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Alternative low-cost overflows for siphonic roof drainage systems: Proof of concept

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ABSTRACT

This paper describes an experimental investigation of alternative overflow systems for roof structures that are drained siphonically. Many buildings that have siphonic roof drainage systems currently incorporate a separate secondary overflow system, which is quite often also siphonic. An alternative low-cost technique that is explored in this study is to connect each overflow outlet to a single, vertical downpipe. Seven different overflow configurations, each with five different downpipe lengths, are investigated in terms of maximum flowrate and corresponding water depth in the gutter. The results of this study are significant in that they do not support the common theoretical assumption that there is a limiting length of a siphonic downpipe over which pipe-full flow may occur before gravity causes the water to accelerate enough for it to no longer occupy the full cross-sectional area. Instead, this study has found that once a downpipe is flowing full, it is possible for pipe-full flow conditions to be maintained over the entire pipe length.

1. Introduction

Siphonic roof drainage systems (SRDS) are a highly efficient type of drainage system that are particularly suitable for buildings with large roof areas that need to be drained quickly. SRDS were first developed in the late 1960s by Ebeling and Sommerhein in Scandinavia [20] and they have much appeal for architects and designers due to the many advantages they offer over conventional roof drainage systems. These include a significant reduction in the number of downpipes required, the possibility of relocating downpipes to areas that are esthetically less sensitive, and the ease of harvesting all of a building's roofwater for later reuse.

Conventional roof drainage systems typically include box, eave or valley gutters that collect the runoff from the roof and channel this rainwater into outlets connected to vertical downpipes located in the soles of the gutters. The volume of water that can enter the gutter outlets depends primarily on the depth of water in the gutter, and on the cross sectional area of the outlet. This volume can be estimated using standard weir and orifice equations [20]. However, the volume is relatively limited because up to two-thirds of the downpipe volume can be taken up by an air-filled core [1,19,26]. This necessitates the installation of many downpipes in conventional roof drainage systems and also requires extensive underground pipework systems (Fig. 1). This has significant cost implications for the broader construction industry.

Unlike conventional drainage systems, the pipework of a SRDS is designed to flow full at its design capacity [18]. Through the use of specially designed gutter outlets and pipework, air is purged from the system and the pipes quickly fill with water. Once the air is purged from the pipes, they then operate under sub-atmospheric pressures. The driving head for the system is the effective difference in levels between the water surface in the gutter and the discharge point, which is usually near ground level. This causes significant increases in both flow velocity and volumetric flowrate compared to traditional systems [20,23]. May [20] explained that these increases can cause siphonic outlets to have up to 10 times the capacity of conventional outlets.

One of the major advantages of SRDS is that the roof runoff from each siphonic system is usually directed into a single downpipe, so the excessive number of vertical downpipes, and the extensive underground drainage pipe system typically associated with conventional systems can be virtually eliminated (Fig. 1). A single downpipe also makes it much easier to harvest all the roofwater from a building. However, some building designs, particularly those with roof areas at different levels, may incorporate numerous siphonic systems and downpipes.

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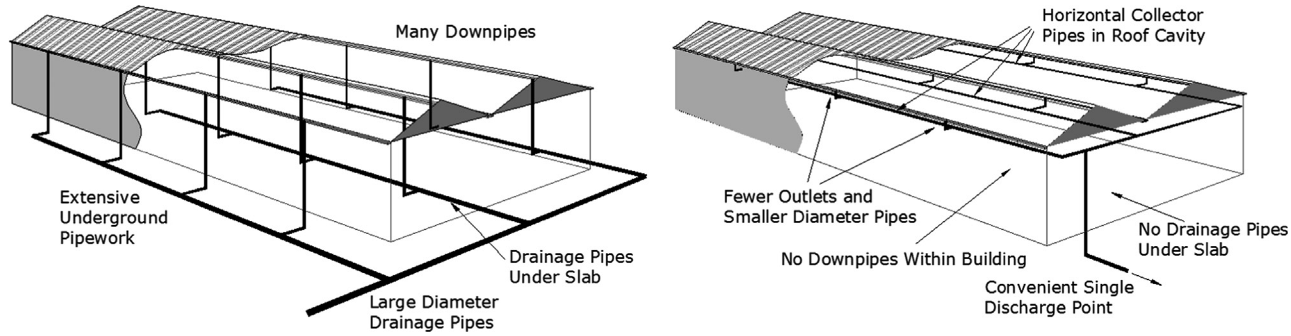

Fig. 1. Conventional and siphonic roof drainage system layout.

