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Siphonic Roof Drainage

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Siphonic Roof Rainwater Drainage – Design Considerations

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ABSTRACT

Siphonic drainage systems offer a number of features that cannot be attained by conventional systems. Large open span structures clear of downpipes are possible with a consequent reduction in underground drainage. Such systems operate very efficiently, especially when compared to conventional systems. Conventional roof drainage has been extensively used over many years and its limitations are well understood and documented in design codes. Experience in the operational use of siphonic systems is, by contrast, less comprehensive - particularly within the UK. A number of failures of siphonic systems within the UK in recent years have not added to confidence. These failures are not the fault of the siphonic systems as a whole, but arose from design or installation inadequacies which could have been avoided. This paper reviews causes of such failures and considers how similar eventualities can be avoided in the future.

INTRODUCTION

Siphonic drainage systems offer the designer a number of design features that cannot economically be attained using conventional systems. These include the ability to allow large span open structures clear of any downpipes, and also a considerable reduction in the extent of underground drainage. Pipes carrying water from the roof operate very efficiently when compared to conventional gravity systems.

Conventional roof drainage has been extensively used over many years and comprehensively documented in design codes. The limitations of these systems are well understood. Experience in the operational use of siphonic systems is, conversely, less comprehensive - particularly in Britain. There is, for instance, at present no UK or European design standard covering the design and installation of these systems.

Consequently, when the designer and end user attempt to undertake a risk analysis there is inadequate independent objective information or guidance upon which to assess the factors influencing the performance of these systems. Such uncertainty reduces confidence, and may limit adoption in many circumstances. Additionally, a number of failures associated with siphonic systems in Britain in recent years have not added to confidence. These failures were not the fault of the system, but arose from design or installation inadequacies, and could have been easily avoided. Through time, this will be addressed as experience increases and as the operating characteristics of siphonic systems become better understood.

This text sets out information that will be of assistance to all those involved in the specification, design and operation of siphonic systems. Furthermore, a brief review of how systems operate and, perhaps more importantly, how they fail is also given.

SYSTEM OPERATION - OVERVIEW

There are a number of key factors that are peculiar to siphonic systems, these are outlined below:

1. Negative Pressure

Siphonic pipework systems are designed to operate with the system effectively purged of air, using the piezometric head available between gutter and point of discharge. They operate at pressures below atmospheric. It is this pressure gradient within system that drives it, thereby operating at capacities significantly greater than an equivalent pipe with a free surface flow hydraulic regime.

This differs from conventional systems, where pipes flow part full. The pressure within the conveying pipework is not designed, or expected, to operate at anything other than these conditions. Pressurisation, in a conventional system, will only occur if the system capacity is exceeded and pipes surcharge.

Under normal operation siphonic systems are typically designed to operate at pressures up to $80kNm^{-2}$ below atmospheric.

2. Fixed Capacity

The capacity of a siphonic system is fixed. It will not significantly increase even if the depth of water in the gutter increases. As the contributing roof area remains unchanged the maximum rainfall intensity that the system can accommodate is, consequently, also fixed. This is a fundamental difference between siphonic and conventional systems.

Conventional systems can accommodate flow in excess of the design capacity - if the depth of water in the gutter increases beyond the design condition. For an orifice outlet, this is proportional to the square root of the depth of flow. Thus doubling the depth in the channel will result in an increase in flow of 41%. In addition, it is possible in some conventional systems for a limited siphonic action to occur below outlets - thereby further increasing its capacity.

Where a siphonic system is concerned, rainfall with a higher intensity than design level can only be accommodated provided a separate overflow is included in the system. Any increase in the depth of flow in the gutter will not increase the discharge.

3. Self Cleansing Action

Two flow conditions occur in siphonic systems:

(1) At low rainfall intensities the pipework runs part full of water. As collector pipes are horizontal, or have a nominal fall, the velocity is below self-cleansing (less than $0.75ms^{-1}$).

(2) As rainfall increases a transition occurs as air is purged and the system becomes siphonic and velocities dramatically increase - velocities of $6ms^{-1}$ are not uncommon.

