Determining Flowrates through Individual Outlets in Siphonic Roof Drainage Systems

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ABSTRACT

This paper describes an experimental investigation that quantifies the flowrates through the individual outlets and tailpipes of a multi-outlet siphonic roof drainage system under both full-pipe and partially-filled pipe flow conditions. A pressure transducer and a propeller-type current meter were installed within each tailpipe to measure the water depth and flow velocity. The hypothesis that it would be possible for a computer model to satisfactorily predict the instantaneous flowrates within each tail pipe using the output from these two instruments was tested.

A lookup data model was developed and the predicted flowrates were compared with measured values. The results suggest that the model can be used with acceptable accuracy to estimate the individual flowrates through the outlets in multi-outlet siphonic roof drainage systems.

KEYWORDS

Siphonic drainage, Multi-outlet, unsteady flow, pressure transients.

INTRODUCTION

In the past, building roofs have usually been drained using traditional gravity-fed roof drainage systems. However, in the late 1960s, the siphonic roof drainage system was developed by Ebeling and Sommerhein in Scandinavia (May, 1995). Siphonic systems now offer an alternative to traditional gravity-fed drainage systems for building services professionals, architects and engineers (Lucke and Beecham, 2010a).

Siphonic roof drainage systems generally incorporate a horizontal collector pipe inside the roof cavity that runs parallel and slightly below the building's box or valley gutters. A series of tailpipes connects the individual gutter outlets to the horizontal collector pipe and a downpipe connects the collector pipe in the roof to the underground drainage system (Lucke and Beecham, 2009). The key components of a siphonic roof drainage system are shown in Figure 1.

In order to accurately model the priming processes and outlet flow distribution in multi-outlet siphonic roof drainage systems, a method of estimating the instantaneous flowrates through the individual outlet tailpipes needs to be developed, particularly when they are experiencing the open-channel type flow conditions that occur during priming. Arthur and Swaffield (2001) developed a numerical flow model of siphonic systems that had the capability to simulate pipe filling, but this is currently a research tool and is not used for routine design of systems.

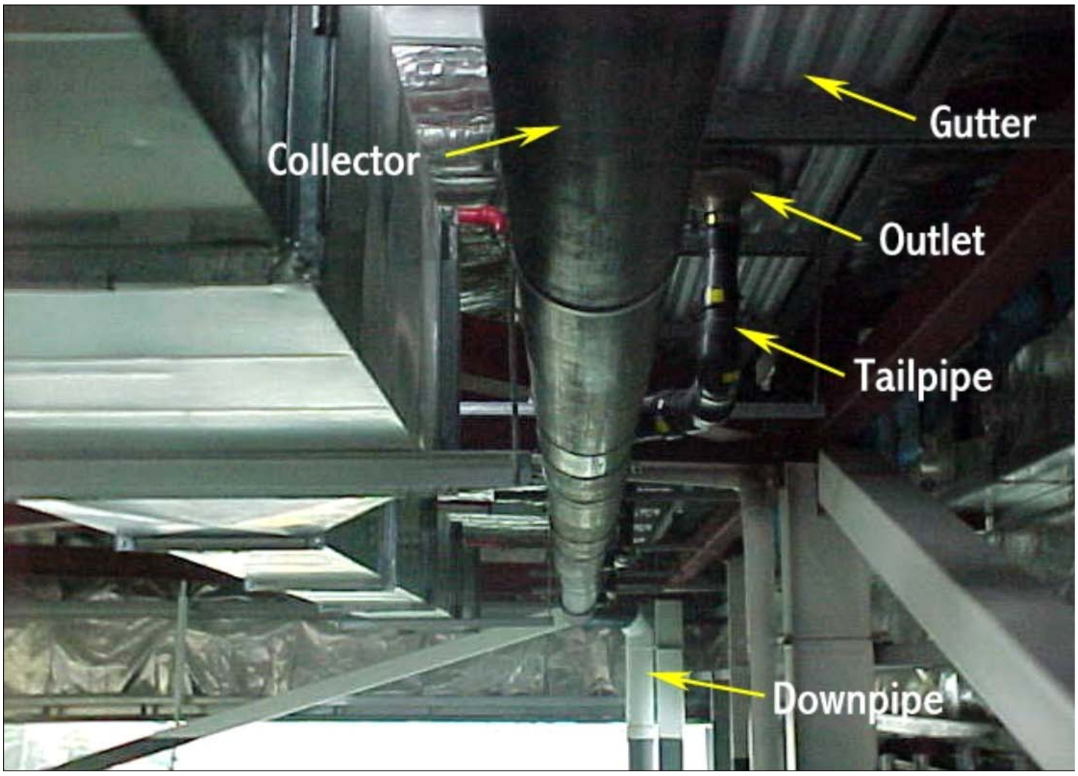

Figure 1. Key Components of a Siphonic System

This paper describes an experimental investigation into quantifying the flowrates through the individual outlets and tailpipes of a multi-outlet siphonic roof drainage system under both full-pipe and partially-filled pipe flow conditions.

