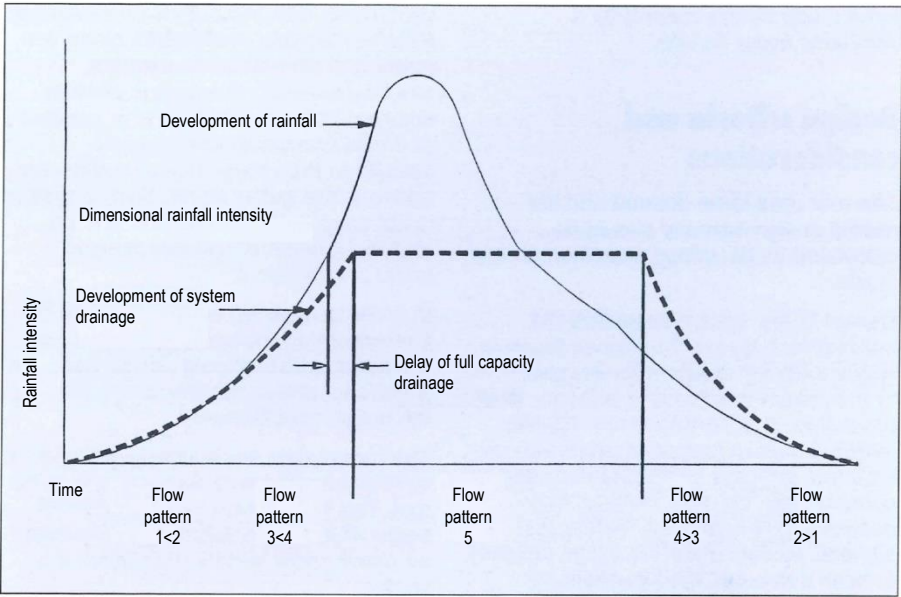


Figure 36 Typical storm flows

If the system has an imbalance, then wavy/pulsating flow may occur more often resulting in a less effective discharge from the roof. Extensive pipe systems may take considerably longer to fill if not designed correctly.

The system will start to discharge under 'siphonic conditions' with water volumes of 50-60% and improve its discharge capacity as water volumes approach 100% of the design rainfall intensity.

Roof outlets currently available tend to cater for nominal flows of 6 l/sec and 12 l/sec. These flow rates are not fixed and are dependent on the working head in the system and the head over the outlet. For exceptional storm intensities such as found in Asia, outlets with a capacity of up to 80 litres/sec are available.

It is important to ensure the free flow of water to all sides of the outlets, on flat roofs they should be located at a minimum distance of 0.5m from vertical walls and not less than 1.5m from intersecting walls or the end of a gutter.

A check of the required free-standing head of water over the outlet is necessary to achieve the maximum discharge capacity as this can vary between different manufacturers.

As with conventional design, it will be necessary to provide an overflow system designed to function when the water retained on the roof or in a gutter reaches an unacceptable level. This is very important with a siphonic system as unlike a conventional system there is practically no spare capacity above the design flow

For example, a gravity system typically running approximately one third full when subjected to an additional 40mm over its design head, could have an increased carrying capacity of up to 20%. This is due to the head of water over the outlet being the driving force in the system.

With a siphonic system the driving force is the difference in height from the water level over the outlet to the 'siphonic break', normally at ground level. Increasing this height by 40mm is insignificant and would typically result in an increased capacity of less than 1%. It will therefore often be necessary to provide deeper gutters to store the additional rainfall above the design figure.

The design of the system must take into account the negative pressures that are created within the pipework. If the maximum permitted negative pressure is exceeded there is a risk of cavitation and collapse of plastic pipes. The maximum permitted negative pressure for a system can be calculated as follows:

Vapour pressure - atmospheric pressure = permitted max. negative pressure

Atmospheric pressure at different elevations above sea level

Elevation above sea level (m)	0	500	1000	1500	2000	2500
$p_a/\epsilon(.g)$ (m)	10.09	9.50	8.95	8.45	7.95	7.45

Vapour pressure at different temperatures

Temperature °C	0	5	10	15	20	25	30
$p_a/\epsilon(.g)$ (m)	0.06	0.09	0.13	0.17	0.22	0.32	0.43

Example

If a system is designed on a building 500m above sea level and the temperature of the rainwater is taken as 10°C, then the permitted negative pressure is $0.13 - 9.50 = -9.37\text{m}$.

The maximum negative pressure must be considered when selecting the working pressure of pipework. Whilst the systems operate well within the pressure range of copper, steel and cast iron, care must be taken when specifying plastics. Manufacturers do not generally publish negative ratings as pipes are normally used for positive applications and therefore the grade of material will have to be confirmed with the manufacturer.

The 'velocity break' is where the full-bore system converts to a conventional gravity system and is an integral part of the design. The receiving pipe must be sized to accept the flow rate (by gravity) that is discharging from the siphonic system. If the velocity of the discharge is high then it may be necessary to introduce an initial collection chamber, to allow the velocity to be reduced before discharging to the sewer via conventional sized drain pipework. Typical velocity breaks are illustrated in Figures 37 and 38.

The positioning of the siphon or velocity break is important, and it must be maintained at all times or the calculations will be invalidated. If the siphon break is surcharged during a storm and the working head increased there could be a significant effect upon the system. Connecting directly from full bore rainwater pipework to full flowing drains extends the working head which increases the negative pressure in the upper part of the system. If the negative pressure exceeds the designed value, the possibility of cavitation increases and under extreme conditions the pipework can implode. Conversely, connections to a surcharging drain will result in backing up in the rainwater pipework and cause the system to overload.

The siphon break will not always be at the bottom of the building as it only needs to be at a height to generate the required working head, i.e., to overcome the system resistances. This may only be one or two storeys down the building.

The system sections must be designed within a head loss balance of typically 400mm between each section to ensure all outlets achieve their design flows within acceptable limits. A section in a system is the run of pipework from each outlet to the velocity break. (Figure 39.)

If this balance is not achieved the system will not function effectively due to increased air entrainment, a reduced discharge capacity and irregular flow. A minimum design velocity of 1m/s is required to enable the system to be self-cleaning, however, during maximum discharge, flow velocities of 6-7m/s are often achieved.

