Development of a test methodology for the verification of system design at the commissioning stage of tall building drainage systems.

M. Gormley

m.gormley@hw.ac.uk

School of Energy, Geoscience, Infrastructure and Society, Heriot-Watt University, Edinburgh, Scotland, UK.

Abstract

Current codes and standards for drainage systems make some reference to the verification and validation of system design and performance at commissioning stage, but most methods fall far short of the ultimate goal of verifying the design once installed. This is particularly true for tall buildings (High-Rise buildings). The focus of these tests is often to identify leaks rather than verify performance, so, air testing, smoke testing, some water testing, combined with soap solutions are all recommended. None of these methods will help with verifying whether the system can cope with the designed loading or prevent destruction of water trap seals due to positive or negative air pressure transients. None of the current test methods recognise positive pressure transients at all. Like any other engineered system, there is a real requirement to verify the system as designed. This research introduces a methodology for a standardized test which can be easily implemented at commissioning stage and uses BSEN12056:2 2000 as the example code, however it is applicable to all codes. The paper introduces an approximated calculated sequence of water discharges from standard appliances into the system at specific times to develop a pressure regime within the system to challenge the designed air pressure equalization system (ventilation system)- using well known equations for terminal velocity and terminal distances The measure of the appropriateness of the calculation is a pressure spike at the base of the stack due to adjoining flows throughout the height of the stack. The calculated procedure has been validated against data obtained from the National Lift Test tower in Northampton, UK – a 34 storey configurable drainage and vent system. The calculation method has been shown to represent a heavy load on the system and thus provides a more realistic test for system performance than those currently recommended in design codes. The method produces a repeatable and predictable system pressure from which system performance can be assessed.

Keywords

Building Drainage Systems, Performance testing, Commissioning, Tall Buildings.

1. Introduction

1.1 General

In the UK, contractors have the responsibility to undertake the hydraulic performance testing of the system, by testing the system to the prescribed requirements based on BS EN 12056 Table NG.1[1]. There is also a need to undertake air tightness tests to ensure that the pipework air tightness requirements comply with the relevant standards. The contractor generally produces signed test certificates for issue to the consultant for checking. This is true for other jurisdictions however for the purposes of this paper only the UK arrangement will be dealt with – methodologies presented would be applicable to any code or configuration.

The consultant generally validates the test certificates and the system is then ready to be handed over as far as the hydraulic performance is concerned. However, when it comes to air flow performance, there is no such obligation on the industry to demonstrate adequate provision and performance. This is generally acceptable for small and less complex systems but not for high rise buildings. The lack of adequate provision can lead to severe system failure which may only become apparent at post-occupancy, which can require disruptive and expensive remedial works to rectify.

It is therefore imperative to develop proper industry recognised guidance for drainage ventilation design.

1.2 Performance related to Airflow

As a simplified approach to look at a system's performance in relation to airflow and pressure transients, the main factor to consider is the loss of water seal below the minimum allowable level prescribed in the building regulations. A minimum of 25 mm of water seal should be retained under working and test conditions. Hence, comparison of levels of depletion of water seal in a system can be co-related to its airflow performance. There are other performance testing requirements including air tightness tests, leakage tests, and pressure testing of stacks however even success in these tests does not prove that the system as a whole will perform adequately from hydraulic and air flow perspectives.

1.3 Pressure Testing

The various methods of pressure and performance testing of foul and surface water drainage systems are detailed within the respective parts of BS EN 12056-2 [1]. Pressure testing can be achieved by using one or more or, a combination of, the following four methods:

- Air testing: this is by far the most common method used where an air pressure of not less than 38 mm water gauge is to be maintained for a minimum of 2 minutes; however, this will not identify the source of any leaks.
- Smoke testing: smoke generated by a pellet or machine is introduced under pressure to the system to give a visual indication of any leaks.
- Soap solution: generally used in conjunction with an air or smoke test, a soap and water solution is applied to each joint. Indication of any leaks is given when bubbles are formed on the outer surface of the joint.
- Water testing: generally only used on small sections of a system, the section of pipe, usually the lowest point of the system, is filled with water up to the flood level of the lowest connected appliance. The test however, is not suitable for pressures in excess of 6 metres water gauge.

Performance testing is a necessary undertaking for all systems to ensure that the trap seals are maintained to a level of no less than 25 mm, when subjected to the effects of self- and induced siphonage and back pressures under peak operating conditions.

Connected appliances should be tested individually and as a group as detailed within the schedules that can be found within BS EN 12056:2000-2. [1]

1.4 Commissioning test

There is a requirement to verify the system as designed. This will require a standardised test flow to be established in the vertical stack whilst observing and recording the effect of the flow on system air pressures and the effect on water trap seals throughout the installation. The purpose of the test is to simulate conditions in which there is an accumulation of flow at the base of the vertical stack (or at an offset) which has the potential to create an occlusion of the air leaving the system, thus generating a back pressure with the potential for system failure. This is an important test to formally commission the system and to check that pressure equalization occurs properly under surcharge conditions. The choice of discharge to ensure a proper test of the system is crucial and can be difficult to obtain.