METHODS

The experimental rig used for this study is shown in Figure 2. The experimental rig had a 600mm wide x 300mm high gutter, was 32m long, 6m high and had four siphonic outlets installed within the gutter. The gutter inflow rate for the experimental rig was measured using a 150mm diameter electro magnetic flow meter (Type ABB Magmaster CL16, factory calibration of +/-0.5% accuracy) that was installed in the 150mm diameter supply pipework. Further details of the rig are provided in (Lucke and Beecham, 2010b). The maximum flowrate of the rig with all outlets operation was measured at 69 l/s. Current meters and pressure transducers were installed in each of the four outlet tailpipes of the full-scale, multi-outlet siphonic roof drainage system (Figure 2). To protect the transducer diaphragms and to ensure the reliability of the readings, the transducers were installed with a sediment trap and bleed plug.

It is clear that any measuring device that intrudes into the fluid will cause some degree of disturbance of the flow. Previous research (Qu et al., 2010) found that while the propeller meter insertion into the flow did cause a minimal backwater effect, it did not significantly affect the overall flowrates. In addition, providing the flow measuring devices are installed in the pipework of each of the outlets in the experimental multi-outlet siphonic system, then the disturbance effects caused by the devices will be balanced and the hydraulic interaction between the outlets will not be affected.

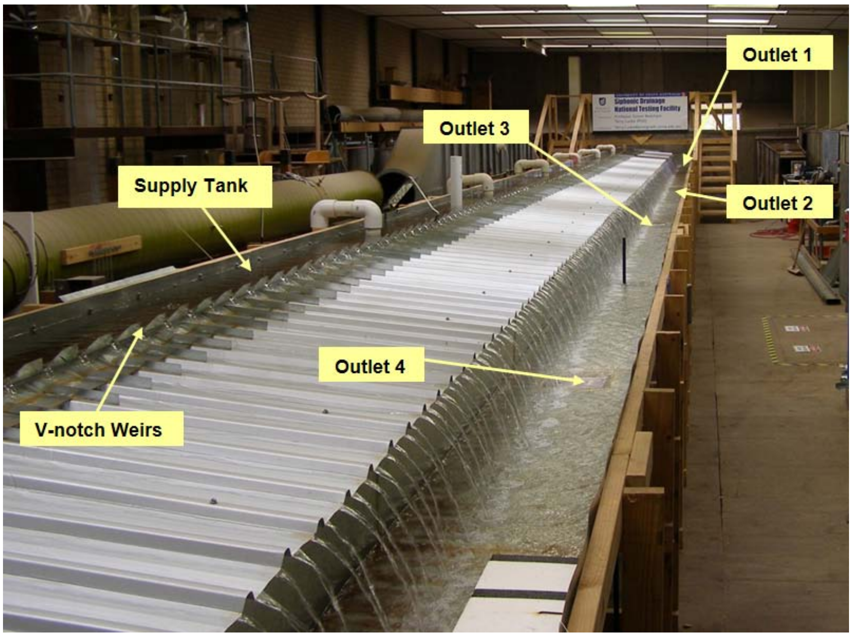

Figure 2. Full-scale Siphonic Drainage Rig

As the tailpipes diameters of the experimental siphonic rig were all different (70 mm, 75 mm, 89 mm and 110 mm), the current meter and pressure transducers of each tailpipe needed to be calibrated separately, in-situ. This presented a variety of challenges. The most obvious problem was, paradoxically, how to accurately determine the flowrates through the individual outlets and tailpipes in order to calibrate the measurement instruments in-situ.

To determine the flowrates through the individual outlets for calibration purposes, a special flow distribution device was constructed. The device was designed so that it could be placed over each of the gutter outlets in-turn and the bottom of the device was sealed against the gutter bottom. This ensured that the outlet was effectively sealed off from water flow in the gutter and none of the gutter water could enter the covered outlet. However, the gutter water could still flow between the sides of the gutter and the sides of the flow distribution device. Water was then supplied to the top of the flow distribution device via a separate supply with an electromagnetic flow meter connected to record the flowrate through the individual outlet. The flow distribution device contained flow spreading vanes to minimise the turbulence of the water entering the sealed outlet. The flow distribution device is shown in Figure 3 installed above one of the four experimental rig outlets.