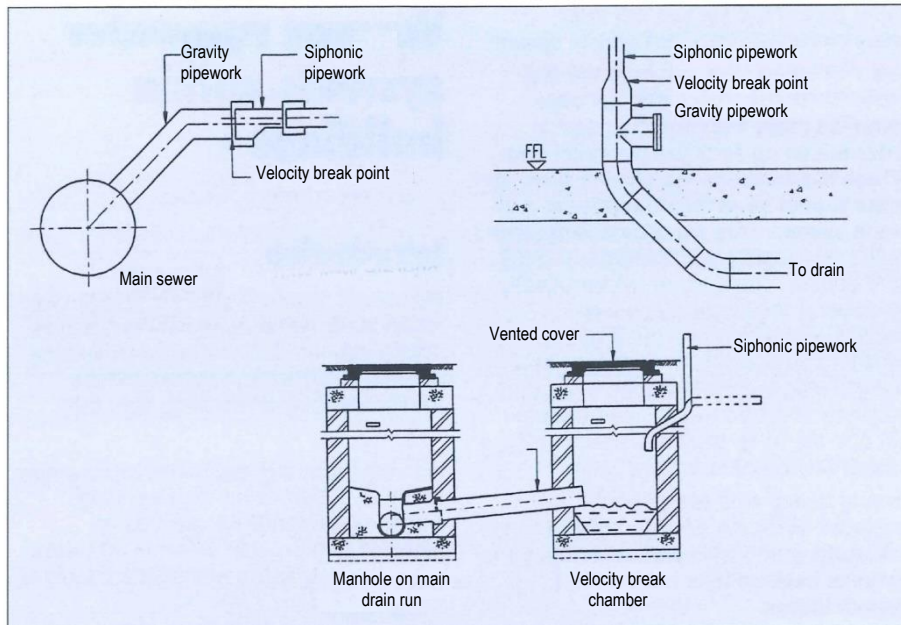


Figure 37 Typical ground level velocity breaks

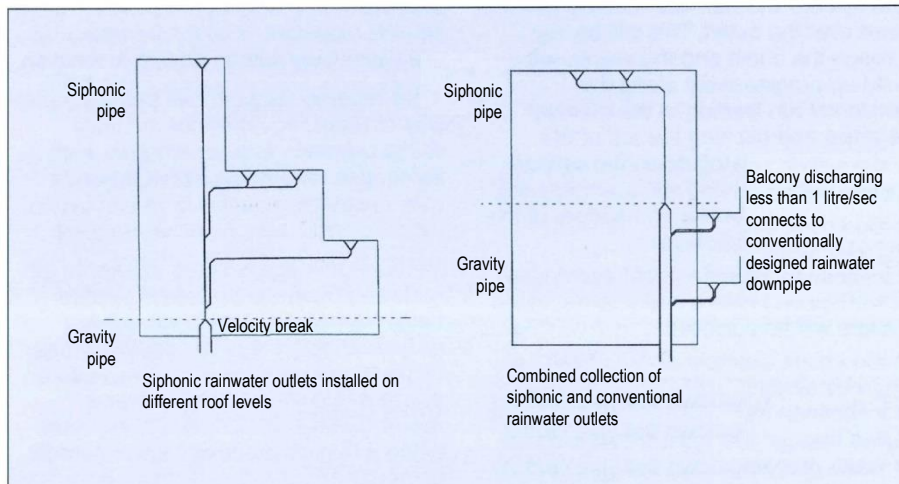


Figure 38 Typical velocity breaks above ground

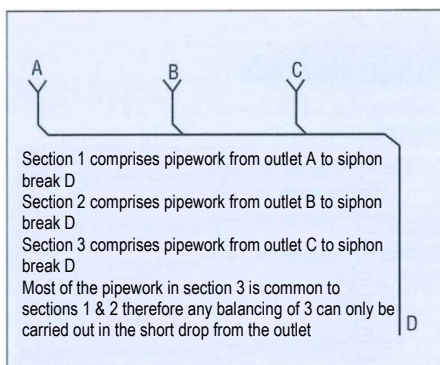


Figure 39 System sections

Consideration should be given to pipe fixing, in particular at changes in direction, as movement and vibration can occur due to the high flow velocities.

Changes of direction should be achieved using 45° bends and branches, both to assist the flow of water and to reduce the resistance.

The high velocity combined with slugs of air during certain flow patterns can generate higher noise levels than would be experienced with a gravity system. Where horizontal pipework is routed above office space or other quiet areas sound insulation should be considered. The outlets themselves generate noise at the point immediately before and after the full-bore flow state. This is caused by air being drawn into the outlet at high velocities.

Joints occurring along the collection pipework should not allow the ingress of air into the system, therefore, during installation there must be the necessary supervision and pressure testing to ensure the system is airtight.

Pipework materials

At present the following materials are being utilised for the installation of siphonic systems:

- Steel
- Copper
- Cast Iron
- Polyethylene

When choosing the material to be used, consideration should be given to the following:

- a. Will the material and jointing method withstand the negative pressure that the system has been designed to, plus a safety margin.
- b. Due to the reduction of vertical pipes longer horizontal runs may be required, provision should be made to accommodate thermal expansion and or contraction (in particular, with the use of plastics).

System design

Procedure

- i. Calculate area of roof to be drained (m^2)
- ii. Calculate the flow of rainwater to be discharged (l/s)
- iii. Has client given any specific design requirements, if not confirm basis of design?
- iv. Note the head. Clearly identify the height from the roof outlet to the velocity break
- v. Fix the position of the roof outlets and hence the area drained, note the individual discharges
- vi. Design the pipework layout, an isometric is useful to mark up the information prior to calculating
- vii. Note the individual pipe lengths and heights within the system
- viii. Calculate the system to achieve the required balance. Note the velocity and negative pressure developed.

This is where a computer program or spreadsheet are essential. The calculations are simple in that for given flow rates and pipe sizes the engineer calculates the head loss in each length of pipe and totals the losses for each section. The losses for each section are then compared to establish the system balance. At this point there invariably follows many recalculations as the losses in the sections are balanced and pipe diameters changed to achieve this. In some cases, in order to fine tune the head loss a length of pipe between two fittings will comprise two different diameters.