At rainfall intensities significantly below the design level, the system can accumulate detritus which will only be washed out when the flow velocities approach the design condition, thereby allowing it to run in a partial siphonic mode. As Figure 1 illustrates, inflows much lower than the design capacity can induce a peak pressure near the design pressure. Thus, if the siphonic system is designed to take a high intensity rainfall event with a return period of

several years, it will not necessarily require a storm of that magnitude for some degree of self cleansing to occur.

RISK ANALYSIS

Risk in the context of this paper is defined as the chance that, or inability of, the system to meet its expectations.

All design involves risk. Designers, and end users, attempt to minimise the risk of failure but can only adopt a rational approach if there is adequate objective independent information or guidance available upon which to consider the factors involved in the performance of systems.

A number of system failures have highlighted factors which require assessment and need to be better understood. These failures could have been avoided at the design or installation stage or had proper maintenance been undertaken.

From investigations into failures, the most significant and prevalent factors are:

1. Interaction between the above and below ground systems.
2. System operating and design pressures.
3. Mechanical failure of pipework operating under pressures below atmospheric.
4. Inadequate capacity.
5. Inadequate maintenance.

1. Interaction between the above and below ground systems

The consequences of flooding at ground level and roof level are very different. Occasional ponding over paved areas, such as roads and car parks, may be deemed inconvenient, but an acceptable risk; the cost in terms of damage is not usually significant. Should the capacity of a roofwater system be exceeded the consequences can be severe with extensive damage and cost. This risk needs to be balanced against the capital cost of providing additional security. Therefore, a roof rainwater drainage system is normally designed to take much higher rainfall intensity than an equivalent paved area. A 50 years rainfall return period might be adopted as an acceptable risk for a roof rainwater system, whereas a 2-year return period is not uncommon for an underground system.

Unfortunately, the underground infrastructure is designed and installed occasionally in isolation, and often many years in advance, of building work. The designer of the underground system will have to make assumptions regarding the type of building and maximum flows to be accommodated. This leads to a discrepancy between the underground system, which has a high risk of surcharging, and siphonic roofwater system that requires a free discharge.

This conflict should then be recognised and incorporated in the design. Buildings have flooded because siphonic downpipes have connected directly into underground systems. To overcome this, one option is to provide a physical siphon break between the two systems so that they may operate independently.

2. System operating and design pressures

Typically systems are designed to operate at pressure up to 80kN/m^2 below ambient atmospheric pressure. However, such pressures can vary and increase due to:

- Partial blockages in outlets.

- Interaction with underground system.
- Changes in pipework configuration from that designed during installation.
- Volumes of air entering the system.

For any well designed and specified system, the design storm will exceed the vast majority of the storms it is expected to meet. Where rainfall events of quite low intensity are encountered, the system will act hydraulically as a 'conventional' roof drainage system. However where increasing rainfall intensities are considered, unsteady partial de-pressurisation of the system will occur. Tests at Heriot-Watt University have shown that this de-pressurisation results in substantial amounts of air being drawn into the system[1], which can exceed the volume of water inflow. The unsteady nature of the flow regime, which has been observed to be cyclic in nature, leads to varying amounts of noise generation, and structural vibration within the system. The structural vibration, conceivably, could lead to physical failure of a component of the system.

