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Siphonic roof drainage system analysis utilising unsteady flow theory

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Abstract

Over the past three years a UK EPSRC research programme has been underway at Heriot-Watt University investigating siphonic roof rainwater systems. This text aims to report the principle findings of the project to date. A brief description of experimental and numerical aims is given. The priming procedure which occurs in an idealised system is documented. The test procedures employed are described, and experimental results are illustrated. The framework employed to numerically model the ambient hydraulics is described in some detailed. Conclusions are drawn regarding the operational characteristics of siphonic roof rainwater systems as a whole. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Roof drainage; Siphonic roof drainage system; Method of characteristics

1. Background

Siphonic roof drainage systems have been in existence for approximately 30 years. In this time, the construction industry has been gradually persuaded by the benefits which these systems offer when compared to the traditional approach. Much of these benefits arise from the fact that systems can become de-pressurised. However, much of the desired benefits only arise at the design condition — typically a storm with a return period in excess of 30 years. When the application was being made for the work reported, it was recognised that the overwhelming majority of rainfall events any siphonic system would have to drain would be well below the design condition. This, coupled with reports of siphonic system failures, convinced the investigators that this was an area worthy of future research.

2. Aims and objectives of research

Siphonic rainwater drainage depends upon the establishment of full bore flow within the pipe network linking roof collection outlets to the storm sewer. The replacement of conventional multiple downpipes by a network of closed conduits offers significant advantages to the building designer, as evidenced by the increasing installation of such systems in buildings such as airport terminals, large warehouses and prestige office developments. However, the establishment of siphonic action depends upon the matching of the network to the expected storm hyetograph and the maintenance of siphonic conditions throughout the storm event — only one storm matches any particular system. Errors in design may lead to systems operating in an inefficient, non-siphonic mode, or to insufficient capacity (flooding). Generation of negative pressure transients may lead to system failure due to pipewall collapse [1]. While siphonic systems have been installed in the UK over the past decade, there is no recognised design standard, and system design is based on steady state calculations which assume a near instantaneous steady full bore entrained air free flow. The aim of the work reported was to develop an unsteady flow model which could simulate conditions within an idealised siphonic roof rainwater drainage system driven by a storm hyetograph during priming. This would enable flow conditions within the rainwater drainage system to be represented within a idealised siphonic drainage system, from initial free surface flow as the storm develops, through a two-phase flow stage, while air entertained, or initially present, in the system is flushed out, until the full bore flow

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Nomenclature

A	flow area (m^2)
c	propagation velocity (m/s)
C	chezy coefficient ($m^{1/2}$/s)
D	diameter (m)
E	modulus of elasticity N/m^2
e	wall thickness
f	friction factor (dimensionless)
f	function (dimensionless)
H	pressure head (mH_2O)
$\bar{H}$	average pressure head (mH_2O)
i	node no. dimensionless
g	gravitational constant (m/s^2)
K	bulk modulus (kg/ms^2)
m	interpolation integer (dimensionless)
Q	discharge (m^3/s)
R	hydraulic radius (m)
S_0	invert gradient (dimensionless)
T	flow surface width (m)
t	time (s)
V	velocity (m/s)
–	volume (m^3)
x	distance (m)
y	gas to total volume ratio (m)
z	elevation (m)
α	invert angle (rad)
ε	interpolation real number (dimensionless)
ρ	density (kg/m^3)
$\bar{\rho}$	average density (kg/m^3)
Δ	change (dimensionless)

Subscripts

f	fluid
g	gas

design condition is reached. The primary objectives of the project were therefore:

1. Within a laboratory environment, investigate pressure transient generation and propagation within a siphonic system during priming.
2. Establish boundary conditions, both stationary and moving, consistent with developing a numerical model based on the method of characteristics.
3. Develop a computer-based design tool, which could provide guidance at the design stage to both system designers and building operators.

3. Description of research

The programme of research has relied heavily on exploiting industrial links and data generated from a siphonic test facility constructed at Heriot-Watt University to build the initial numerical model. Once a prototype numerical model was developed, it was further enhanced and fine tuned using data collected at the Heriot-Watt University facility, from installed systems, and results obtained from test facilities operated by HR Wallingford and elements of the siphonic rainwater industry. The strength of this project has largely been due to the close links made with industry and local system operators, as well as the strong background the investigators have in numerically modelling building drainage systems.

4. Design considerations

For any given application, siphonic roof drainage systems are normally designed to cope with the steady-state pressures associated with a selected 'design storm', which is normally specified in terms of a steady rainfall intensity (in the UK this is in accordance with BS 6367 [2]). Selection of a rainfall intensity at the design stage is based upon the geographical location, and by balancing the risk of failure against the cost of allowing for additional roof drainage capacity [1,3]. However, it can be seen that this approach will lead to one of two post installation eventualities each time a storm occurs:

1. *A storm occurs which exceeds the design rainfall intensity*. Practically, irrespective of the design rainfall intensity selected, this will always eventually occur, and will result in flooding to some extent. Well-designed systems make allowance to ensure that any overspill is directed to areas where it can be managed, or any damage caused is limited.
2. *A storm occurs which is less than the design rainfall intensity*. For any well-specified system, the vast majority of the storms encountered will fall into this category. Where rainfall events of low intensity are encountered, the system will perform as a 'conventional' roof drainage system. However, as increasing rainfall intensities are considered partial unsteady de-pressurisation of the system will occur. Testing has shown that this de-pressurisation results in substantial amounts of air being drawn into the system, this can exceed the volume of water entering the system in some circumstances. 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 unsteady pressure regimes which have been observed to occur within the test rig used in this study (Fig. 1), when the system is draining an inflow less than the system capacity, are illustrated by the data presented in Figs. 2 and 3.

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