This is quite valid as the calculation is about balancing head losses and velocity variations are secondary.

The designer should aim to use all of the available working head in each section leaving as near as practical zero head on the last pipe. In reality this will be a small negative or positive figure but with a maximum difference of 400mm between the lowest and highest section.

These calculations are possible by hand, but they are very time consuming and a simple spreadsheet will save many design hours. Alternatively, some of the specialist designer installers and outlet manufacturers are now releasing their design software to consultants.

Where outlets are located in a common gutter any small differential in system pressure will result in load sharing between outlets. This is a valid adjustment to a calculation but can only be carried out by trial and error. When the flow rates have been adjusted to achieve a pressure balance the resulting hydraulic gradient and increase in flow depth must be checked to ensure the gutter has adequate depth. This method of balancing should only be used when a balance cannot be achieved with the available pipe lengths. It must not be used for outlets in separate roof areas.

Alternatively, some proprietary software will size orifice plates for insertion in the outlets to fine tune a system. This can be a useful method of adjusting a system on site where for instance the intended pipe lengths or numbers of fittings have not been achieved resulting in an imbalance.

When balancing a system, the engineer will often find the need for additional short lengths of pipe in order to fine tune the head losses. For this reason, when numbering a system prior to calculating always break the system down into more than one length between each fitting. A short length upstream of each junction is often useful when balancing. Also, with a run of pipe serving a series of outlets in a gutter, it can be beneficial to run the branches parallel to the main run for a short distance before connecting. This will allow more flexibility in pipe lengths and sizes when balancing.

Balancing a system is simply a matter of achieving the same head loss in each section. This inevitably means that with a typical run of pipework serving outlets in a gutter and dropping at one end, the branches closest to the drop will be smaller in diameter. This is due to the need to create additional head loss in these branches. Failure to achieve this will allow outlets on these branches to over perform and introduce air into the system, breaking the siphonic effect.

The upper part of the system will then operate as an undersized gravity system.

The section of pipework from the last branch to the siphon break will often comprise more than one diameter in order to use up all of the working head. Where this happens the smaller diameter pipes should be at the downstream end of the system. This will allow the system to fill more rapidly and therefore run full bore sooner. The system will be equally balanced if the larger pipes are positioned downstream, but it will be difficult or impossible to fill them with water during the early stages of a storm. A system must be fully primed before it will operate at its design capacity and the sooner this is achieved the better.

Having designed a few systems, the engineer will see a common theme to the calculations and will soon get a feel for a system's balance by observing the system losses.

Taking a typical run of pipework say 0.5m below a gutter with a drop at one end.

The system will start with a small positive head over the outlet. This will be lost through the outlet and the losses will build up progressively along the horizontal run leading to the greatest negative approaching the top of the vertical drop. Moving down the vertical pipe the system head will overcome the previous losses until at the bottom of the system zero is indicated.

If this can be repeated from each outlet to the siphon break a perfectly balanced system will be achieved.

In the above example all pressures are negative along the horizontal pipe run. It is a common misconception that water is pulled through the system by the action of water dropping down the final vertical pipe and that therefore all pressures along the horizontal pipe must be negative. In a situation where the horizontal run is midway down the building and drops from the outlets are of sufficient height to overcome losses in that branch (probably in excess of 1.5m), positive pressures will appear. If the branches are of sufficient height most of the horizontal pipework could be positive. This is perfectly valid as the working head is the total height of the system not just the final vertical section of pipework.

The design of a siphonic system is closer to a cold water down service than a gravity drainage system. If the system is thought of as a cold water down service served by several water cisterns supplying one outlet, then it can be easier to grasp the concept. The level of water in the cistern (above the outlets) is minimised by the use of vortex inhibitors in the outlets. Now all that has to be done is to size the pipes to achieve identical head losses from each cistern to the outlet.

Vacuum rainwater systems within buildings

Introduction

Rainwater systems within buildings have traditionally relied on gravity to function. This has been due to the overwhelming reliability of gravity systems and the traditional form of buildings over the millennia.

As architects and engineers explore new forms of construction the Plumbing Services Design Engineer has to respond and provide systems that work in harmony with the architectural form of the buildings.

This in recent years has led to the incorporation of siphonic rainwater systems within developments which allow smaller pipework to be incorporated but still essentially rely on gravity to function.

More recently vacuum has been seen as way of providing rainwater drainage within buildings with advantages such as being able to route pipework upwards over obstructing beams or in fact over long distances with no or minimal fall.

Vacuum drainage isn't the answer to all rainwater drainage problems; several fundamental questions have to be answered before it is considered by the designer for use on a project to ensure that it is suitable. Vacuum systems require maintenance and rely on there being a reliable electrical power source.

The following section identifies the major components within systems and discusses their operation.

Fundamentals

Intensity

As with any rainwater system the designer must review the parameters to which he is going to design. This obviously starts with the question of what rainfall intensity is to be used. Many methods exist for obtaining the point rainfall intensities to be designed for linked to the level of risk and the security required for the building.

These methods suggest an intensity for design based on a gravity system where only limited possibilities of failure exist such as blockages. A mechanical system by its nature incorporates a greater number of possibilities for failure and for this reason the engineer must also consider this against whether a vacuum system is suitable for a particular building.

For instance, it may be an acceptable risk to incorporate a vacuum system within an office development but not in an art gallery where the consequence of failure is greater. Each building should be considered on its own merits and the pros and cons considered before any system is selected for use. Even then the designer should consider the form of the roof, a flat roof with internal parapet gutters is less secure than a pitched roof with eaves gutter that would purely shed water over the side at times of failure.

Components

Vacuum systems used for draining water from roofs and other similar areas incorporate similar items of equipment to foul drainage systems, including vacuum pumps, vacuum pipework, vacuum vessels, discharge pumps, actuators and interface valves.