1.5 Summary

In summary, there are a number of methodologies for the commissioning and testing of BDS from different jurisdictions internationally, however the tests described briefly above cover most. Unlike other engineered systems in buildings (water supply and electrics for example) there is no real weight given to commissioning and testing of systems. The next section offers a proposed methodology for a commissioning test.

2. Test Procedure

2.1 Test Schedule

The procedure described below

i) **Wet the pipe** . Flush the WC closest to the top of the vertical stack to be tested three times in order to wet the pipe and create normalised conditions. Note: this is particularly important on new systems which may be dry and dusty.

ii) **Initiate pseudo-steady flow**. Turn on flow from five showers near the top of the stack to be tested, this will set up a pseudo- steady flow in the stack.

iii) **Initiate WC flush sequence**. Flush three WCS into the system, delayed in time as determined by the method shown below.

iv) **Observe trap seal performance**. The observation of the test is important. A visual inspection can help, however, other means would be beneficial. For example, the recording of system pressures near the base of the stack under surcharge conditions. Proprietary engineered options for the determination of system seal performance are also available and should be considered for this test.
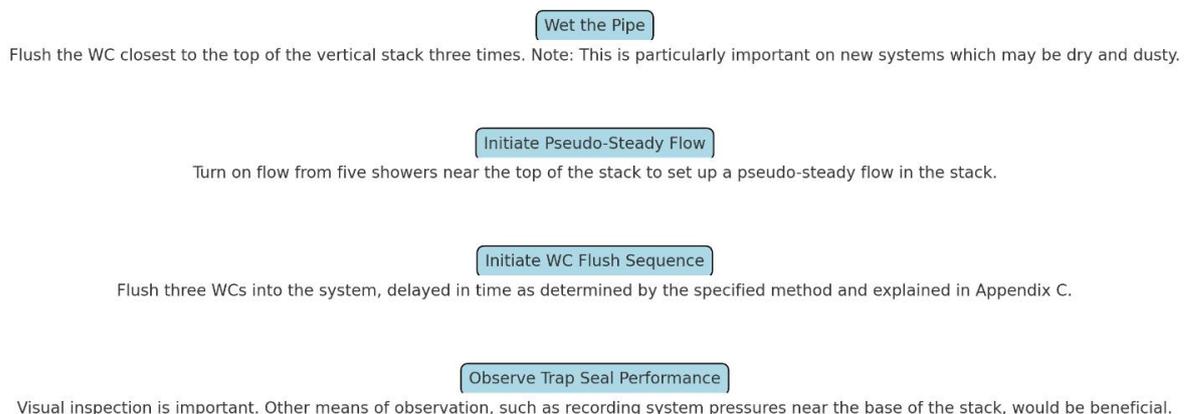

Flush the WC closest to the top of the vertical stack three times. Note: This is particularly important on new systems which may be dry and dusty.

Turn on flow from five showers near the top of the stack to set up a pseudo-steady flow in the stack.

Flush three WCs into the system, delayed in time as determined by the specified method and explained in Appendix C.

Visual inspection is important. Other means of observation, such as recording system pressures near the base of the stack, would be beneficial.

Figure 1. Process flowchart of the test procedure

An example of how this works may be illustrative. For a 100mm vertical pipe there is a necessity to discharge a total cumulative water flow of approximately 5.2 l/s at the base of the stack. The best way to achieve this is by flushing three standard 6 litre toilets – synchronised so that each flow joins the preceding flow to increase the total flow at that point. There is therefore a requirement to delay flushing toilets until the flow from the next highest toilet has arrived. **Testing all toilets at the same time is meaningless and will not have the desired effect.** The pseudo-steady flow is used to form a baseflow for the test because trying to load the system fully with WC flushes is too difficult to achieve. By including a pseudo-steady flow upon which to add transient WC flushes, allows both steady flow and transient effects to be considered. This method is therefore a compromise between steady and unsteady methodologies and a recognition of the difficulty with which such tests could be carried out on site.

2.2 Toilet flush sequence timing

Figure 2 below illustrates the process for calculating the time a WC flush will take to reach the base of the stack.
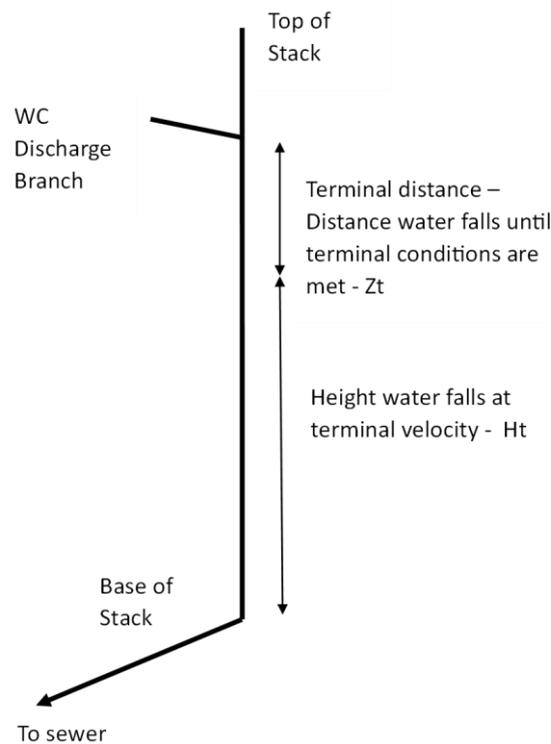