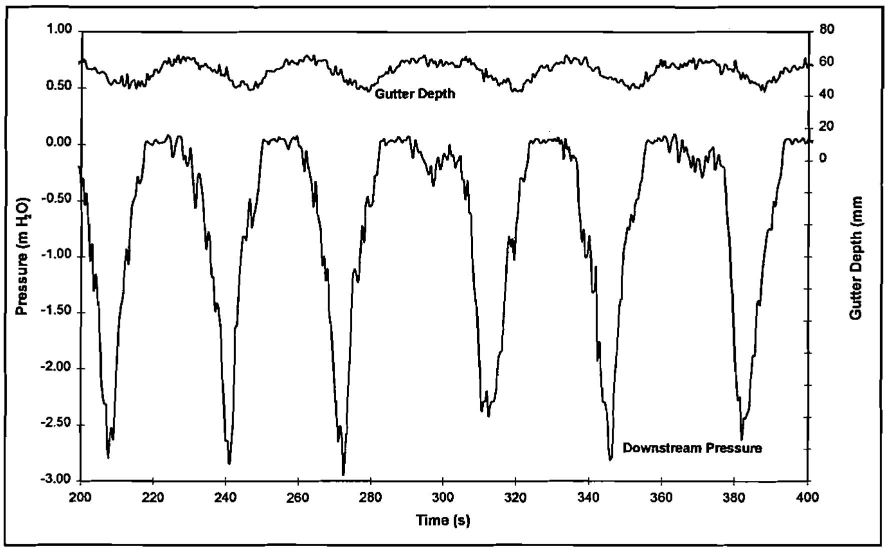

Figure 1 : Ambient pressures in the system for a steady gutter inflow rate of 42% of the measured capacity.

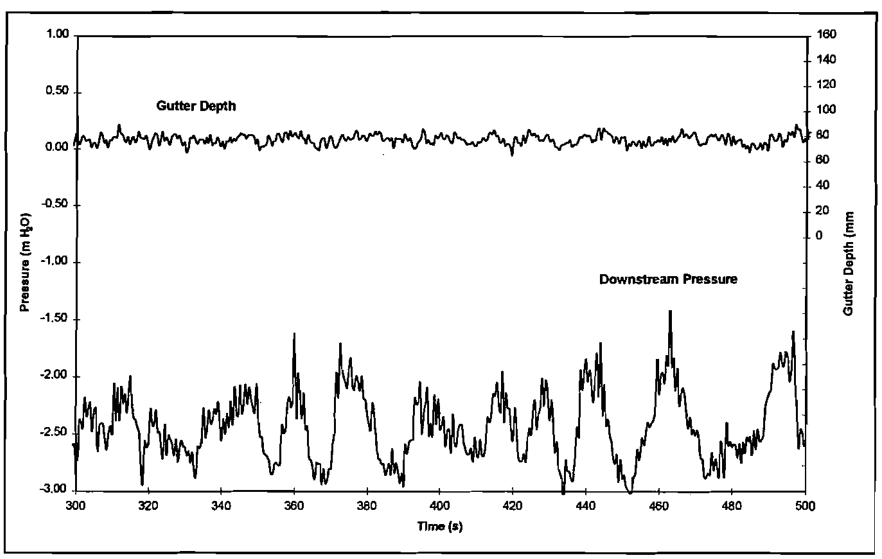

Figure 2 : Ambient pressures in the system for a steady gutter inflow rate of 81% of the measured capacity of the system.

The unsteady pressure regimes which have been observed to occur within the test rig at Heriot-Watt University[2 & 3] are illustrated by the data presented in Figures 1 and 2. Figure 1 illustrates data where a cyclic pressure history was recorded. The frequency of the cyclic response of the system was found to be related to the rate of inflow, and the lengths of the horizontal and vertical pipework. Figure 2 shows that even in instances where the rate of gutter inflow is approaching the measured capacity of the system, the ambient pressures are far from steady.

3. Mechanical failure of pipework under negative pressures

Siphonic systems have failed due to the deformation of pipework under negative pressure. Whilst there is extensive independent test information available relating to the operating characteristics of pipework under positive pressures, no equivalent independent data exists for negative pressures (i.e. below atmospheric). There are currently no recognised international standards for siphonic roof rainwater drainage pipes operating under negative pressures.

The elastic stability of pipes should be considered when analysing the risk of buckling of under internal vacuum or negative pressures. The critical pressure for a long pipe is:

$$P_{buc} = 2.2E\left(\frac{t}{D}\right)^3$$

Where

E =	Creep Modulus
t =	Wall thickness of pipe
D =	Pipe diameter

The ability of pipes to accept a negative pressure is a function of:

- Elastic behaviour of the pipe material.
- Ratio of wall thickness to pipe diameter.
- Temperature.
- Temporal effects.
- Load history.

The Creep Modulus will vary with both time and temperature. The short term modulus is higher than the long term modulus - in the short term the buckling capacity will be approximately four times that of the long term value. A minimum factor of safety against buckling should be 6[4&5].