Interface valves and actuators

The interface valves are located within the box receivers designed as part of the gutter system. It is important that some form of box receiver or sump is used in order to ensure that the interface valve, when called upon to function, will have a reasonable quantity of water to discharge. The system will, for lower rates of runoff, remove water from the sumps intermittently as they fill up and stop once the sumps are empty. The actuators which should be located remotely from the interface valves in a position to aid maintenance, sense the rise in water level within the sump/box receiver and open the interface valve for a predetermined time, sufficient to ensure the sump unit/receiver is emptied.

Vacuum pipework

The vacuum pipework consists of a network of pipes which are routed back to the main collecting vessels. These pipes are constantly maintained at vacuum, the level of which is dependent on the lift required of the system. If a system is required to lift rainwater through 2m vertically then the vacuum the system generates must be in excess of the 2m lift required.

Vacuum vessels

The vacuum vessels within a surface water system serve two functions. Initially they act as vacuum buffers that enable the system to function and for the vacuum pumps to operate. The buffer allows the vacuum pumps when called upon to operate to do a reasonable amount of work replenishing the vacuum in the buffers before they need to turn off.

Systems with low volumes would require the pumps to constantly be switching on and off in response to valves opening.

Their second function is to act as a holding tank prior to discharge to the sewer/discharge system. This is necessary as vacuum systems need to be pumped to waste, it is not possible to simply open a valve on the vessels and allow them to empty by gravity. Vacuum, and therefore the operational status of the system, must be maintained at all times and the opening of a valve on a vessel would result in vacuum being lost. The provision of vacuum tanks gives the designer the opportunity to provide attenuation within the system. This is where the allowable discharge to the sewer is less than the expected runoff from the roofs. As local authority sewers become more congested the requirements for attenuating of discharge become more and more likely. Many projects within built up areas now require some form of attenuation. The attenuated runoff is stored within the vessels whilst the discharge is arranged to release water to the sewer at a controlled rate, the excess being the volume required to be stored within the vessels.

If the required attenuation storage is high a separate storage vessel should be provided to receive the pumped discharge from the vacuum vessel.

Local authorities will need to be consulted as to what their limits of discharge are likely to be and what level of protection is required. This will be specified as an allowable discharge in l/s and a return period critical storm to be protected against. The return period will be given by the local authority and could be for example 10 years. The duration of the storm that gives the critical (maximum) volume of storage will then have to be calculated. The actual stored volume is dependent on the areas drained, the limit set by the local authority and the allowable flow to the sewer. These calculations balance the inflow with the outflow and give a resultant volume required to be stored throughout the storm. If allowable discharges are relatively high, then short sharp flash storms can result in peak storage volumes whilst longer storms require peak storage when allowable discharges are small.

The calculations required for this type of analysis are complex and require input hydrographs for storm profiles relevant to the location of the site and for the duration of storms likely to yield the critical volume, usually between 30 minutes and 2 hours duration. These are most easily assessed using proprietary software.

Vacuum pumps

The vacuum pumps are required to generate the vacuum within the system. These should be arranged as duty, assist and standby. Their duty cycle should be rotated after each operation to yield even wear on the pumps. The pumps are connected via a header to the vacuum vessels and operate on pressure switches to maintain the vacuum in the system.

The vacuum pumps draw the air contained within the vessels above the water surface to maintain a vacuum and this needs to be expelled outside. Although relatively clean water is contained in the vessels it may contain leaf debris which over time will rot and cause odours. The discharge from the vacuum pumps should therefore be directed to discharge in a location so as not to cause nuisance. Location in accordance with the building regulations for vent pipes would be appropriate for such a termination but it should be remembered that the discharge is forced by the vacuum pumps and could be moisture laden, so siting next to surfaces where it could readily condense such as metal cladding systems may cause staining.

Any moist air within the vent will have a tendency to condense and run to the bottom of the vent during times when the vacuum pumps are not operating. To remove condensation from the discharge line a small suction line is connected into the discharge at its lowest point to suck the condensate back into the vessels by opening a solenoid valve on the small bleed line before the vacuum pumps operate.

Discharge pumps

Having been filled with the surface water from the roofs, the discharge pumps empty the contents of the vessels into the drainage system or sewer. Vacuum pumps used for the discharge of water from a vacuum must be designed specifically for this use. Conventional pumps are designed to draw water under flooded suction yielding a positive suction head. Pumps used on vacuum systems need to draw water from a vessel that is at a negative head and raise its pressure sufficient to overcome the negative head plus any lift involved. It is important when specifying duties for systems that it is clear exactly what the pumps need to achieve, to avoid confusion it is worth stating both the lift the pump is required to perform as well as the negative head the pumps are to overcome.

On start-up of the discharge pumps, they must overcome the maintained level of vacuum in the vessels. In order to allow the pumps to discharge efficiently certain other components within the system need to operate.

Table 28 Typical control sequence

If the discharge pumps were to start pumping out the contents of the vessels, then as the water level drops within the vessels the air above its surface will become more rarefied and the vacuum in the vessels will increase to a point where the discharge pumps may not pass any more water. To ensure the level of vacuum in the system does not increase due to the discharge pumps functioning the increased vacuum must be released. This can be done by opening a small solenoid valve on the top of the vessel so as to admit air into the vessels to replace the volume of water being removed. The opening of the solenoid can also help in priming the pumps by ensuring the water in the suction headers is not drawn away from the impeller by the vacuum in the vessels.

Some manufacturers achieve this by having a balance line connected to the discharge side of the pump linking back into the vessels which ensures even pressure either side of the pump at all times until it operates. When this happens the balance line is shut with a solenoid valve ensuring the pumps discharge to waste and not back into the vessels.

Vessel operating cycle

On initial start up the vessel is empty and the system is at atmospheric pressure. The pressure within the vessels is registered by the pressure switch and starts the vacuum pump to expel air from the vessels and system. Upon reaching the design level of vacuum the pressure switch shuts the vacuum pumps down, the system will sit in this static mode until the pressure drops in the system once again whereby the vacuum pumps will start to replenish the vacuum. See table 28.

A drop in vacuum can be caused by either a leak within the pipework and system or by the admittance of water into the system. It is important to ensure the system does not incorporate any leaks as this, even if small, will cause the system to cycle the vacuum pumps which will increase wear on them leading to premature failure.