The flow distribution device shown in Figure 3 was used to calibrate the instruments installed in each of the tailpipes. A range of known, steady flowrates were generated in the tailpipe by supplying water to the flow distribution device via the separate supply. The tailpipe instrument readings were recorded and logged during this process.

In order to replicate authentic operational flow conditions within the tail pipes and to measure the effects that flow through the other three outlets had on the flow patterns in the outlet being calibrated, water was also supplied to the box gutter of the experimental rig during the testing procedure. The rig flowrate to the other three outlets was always three times greater than the flowrate supplied to the outlet being calibrated. For example, if the flowrate through the flow distribution device was 1 L/s, then the flowrate supplied to the full-scale rig gutter would be 3 L/s. The full range of calibrated flowrates for each outlet is shown in Table 1.

Figure 3. Flow Distribution Device Installed Above an Outlet

Table 1. Calibrated Test Flowrates

Calibrated Outlet Flowrate (L/s)	Full-scale Rig Gutter Flowrate (L/s)	Calibrated Outlet Flowrate (L/s)	Full-scale Rig Gutter Flowrate (L/s)
0.25	0.75	5.00	15.0
0.50	1.50	5.50	16.5
0.75	2.25	6.00	18.0
1.00	3.00	6.50	19.5
1.25	3.75	7.00	21.0
1.50	4.50	7.50	22.5
1.75	5.25	8.50	25.5
2.00	6.00	9.00	27.0
2.50	7.50	9.50	28.5
2.75	8.25	10.0	30.0
3.00	9.00	11.0	33.0
3.50	10.5	12.0	36.0
4.00	12.0	13.0	39.0
4.50	13.5		

RESULTS AND DISCUSSION

In order to determine whether a computer model could satisfactorily predict the instantaneous unsteady flowrates within the tail pipes of a multi-outlet siphonic roof drainage system, the new measurement technique was trialled on the full-scale system shown in Figure 2.

The flow distribution device shown in Figure 3 was used to supply constant flowrates to the isolated outlets and connecting tailpipes. Unfortunately however, the calibration testing results revealed that a variety of cyclic and fluctuating flow conditions could occur in the tailpipes for each of the constant test flowrates. The measurement instruments were therefore found to produce a number of different readings in the tailpipes at constant inflow rates.

The fluctuating flow conditions that occurred in the tailpipes appeared to be caused by negative pressures resulting from localised siphonic action generated within the tailpipes during the priming stage. This phenomenon has been described in previous research studies (May and Escarameia, 1996; Arthur and Swaffield, 2001; Wright et al., 2002, 2006). May and Escarameia (1996) described how tailpipes can be considered as “mini-systems” that can be designed independently of the rest of the siphonic system during the early stages of priming.

A method of measuring the water levels within the pipes that is not affected by fluctuating pressures needs to be developed. Such a measurement method would greatly improve the accuracy of this and any future models used to predict unsteady flowrates. This is an area for future research.

Lookup-data Model

Analysis of the transducer readings during calibration testing revealed that the cycle times of the pressure fluctuations in the tailpipes were often relatively constant. Further analysis showed that the pressure variation trends within the cycles were also relatively constant. The results commonly identified two main pressure trends and these were categorised as being either high or low pressures.

Low pressure trends were caused by siphonic action occurring within the tailpipes (May and Escarameia, 1996). Low tailpipe pressure was generally accompanied by a corresponding increase in propeller revolutions representing an increase in flow velocity. High pressure trends were due to cessation of the siphonic action and the corresponding re-pressurisation of the system (Wright et al., 2002). Low propeller revolutions were generally recorded during high pressure periods in the tailpipe.

These relatively consistent high and low pressure trends led to the development and trial of a new computer model that would estimate flowrates by comparing the instantaneous readings from the pressure transducer and current meter to a list of previously recorded flow data to find the best data match. A "lookup-data" table was created from the calibration data for each outlet. The lookup-data table listed the average pressure transducer and current meter readings recorded during the high and low pressure periods of the calibration testing. The lookup-data table for Outlet 4 is shown in Table 2.