1.1. Siphonic design

The theory of siphonic action has long been understood and is broadly based on simple energy principles, as expressed by Bernoulli's energy equation [20]. The current steady (peak) flow design of SRDS generally uses a version of this equation that estimates the difference in energy between two points (1 and 2) by summing the pressure, kinetic and potential energies at those points (Eq. 1). This energy is then balanced against the pipe system's friction (H_f) and form losses (H_L).

$$\left(\frac{P_1}{\rho g}+\frac{Q_1^2}{2gA_1^2}+z_1\right)_{\text{Point 1}}-\left(\frac{P_2}{\rho g}+\frac{Q_2^2}{2gA_2^2}+z_2\right)_{\text{Point 2}}$$
$$=\sum H_{1,2}$$
$$=\sum H_f+\sum H_L \quad (1)$$

where: P is pressure, Q is flowrate, ρ is density, g is gravity, A is cross-sectional area and z is height above datum.

Although SRDS are designed to operate under pipe-full flow conditions, they can also operate efficiently when the pipes are only partially full. The transition between these two flow states involves priming or unpriming of the system. Priming is the term used to describe the process where resistance to flow is sufficient to cause the pipe system to purge air from the pipework and become full of water [2,20]. It is the friction and form losses present in every pipe flow situation that resists the movement of the water and assists in the development of pipe-full flow conditions [19]. The priming action that occurs in SRDS is an extremely complex process. Although there have been a number of studies undertaken to try to better understand the priming process [3,16,23] it is still not fully understood.

The design of a SRDS for a commercial building can be a highly complex procedure. It generally involves an iterative design process of adjusting pipe lengths, pipe diameters and the inclusion or exclusion of pipe fittings, in order to accurately balance both sides of Eq. (1) for a particular design storm. This is usually only possible by using a computer program [20]. Apart from ensuring that a SRDS has the capacity to cope with the roof runoff from a particular design storm, the other principle design objectives are to ensure that the outlets are balanced during operation and that the pipe pressures do not become too negative [20].

Previous studies [2,3,17,20] and design manuals [4,25] suggest that the expected internal pipe pressures should be limited to a minimum pressure of 90 kN/m^2 below atmospheric pressure. This pressure limit is currently recommended for two reasons. The first is to ensure that the generation of negative pressure transients does not lead to system failure due to pipe wall collapse [2]. The second reason is to reduce the likelihood of cavitation, which could lead to serious erosion damage on the inside of the pipes [17,20].

As siphonic drainage systems are designed for pipe-full flow conditions, the design usually assumes that there is no air in the system. To achieve this, most siphonic outlets are specially designed to reduce the amount of air entering the system. This is often achieved by including some type of baffle plate, or similar configuration, in the outlet's design (Fig. 2a). These baffle plates help restrict the formation of a vortex above the outlet that would otherwise draw air into the system. Air drawn in through a vortex

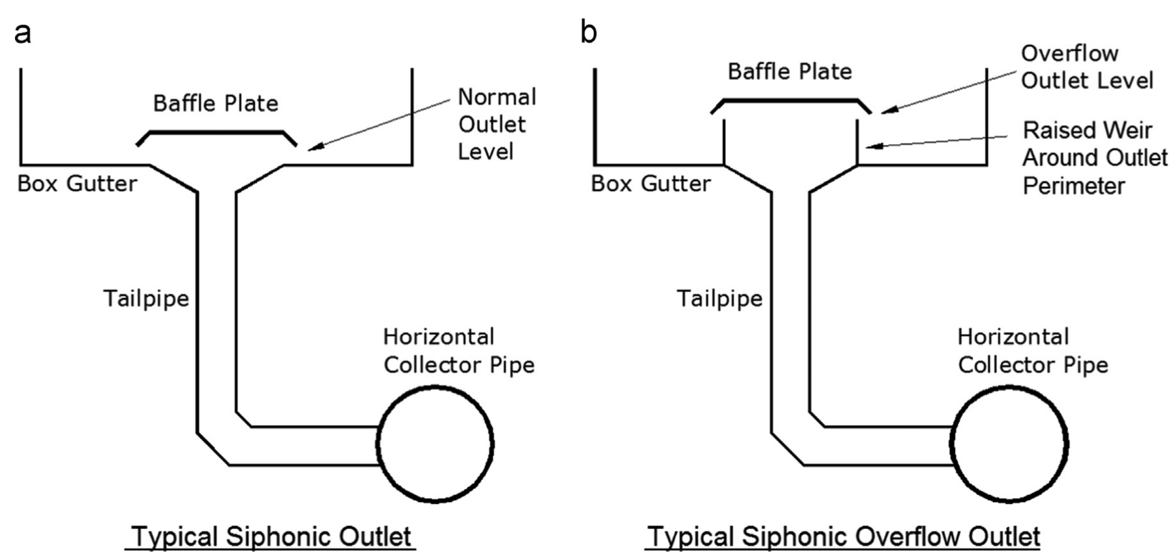

Fig. 2. Normal and overflow siphonic outlets.