Water entering the system will be pushed along towards the collecting vessels each time the interface valve, within the box receiver or sump, operates. The water will therefore move along the pipework system in pockets, each containing the volume drawn into the system at each operation of the interface valve. The heavier it rains the closer together these pockets of water become.

Table 28 Typical control sequence

Condition	System function
System charged with vacuum whilst it is rarely not raining	System remains static. Vacuum pumps cut in to maintain vacuum and to exercise pumps.
Rain starts	Gutters convey water to the box receivers. Water levels in receivers rise. Sensors detect the rise. At the set level the interface valve will open and allow the pipework to draw water into it, emptying the box receiver. When empty the interface valve will close. The entry of water into the system will lower the vacuum level in the pipework and vessels.
Interface valves open allowing slugs of water to enter the system. Vacuum levels within the system drop to below lower set point.	At lower set point the vacuum pumps will start to replenish vacuum. Prior to vacuum pumps starting the vacuum pump discharge line will be purged of condensation via a link back to the receiver vessels. This is achieved by a solenoid valve opening and closing prior to the pumps starting.
Repeated opening of discharge valves and transport of rainwater to the vessels causes them to become full and need emptying.	High level float, or sensor, will initiate the discharge pump.
Water level in tanks drop during pump out to the lower level float or probe.	Discharge pumps are stopped and system returns to normal, awaiting next cycle of operation.

In order to assist in the transport of the water, reforming points are fitted in the system. These take the form of a trap in the pipework, which allows the water pockets to reform across the diameter of the pipe ensuring they get transported along the system the next time a valve opens. Without reforming pockets, it is possible for the water within the pipework to pond at the base of the pipe and for the air within the system to rush past when the interface valves open and for the water not to be transported along the pipe efficiently.

The water moves along the system until it arrives at the vacuum vessels. The vessels fill and upon reaching a high-level float switch or sensor the discharge pumps will empty the vessels. The pumps are arranged to shut off once a low-level cut-out switch or sensor has been reached.

As all rainwater systems are designed to function for a finite rainfall intensity and it is likely that it will rain at an intensity greater than this at some point in the life of the system certain safeguards need to be incorporated.

In order to ensure the system does not overflow and flood the vacuum pumps a means of shutting the vacuum lines need to be incorporated into the system. This is often achieved by the introduction of a motorised valve in the vacuum line and a high-level flooding float/sensor introduced into the vessels.

The high-level flooding float/sensor will isolate the vacuum pumps from the vessel in the event of a high-water level in the vessels ensuring that water cannot enter the vacuum pumps.

Design hints

- Allow freeboard at the top and bottom of the vessels for dead water and freeboard. The operating band of the vessels between high water level and low water level is the actual holding capacity of the tanks. This is the actual volume required for retention. The vessel volume must be greater than this to allow for freeboard and dead water.
- Operate the system at as low a vacuum as possible. This will reduce the tendency for leaks and reduce the noise from the interface valves.
- Fix the pipework adequately. The velocity of water slugs is high and can cause vibration at changes of direction and if not properly braced.
- Ensure the discharge pumps discharge into an adequately sized/vented drain.
- Discharge lines should rise to high level and loop into the top of the drain in order to eliminate siphonage assisting the discharge pumps and greater volumetric flows entering the drainage system than the design discharge.
- Locate interface valves in easily accessible locations. It is not necessary for them to be immediately adjacent to box receivers.
- Consider acoustically treating pipework in sensitive areas.

- h. Provide duplicate interface valves in gutters to provide backup in the event of one becoming stuck.
- i. Hold adequate supplies of spares on site to assist in the routine maintenance of the plant.

Vacuum drainage systems

Introduction

Vacuum systems for the transportation of wastewater can be divided into two basic systems: within buildings and outside buildings. European Standards, adopted as British Standards, have been written for these two systems. The Standards contain the design, installation and performance requirements for vacuum drainage and vacuum sewerage systems. However, such systems are currently manufactured by a few international companies that fiercely safeguard their system design details. Hence, although the Standards specify the requirements for systems and set out the design principles, the actual design process depends upon the performance of the individual components and the design philosophy of the manufacturer. The main manufacturers of vacuum systems use different design philosophies, and this results in their use of different pipe sizes, pipework configurations and interface valve sizes.

It would be wrong for this book to recommend one manufacturer's system, as each prospective installation usually requires a unique design. Unlike a conventional gravity drainage or sewerage system, a vacuum system should be considered as a complete machine and not a simple hydraulic network. Engineers often want to be able to design a vacuum system in the same way that they would design conventional systems. However, currently the information they require, such as the performance characteristics of the interface valves, is not in the public domain. Hence, designers, specifiers and clients are only able to use the Standards, and information such as this section, to help them decide if a vacuum system is applicable for the project they have in mind and agree an informed specification for any system.

Background

Generally, the modern vacuum drainage system is believed to have been started by the development of the vacuum toilet by Mr Joel Liljendahl in the mid-1950s. The concept of his system was to separate the heavily polluted waste and the lightly polluted water (black and grey water) for separate treatment. The vacuum toilets used only about 1 litre of water per flush improving the efficiency of the system and making treatment easier. This two-pipe system, although environmentally friendly, met with quite a lot of resistance because houses needed to be re-plumbed and the vacuum toilet required more maintenance than a conventional toilet. This led to the development of the single pipe vacuum drainage system generally employed today.

Whilst the original systems were developed for domestic wastewater transportation, the systems evolved in two different areas: transportation and land-based systems. The majority of work has been in the transportation sector, and the marine industry continues to be the major user of the system, where the need to conserve wholesome water, and the problems of confined pipework runs and sewage disposal are paramount. For the same reasons this technology was adopted by the other forms of mass transport, i.e., airlines and railways. Today some 5,000 ships, from yachts to cargo vessels to ocean-going cruise liners, 50 major airline companies, and over 100 train installations use vacuum drainage systems.

The building sector has been slow to adopt this new technology, but with the restrictions placed on new projects such as small conduit, ceiling voids and service ducts, and the growing awareness of the need to limit water consumption, the system is finding a place in the building sector.