HDPE (high density polyethylene) pipework is commonly used in siphonic drainage systems, and is available as 3.2, 4.0, 6.3, 10 and 16 bar rated. However, this relates to the positive pressure rating of the pipe. Following the in service failure of a number of pipes within siphonic installations, tests were undertaken at Heriot-Watt University. These were conducted on unrestrained 3.2 bar HDPE pipes at an ambient temperature of 20 °C. The results indicated that for this class of pipe;

(1) Pipes collapsed at a pressure of -86kN/m².

(2) At a pressure of -80kN/m² or lower pipes collapsed within 4 minutes of reaching the test pressure. (This is the minimum pressure siphonic systems are normally designed to achieve). The pressure history is illustrated in Figure 3.

(3) Pipes could sustain pressures of up -65kN/m² for one hour.

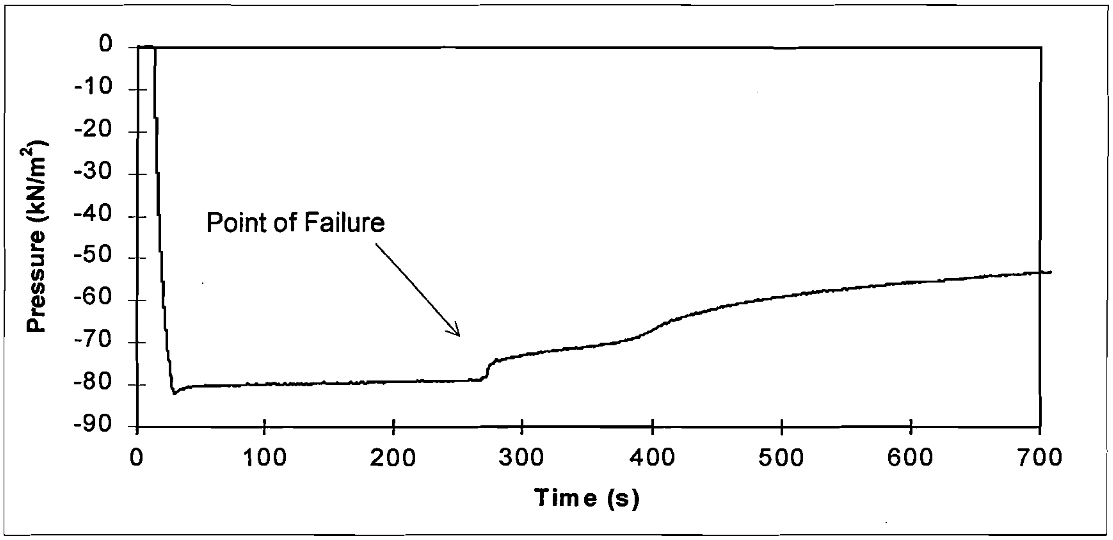

Figure 3 : The failure pressure history of a 200mm ID HDPE pipe.

The cross sectional area of the collapsed and deformed pipe was approximately 10% of the original value as illustrated in Plate 1. As HDPE is an elastic material, once the test pressure is removed pipes will resume their original shape over a period of days or weeks. However, the implosion imparts a permanent deformation that may not be perceptible to the eye. Pipes tested a year after being deformed were only able to withstand 50% of the pressure of a new pipe. On visual inspection these appeared to be the same as new pipes. Consequently, if a system has suffered damage it may not, unless close inspection is possible, be readily apparent. However, the weakened pipe, unless replaced, may collapse in service if it operates siphonically.

Plate 1 : The collapsed cross section of a 200mm ID HDPE pipe.

The tests indicated that HDPE pipework of this rating should not be used. If 3.2 bar rated HDPE pipework is used it should be limited to a maximum pressure of -65kN/m^2. Higher

rated pipework will accept greater negative pressures. However, testing is required to prove such pressures.

Some manufacturers and siphonic designers are aware of the limitations of pipes under negative pressures and restrict use of low pressure rated pipework or limit design pressures in systems to that which the pipes will accept. This information is not however readily available or universally appreciated, consequently systems have failed due to the use of inadequately rated pipes.

Comprehensive impartial testing is required under a variety of regimes to give designers and specifiers adequate information on the long-term performance of different types and sizes of pipe.