To estimate the flowrate, the computer model would examine the current meter revolution reading. It would then look through the lookup-data table and identify rows that have the same value (or the closest fit) in the first column Table 2. The model would then compare the transducer reading with the value in the second column of the previously identified rows to find the most appropriate match. The model would then predict the flowrate by reading off the value in the third column of the selected row.

Table 2. Lookup-data Table for Outlet 4

Average Current Meter Reading (Revs/s)	**Average Transducer Reading (mA)**	**Flowrate (L/s)**	**Average Current Meter Reading (revs/s)**	**Average Transducer Reading (mA)**	**Flowrate (L/s)**
1	**2**	**3**	**1**	**2**	**3**
0	10.2700	0.00	34	10.9202	3.50
8	10.2638	0.25	34	10.2774	3.45
8	10.2686	0.25	35	10.9760	3.96
15	10.2763	0.50	38	9.6971	4.00
15	10.2822	0.50	36	11.0012	4.60
18	10.3497	0.74	40	9.2378	4.60
18	10.3583	0.74	37	11.0440	5.00
20	10.4209	1.00	43	8.5362	5.00
20	10.4492	1.00	36	11.1320	6.00
23	10.5014	1.24	48	7.1082	5.70
23	10.5175	1.25	38	11.4697	7.00
25	10.5418	1.55	54	5.2838	6.80
25	10.6362	1.55	33	12.1002	8.00
27	10.5989	1.75	58	4.3593	7.70
26	10.7369	1.76	37	12.2301	9.60
28	10.6390	2.00	62	3.3132	9.00
28	10.8044	2.01	42	12.2650	10.80
30	10.6897	2.53	64	2.5965	10.00
29	10.7618	2.25	45	12.2424	11.60
30	10.7167	2.50	67	2.2487	10.70
30	10.7332	2.50	49	12.4251	12.00
31	10.7854	2.74	65	2.1210	11.60
31	10.7696	2.70	51	12.5390	13.00
32	10.8079	3.00	62	2.0947	12.00
32	10.6084	2.90			

In order to test the accuracy of the new lookup-data model, a randomly selected set of flowrates were run through the multi-outlet rig for a period of just over 15 minutes. The flowrates were selected by adjusting the butterfly valve in the main supply line at various intervals from between one and three minutes. A comparison between the measured rig flowrate and the flowrate predicted using the lookup-data model was made for each outlet. The comparison for Outlet 4 is shown in Figure 4. The results for the other three outlets were similar to those shown in Figure 4.

The measured flowrate values for Q4 shown on Figure 4 were estimated by dividing the total flowrate supplied to the test rig by the number of outlets (four). This estimation method assumes an equal distribution of the gutter flow between the outlets, which is of course, possibly erroneous and verification of this assumption is the underlying reason for this study. Figure 4 shows a reasonable relationship between the measured and the predicted flowrates using the lookup-data for Outlet 4, despite the uncertainty in quantifying the individual flowrates.