Applications

Particular consideration should be given to the use of vacuum drainage in the following circumstances:

- a. Water shortage or other reasons for reducing water consumption.
- b. Limited sewerage capacity
- c. Where separation of black and grey water is desired, e.g., where grey water is reused
- d. Where separation of wastewaters is desired, e.g., for different treatments
- e. In hospitals, hotels, office buildings or other areas where congested usage occurs

- f. When flexibility in pipe routing is required to drain appliances or where frequent pipe layout changes are expected
- g. Building refurbishment
- h. Where drainage by gravity becomes impractical
- i. In complex building structures and
- j. In penal installations where isolation and control of the appliances is necessary to prevent concealment of weapons and drugs.

Black and grey water

The collection arrangements and small-bore pipework of vacuum drainage systems provide the possibility of easily separating grey and black water. This was one of the original aims of the invention by Mr Liljendahl. This would be of particular advantage if sewerage capacity was at a premium as the grey water could be run to a water course after preliminary treatment. Also, it would be of advantage if there was a requirement to use the grey water for reuse or irrigation.

Retrofit and newbuild flexibility

When conventional gravity drainage systems are extended as in refurbishment work, the existing gravity drainage system can be fed into the vacuum drainage system. This may be achieved by the use of a sump into which the wastewater from the gravity system drains. When sufficient water has accumulated in the sump, an interface valve will open allowing the wastewater to enter the vacuum drainage system. This arrangement can also be used to collect rainwater or as an interface between a building with conventional drainage and a vacuum sewer.

System descriptions

Definitions of terminology

A selection of the fundamental definitions that are required to understand the terminology of vacuum drainage systems are listed below. A complete set of definitions is contained within the European Standard EN 12109.

Buffer volume: The storage volume of the interface unit which balances the incoming flow of wastewater to the output capacity of the discharge valve.

Controller: The device which, when activated by its level sensor, opens the interface valve and, after the passage of wastewater and normally air, closes the valve.

Interface valve: A valve which admits the flow of wastewater only or wastewater and air into the vacuum drainage system pipeline.

Lift: Section of vacuum pipeline with an increase in invert level in the direction of flow.

Reforming Pocket: A low point in the piping profile installed intentionally to produce a controlled slug flow.

Service Connection: The section of vacuum pipeline connecting an individual interface unit to the vacuum main.

Slug: An isolated quantity of wastewater flowing full bore through the vacuum pipeline.

Vacuum: Any pressure below atmospheric.

Vacuum Station: An installation comprising vacuum generator(s), a means of discharge, and control equipment and which may also incorporate vacuum vessel/holding tank(s).

The vacuum transport process

An understanding of the vacuum transport process is helpful to the system designer. As long as no interface unit is operating, little wastewater transport takes place. All wastewater remaining in the vacuum pipework will drain, by gravity, into the reforming pockets when all upstream interface valves are closed. When an interface valve opens, the differential pressure between the vacuum in the system and atmosphere, forces the wastewater into the vacuum pipework. Whilst accelerating, the wastewater is transformed into foam and soon occupies only part of the vacuum pipe cross section so that the momentum transfer from air to water takes place largely through the action of shear stresses. The magnitude of the propulsive forces starts to decline noticeably when the interface valve closes but remain important as the admitted air continues to expand. Eventually, friction and gravity bring to rest the wastewater at the low points of the pipework system, such as reforming pockets and at the bottom of pipeline lifts.

The vacuum drainage system transports wastewater by means of atmospheric pressure acting against vacuum.

When designing systems greater than 100m in length (from the valve to the vacuum station), a series of reforming pockets must be used. These minimise the break-up of the wastewater slug and reform that portion of the slug that remains in the piping between interface valve discharges.

The reformed slug is then propelled by the air admitted during the next discharge.

Once the interface valves have operated, the discharge travels to the vacuum station, normally located at ground or basement level. Air is discharged to atmosphere only from the vacuum station. From the vacuum station, the wastewater is pumped automatically to the building outfall connection, to discharge into the external drainage system by gravity.

To design a reliable and economic vacuum drainage system, it is necessary to generate sequentially high acceleration and self-cleansing velocities with the least amount of energy.

NOTE:

A vacuum drainage system is NOT a reversed pressure system where all the water would be accelerated simultaneously.

Basic components

A vacuum drainage system may be considered as comprising four elements:

- The automatic interface units (AIU)
- The vacuum toilets
- The pipework
- The vacuum station.

Interface units

The valves that form the interface between the vacuum drainage lines and the appliances can be used directly with some appliances and with buffer volumes for others. When used with buffer volumes, level sensors and controllers, the valves are termed interface units (AIUs). Although AIUs are operated by air, non-automatic units may use electricity to control their operation.

They are of various sizes of interface valve up to about 100mm bore. The larger valves are used in vacuum sewerage systems.

Typically, a complete interface unit is composed of a buffer volume of varying size, a sensor to sense the wastewater level in the buffer volume, a controller which operates a pilot valve to open and close a vacuum supply line to the interface valve. In many designs of interface unit, level sensors and controllers are combined into one device.

Vacuum toilets

A vacuum toilet uses air instead of water to remove the contents of the bowl and is a form of interface valve. Usually, it includes a flushing rim and the toilet's controller may have a memory function so that it will operate as soon as there is sufficient vacuum available.

Typically, when operating a flush button, pressurised water is introduced into the bowl through a water valve and a flushing ring with holes to clean the bowl. Simultaneously the interface valve opens and the pressure differential in the piping forces the contents through the valve. Before the interface valve closes, air is drawn into the pipe. The flush water valve stays open for about two seconds to re-establish the water pool in the bowl. The typical water consumption for this timing sequence would be 0.8-1.5 litre per flush. Vacuum toilets may be re-flushed in less than a quarter of the time taken for a conventional WC to refill, on average, a vacuum toilet will take 3 seconds to complete a flush cycle.

Ejector unit

Ejector units are used on small systems, which require approximately 40m³ of air an hour at peak flow. They have the advantage of having a lower capital cost, being small in physical size and with fewer working parts than vacuum pumps and are easy to maintain and operate. However, they are less power efficient than a conventional vacuum station and, therefore, are more expensive to run. The control of this kind of vacuum station is similar to a conventional pumping station. These units can also receive discharges from gravity drainage systems directly into the tank. However, wastewater containing high levels of detergents may cause foaming problems.