4. Inadequate capacity

The design roof rainwater systems needs to be integrated with that of all elements including the roof, overflows and conveyance systems. The capacity of the system is the sum of the conveyance system (siphonic) and overflow. Systems have failed where these have been designed individually with no overall co-ordination. Architects, and other designers, do not always understand fully the operating characteristics of siphonic systems. The siphonic system, overflow and roof have been designed in isolation with no overall, or individual rainfall intensity parameter set.

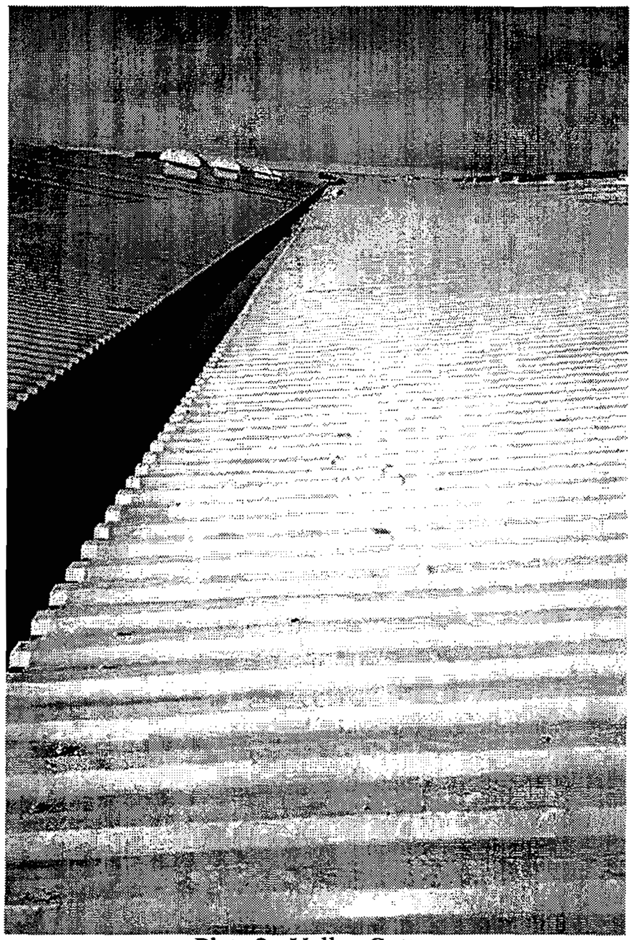

Plate 2 : Valley Gutter

The tendency to divide elements of a building during design and construction has resulted in siphonic systems having been designed, and installed, without an adequate overflow provision.

Design rainfall intensities need to be determined relative to the probability that this event will be exceeded during the life of the building. This risk analysis is critical to the overall design of the building - particularly where any overflow can enter the building. This applies particularly to enclosed valley roofs (Plate 2) where, without an adequate overflow, rainwater will enter the building if the gutters surcharge.