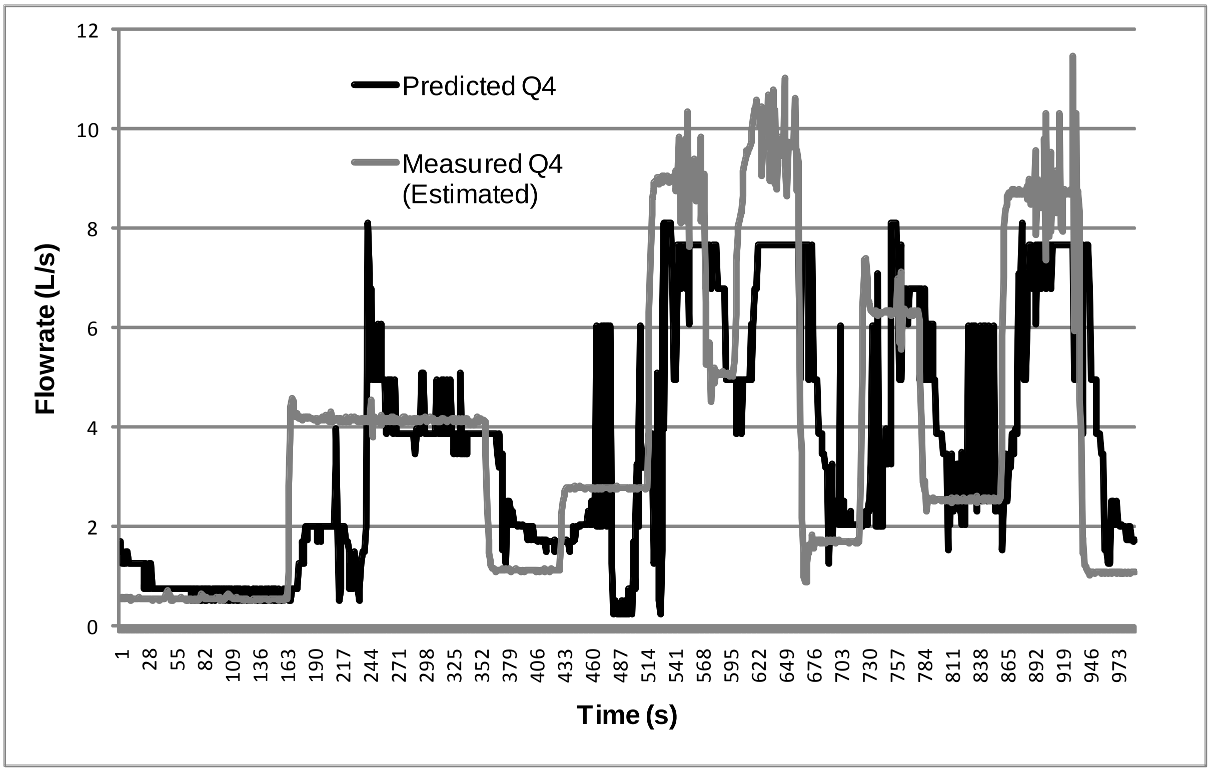

Figure 4. Comparison of Measured and Predicted Flowrates Using Lookup-data for Outlet 4

The results shown in Figure 4 are very promising and suggest that it may be possible to use the lookup-data model developed in this study to satisfactorily estimate the individual flowrates through the outlets in multi-outlet siphonic roof drainage systems.

CONCLUSIONS

This paper describes an experimental investigation into quantifying the flowrates through the individual outlets and tailpipes of a multi-outlet siphonic roof drainage system under both full-pipe and partially-filled pipe flow conditions. A pressure transducer was installed within each tailpipe to measure the water depth and a propeller-type current meter was installed to measure the flow velocity. The hypothesis was that it would be possible for a computer model to satisfactorily predict the instantaneous flowrates within each tail pipe using the output from these two instruments.

A "lookup-data" computer model was developed that estimated flowrates by comparing the instantaneous readings of the pressure transducer and current meter to a list of previously calibrated flow data to find the best data match. The results of the lookup-data model developed in this study were very promising and suggest that it may be possible to use the model satisfactorily to estimate the individual flowrates through the outlets in multi-outlet siphonic roof drainage systems.

A method of measuring the water levels within the pipes that is not affected by fluctuating pressures needs to be developed and this is an area for future research.

REFERENCES

Arthur, S. and Swaffield, J.A. (2001). Siphonic roof drainage system analysis utilising unsteady flow theory, *Building and Environment*, **36**, 939-948.

Lucke, T. and Beecham, S. (2009). Cavitation, aeration and negative pressures in siphonic roof drainage systems, *Building Services Engineering Research and Technology*, **30**(2), 103-119.

Lucke, T. and Beecham, S. (2010a). Capacity loss in siphonic roof drainage systems due to aeration, *Building Research and Information*, **38**(2), 206-217.

Lucke, T. and Beecham, S. (2010b). Aeration and gutter water levels in siphonic roof drainage systems, *Building Research and Information*, **38**(6), 670-685.

May, R. (1995). Design of conventional and siphonic roof drainage systems, in Proceedings of Public Health Services in Buildings – Water Supply, Quality and Drainage, IWEM conference, London.

May, R. and Escarameia, M. (1996). Performance of siphonic drainage systems for roof gutters, Report No. SR463, Wallingford: HR Wallingford, 1996.

Qu, Y., Lucke, T. and Beecham, S. (2010). Measuring flowrates in partially-filled pipes in siphonic roof drainage systems, in Proceedings of 15th Flow Measurement Conference, Taipei, Taiwan.

Wright, G.B., Swaffield, J.A. and Arthur, S. (2002). The performance characteristics of multi-outlet siphonic rainwater systems, *Building Services Engineering Research and Technology*, **23**(3), 127-141.

Wright, G.B., Arthur, S. and Swaffield, J.A. (2006). Numerical simulation of the dynamic operation of multi-outlet siphonic roof drainage systems, *Building and Environment*, **41**, 1279-1290.