Vacuum station

A vacuum station has three functions:

- Generate vacuum
- Receive and forward the wastewater and
- Control and monitor the system.

Although vacuum stations may be used with similar systems as the ejector unit, they are used mainly for larger systems, i.e., greater than 40m³ of air. They are large units with a higher capital cost but typically are cheaper to run than ejectors.

The machinery installed is similar to that of a conventional wastewater pumping station or lift station, and consists of a collection tank, wastewater forwarding pumps, vacuum pumps, controls and alarms, and where required a standby generator.

The vacuum receiver tank size and/or number of tanks depends on the number of appliances connected to the system and the expected frequency of discharge.

Each tank incorporates level switches that control the discharge pumps automatically, vacuum regulator switches which control the vacuum pumps and level alarms which can be audible or connected to the building management system.

Vacuum generating and forwarding pumps

Vacuum generating pumps

Vacuum pumps of the liquid ring and sliding vane types are both suitable for use in vacuum drainage systems. Vane type vacuum pumps are recommended for most projects since they are more efficient, i.e., they have a greater throughput of air and are less temperature sensitive than similarly powerful liquid ring pumps.

The maximum vacuum provided by a liquid ring pump often will not exceed -0.8 bar gauge, whilst the maximum vacuum of a vane pump will typically be closer to -1 bar gauge. This will affect the choice of pumps where vacuum levels of a greater magnitude than the normal -0.5 to -0.7 bar gauge operating range will be required, or for projects at high elevations where atmospheric pressure is lower.

A vacuum switch attached to the pipework and adjustable timer are used to control the vacuum pumps. A second vacuum switch may control a low vacuum control alarm signal. These switches are fitted with stainless steel bellows to protect against corrosion from any gases evolving from the wastewater.

Forwarding pumps

Forwarding pumps are required to discharge the collected wastewater to the external gravity sewerage system. These pumps are designed to operate with a large pressure differential across them with their inlets under vacuum. The size of the forwarding pump is a function of the following: design peak flow, volume to be discharged, and the permissible discharge rate for the receiving sewer.

To enable some forwarding pumps to work, a vacuum balance line may be required downstream of the discharge pump to reduce the pressure differences across the pump (a balance line is not required with an ejector system). To prevent loss of vacuum when the pump is not discharging, a check valve is required in the discharge pipework downstream of the connection of the balance line.

Controls

System controls

The vacuum drainage system control panel contains the main power switch and the pump operating system which includes: magnetic starters, overload protection, control circuitry and hours run meters for each vacuum and forwarding pump. A data recorder may be built into this panel, as well as the collection tank level control relays. Alarm and telemetry systems may also be included if required.

Pump controls

The controls should be designed so that, where stand-by pumps and collection tanks are installed, both the vacuum and forwarding pumps alternate their use and are interconnected and controlled to allow them to be used with either tank automatically. The pump controls will include logic controllers that will be connected to the various level and vacuum sensors. The signal to start the discharge comes from the high-level switch in the collection tank, the stop function is either controlled by a low-level switch or timer. For example, when the high-level sensor indicates to the logic control that water has risen to the high level, this sequence of operation will commence:

- i. The controller will close automatic valve in balance line, where fitted, and start the forwarding pump
- ii. If level does not fall within the pre-set time, a second pump will be started, or an alarm generated
- iii. If level reaches the high-level alarm sensor, then an alarm is given, and the vacuum system is shut down
- iv. When the water level has fallen to a low-level sensor or after a pre-set time period, the controller will stop the forwarding pump(s) and open the automatic balance line valve, if fitted.

In systems where only black water is being collected it is prudent to use the second forwarding pump as a circulation pump. This circulates sewage within the collection tank and breaks up any solids which may have formed on the surface of the wastewater. This operation should be programmed into the logic system as the first step in the discharge cycle.

Collection tank level controls

Level detectors are available in various forms, some are float switches, others are fixed probes that may be conductive, inductive or capacitive. Where a lot of condensate is being collected, for example in supermarkets with chiller cabinets, the mineral content of the water may affect the operation of the system and conduction probes may need to be used.

Level detectors, of some form, are fitted to all collection tanks. The signals from the six common detectors control the discharge pumps and alarms as follows, in ascending order of height from the base of the tank:

- i. Earthing probe, or sensor float switch or similar
- ii. Both forwarding pumps stop
- iii. Lead forwarding pump start
- iv. Assist forwarding pump start
- v. High level alarm
- vi. High level cut-off - stop vacuum pumps.

Vacuum gauges

It is important that all vacuum gauges be specified to indicate gauge pressure and have stainless steel bourdon tube and socket.

Vacuum gauges should be provided at the following locations in positions that can be viewed easily:

- a. the side of the vacuum moisture removal tank (where fitted)
- b. the collection tank
- c. one gauge on each incoming vacuum main or header.

It is important that these gauges are located above the incoming pipes and in a position that is easily viewed from the operating position of the isolation valves.

Combined vacuum generator and forwarding pump

A combined vacuum generator and forwarding pump or 'vacuumator' is a screw vacuum pump with liquid ring seal with a macerator for breaking up any solids passing through it. The macerator consists of one rotating knife fixed to the shaft and one stationary knife fixed to the suction chamber.

The combined vacuum generator and forwarding pump;

- a. generates vacuum
- b. macerates solids
- c. pumps wastewater in the same operation.

A combined vacuum generator and forwarding pump can generate vacuum directly on the pipeline to an appliance and discharge to a gravity system in the same operation. Vacuum tanks or collecting tanks are not required normally. Combined vacuum generators and forwarding pumps can be used for all size of systems.

The size and number of combined vacuum generator and forwarding pumps to be used depends upon the required capacity. Combined vacuum generators and forwarding pumps have a small footprint compared to conventional vacuum stations and can be located in small ducts. A combined vacuum generator and forwarding pump is more power efficient than an ejector system, but a large number of combined vacuum generator and forwarding pumps would be more expensive to purchase and run than a comparable vacuum station-based system.