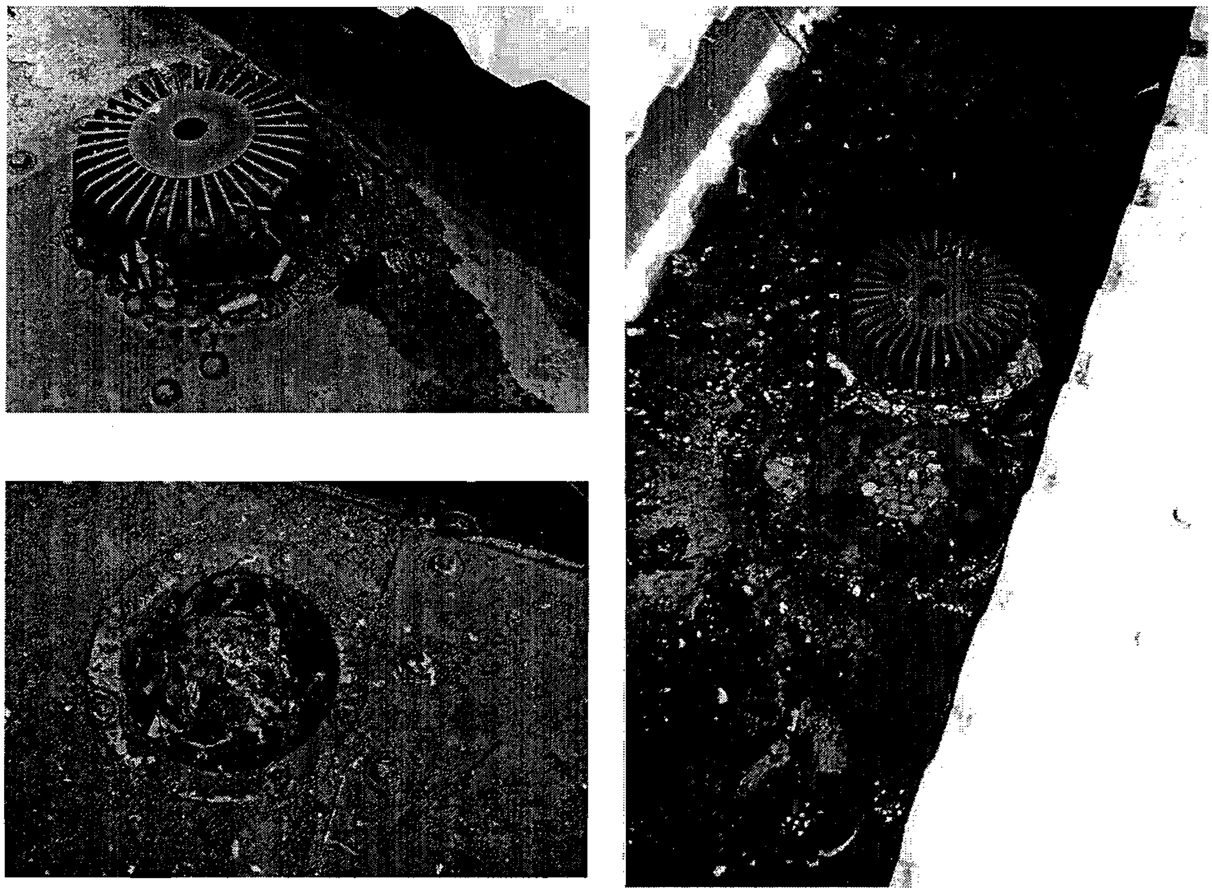

Plate 3 : Blocked Outlets.

5. Blockages

Siphonic outlets are typically between 50mm and 65mm diameter and therefore susceptible to blockage and blinding (Plate 3). Leaf guards are fitted to outlets for protection.

Maintenance of gutters is often neglected, and whilst on a conventional outlet this may be tolerated to some extent, where a siphonic system is concerned the consequences are considerably more serious. Detritus such as biological growth, wind blown materials, construction waste and material dropped by birds can rapidly accumulate on a roof.

Initially outlets should be inspected at least 6 times a year. A maintenance programme should be developed based upon the results of the first year's inspections.

Regular inspections can only be undertaken if access onto the roof is. Access onto a roof is often a secondary consideration and designed for infrequent access in the form of a vertical ladder and hatch and no safe walkway provided across a roof. Rarely is the person cleaning the roof considered, or any facility provided to remove detritus from the roof. If access is difficult, this increases the possibility that maintenance will be neglected.

CCTV surveys of recently completed buildings have identified a considerable amount of construction debris in roof drainage pipes including; wire, disposable gloves and rolls of tape - all of which would affect the capacity of siphonic systems. At hand-over, a CCTV survey should be required to prove the pipework system is clear, as far as possible, of any obstructions.

CONCLUSIONS

(1) Siphonic systems are effective solutions in many situations and confer many advantages which conventional systems cannot meet. They do have special operating characteristics that need to be carefully considered along with higher maintenance requirements.

(2) Systems have failed in the past, but this was often due to the use of pipes that have collapsed under negative pressures, inadequate overflow capacity, and insufficient maintenance.

(3) Systems need to be carefully designed and monitored during installation. The designer should verify any deviation from design.

(4) Pipe materials need to be capable of withstanding design pressures for an extended period without deformation. In the absence of any standard independent testing, performance guarantees should be provided.

(5) The system capacity (including overflow) should be adequate. This should be based on the risk of a storm event exceeding its capacity and its consequences. It may need to be based upon a cost benefit analysis.

(6) Maintenance facilities, including access, should be adequate and routine inspections procedure recommended by suppliers.

(7) Further independent objective research is required to understand how siphonic roof drainage systems operate in the field.

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