Check and isolation valves

A check valve is installed in each vacuum pump suction line to maintain the vacuum in the system. Check valves are also fitted on the discharge from a vacuum discharge pump, and often are fitted on the service connection from an appliance.

Isolation valves are fitted to all forwarding and vacuum pumps to allow their removal without disrupting the system. Also, they are fitted in strategic locations to enable sections of a system to be isolated for service. Isolation valves should be suitable for vacuum use and may be of the eccentric plug type or resilient face gate type and have a clean opening of not less than the nominal diameter of the pipe. Both check and isolation valves must be capable of withstanding 0.8 bar gauge vacuum, when open, and a differential pressure of 0.8 bar, when closed on a functioning system.

Pipework

Usually stainless steel and thermoplastic (ABS, HDPE, PVCu or MDPE) pipes are utilised for the construction of the vacuum pipelines, the selection of pipeline material is dependent upon its location and the characteristics of the wastewater. All pipes used should be suitable for vacuum, and the minimum pressure rating for thermoplastics should be 10 bar but higher ratings shall be used if the pipe has an initial ovality; if progressive deformation or long-term loss of strength due to high temperature is likely to occur. The velocities of water within the pipework and the resulting percussive effects at changes of direction lead to the requirement for such pressure rated pipe. Standard manufactured fittings are used where available; Y junctions for incoming branches should be 45° and reducers be concentric.

Generally, joints should be smooth and protrusion free to ensure full flow conditions.

Not all rubber ring pipe joints are suitable for vacuum systems, the manufacturer should supply a guarantee along with the test certification that the products are appropriate for vacuum drainage applications.

Design

Design requirements

The system should be designed to accept discharges from all appliances planned to be connected to the system. The designer should take into consideration any known possible future additions or modifications to the system to avoid future installation and operating constraints.

Design criteria

In order to design a vacuum drainage system, the following basic parameters should be determined and obtained:

- i. Service life expectancy
- ii. Type of building
- iii. Number of people the system is to serve
- iv. Types, number and location of appliances to be connected
- v. Wastewater temperature range (high temperature grey water discharges shall be specified concerning temperature, flow, batch volume and frequency)
- vi. Ambient temperature range within which the system shall operate
- vii. Minimum vacuum level required to operate the interface units and vacuum toilets
- viii. Air to water ratios required for the interface units
- ix. Air consumption of vacuum toilets
- x. Permissible leakage factors.

The following parameters are required to calculate the pipe sizes and system layout. They should be determined by the designer and equipment supplier for each system:

- i. Total wastewater flow
- ii. Vacuum toilet flush frequency
- iii. Dynamic losses between the vacuum station and the furthest appliance on each pipeline
- iv. Static losses between the vacuum station and the furthest appliance on each pipeline

- v. Required operational level of vacuum
- vi. Required vacuum generator capacity
- vii. Required forwarding pump capacity, if utilised
- viii. Required collecting tank capacity, if utilised
- ix. Pipe sizes
- x. Vacuum recovery time.

Pipework design

Vacuum systems are designed to operate on two-phase air to liquid flows. The air in the pipework is not, as in a conventional horizontal gravity system, flowing above the wastewater but is entrained into the wastewater where its expansion propels the wastewater and lowers its bulk density. These factors enable the wastewater to behave more like a gas than a liquid and in particular flow uphill.

The strength of thermoplastics is affected by temperature. In industrial installations where high wastewater temperatures are anticipated, care must be taken in the selection of pipe materials. Wastewater temperatures greater than 70°C should be notified to the designer, so that the design can limit, by pipework design and buffer volume sizing, possible boiling due to pressures lower than atmosphere.

The pipes are installed in a near horizontal profile, without backfall (0.2-0.5% fall) to a suitably located vertical pipe. Once the vertical pipe (stack) is installed, all horizontal pipes may be connected at each level in the building in the void between floor and ceiling, subject to lift height restrictions.

All service connections from the interface units could either be lifted to the pipeline in the ceiling above or dropped through the floor to the pipeline below. This makes installation one floor at a time possible which is particularly valuable in building refurbishment.

Preferably, connections to horizontal pipelines should be arranged so that the branch pipe enters from the top by way of a Y-fitting. As a minimum it shall connect into the top sector of the vacuum main pipeline contained within the angle of $\pm 60^\circ$ about the vertical axis. Vertical lift piping connecting to horizontal pipelines should enter from the top by way of a Y-fitting. Precautions should be taken, e.g., the use of a check valve suitable for vacuum drainage, to prevent filling the rise with wastewater by back surges. Horizontal piping connecting to vertical stacks should enter by way of single Y-branches. Multiple connections should be at staggered levels where practical.

For a larger building it is customary to divide the system into smaller subsystems, possibly with a crossover, if not cost prohibitive, so that, in the event of failure of part of the system, each subsystem could operate as a standby for the other. The crossover pipework would be located between the vacuum station and pipework manifold of each subsystem. An isolation valve, the crossover valve, located within the crossover pipework would, for normal operation, be closed.

Maintainability

System maintainability affects not only maintenance costs but also availability. The following aspects are the minimum that should be addressed as part of system design:

- i. Fault finding procedures
- ii. Access to all interface units, isolation valves, cleaning eyes, check valves and other items that need inspection and/or service
- iii. Procedures for removal of interface units and their temporary effect on system performance, if any
- iv. Maintenance schedules for interface units in relation to cycle frequency and endurance
- v. Estimated repair or replacement times of interface units
- vi. Maintenance schedule for vacuum station equipment
- vii. Procedures for removal or repair of vacuum station equipment and their temporary effects on system performance, if any
- viii. Estimated repair or replacement times for vacuum station equipment
- ix. Precaution routines if system performance is temporarily lost or reduced
- x. Training of maintenance personnel
- xi. Recommended stocking of spare parts
- xii. Estimated cost of maintenance per year.

References

The Environment Protection Agency (EPA) in USA.

Internet sites, and manufacturer's literature.

IoP/BRE/CIBSE Vacuum Drainage Systems Guidance (book and video)