Figure 2. System layout for the calculation of WC flush test sequence

WC flushing is initiated at the branch level. This water will enter the vertical stack and fall under gravity. The flow will accelerate until terminal velocity is achieved. The flow will continue to fall at terminal velocity until it reaches the base of the stack. It is important to note that the test is not just a measure of the time it takes for a flush volume to reach the base of the stack, but rather, the time at which a positive pressure spike is observed at the base of the stack. The total flow at the base of the stack will be the flow from the combined shower flows and the peak of the WC flow. In order to calculate this time a number of factors need to be taken into account.

The calculations lead to an approximation, since there will be slight variations between systems which can't be accounted for in every eventuality. WCs are an imprecise device with delays between initiating a flush (pushing a button or lowering a lever) and water leaving the appliance. Other variables include the time taken for the flow to leave the bowl in addition to the differing characteristics of flush itself.

2.2.1 Calculation method.

The basis for calculating terminal velocity is as follows

$$V_t = K\left(\frac{Q_w}{D}\right)^{0.4}$$

Eq. 1

provided that

$$K = \left(\frac{0.2173}{n^2}\right)^{0.3}$$

Eq. 2

Where

Vt is terminal velocity in m/s

Qw is water flow rate in l/s

D is pipe diameter in m

K is a calculated factor

n is the Manning coefficient.

This expression was first developed by Wyly [2] and Wyly and Eaton [3]. A typical smooth pipe value of Manning n of 0.007 yields a K value of 12.4, however the more comprehensive Colebrook–White expression suggest a value of K=14.99 for smooth pipes with k=0. For a smooth pipe a K value of 12.4 will assure that the conditions of Equation 2 are met.[4]

The vertical distance Zt associated with the establishment of terminal conditions is given by

$$Zt = 0.159 V_t^2$$

Eq. 3

Where

Zt = Terminal distance (m)

Vt = terminal velocity (m/s)

From experimental work the average velocity in the Zt zone can be taken as 1m/s for a standard 6 litre WC flush.

Therefore, the time taken for the peak pressure to appear at the base of the stack as a result of a 6 litre flush can be approximately determined from

$$(Z_t . V Z_t) + (H_t . V_t)$$

Eq. 4

Where:

Z_t = Terminal distance in m

VZ_t = approximate mean velocity before terminal velocity has developed. In m/s

H_t = The length of pipe where the flow is at terminal velocity in m

V_t = Terminal velocity in m/s

2.2.3 Example

For a discharge where the discharge height is 75m from the base of the stack with a standard 6 litre flush in a 100 mm pipe. The peak water flow can be taken as 1.8 l/s at the point of discharge and the assumed flow from the combined shower discharge is 2 l/s then using a K value of 12.4 (based on a manning value of 0.007 for a smooth pipe) [4]

$$V_t = 12.4 \, ((1.8 + 2)/0.1))^{0.4}$$

$$= 3.35 \text{ m/s}$$

Giving a terminal distance of 1.8m

Therefore, for a single flush from 75m on top of a pseudo-steady flow of 2l/s the time taken for the flow to produce a pressure peak at the base of the stack would be;

$$(1.8 * 1.2) + (73.2 * 3.35)$$

$$\cong 23 \text{ seconds}$$

The same process is carried out with subsequent flushes so that they combine at the base of the stack to give maximum pressure peak for the given flows.

It can be seen that the contribution to the overall timing in a tall building is primarily influenced by the flow in the Ht zone as shown in Figure 2 and the overall time contribution in the terminal distance zone Zt is minimal to the overall timing. It is therefore recommended to initiate the WC flushes as near to the top of the stack as possible to minimize the risk of not achieving peak pressure at the base of the stack. Organising the flushes within 2 floors is preferred.

The delay between flushes is therefore the difference in calculated travel time between subsequent flushes.

For the previous example, if a second flush (from WC2) was initiated at 50m from the bottom of the stack then it would take approximately 15 seconds to produce the pressure peak at the base of the stack. Note that the calculation for WC2 must include the adjoining flow from WC1, so terminal distance and terminal velocity below WC2 discharging branch will be different. The terminal distance increases to 2 metres and the terminal velocity increases to 3.58 m/s. WC2 would therefore need to be flushed (23-15) 8 seconds after the first WC situated at 75m from the base of the stack

2.3 Influence of branch length on timings.

The above calculations are based on the assumption that the vertical stack is within 1.5 metres of the discharging WC. For distances greater than this, additional time is needed for the flow to reach the vertical stack. Times should be generally adjusted by 1 second for every metre of extra branch length to the discharging WC. This again, is an approximation which has been shown to be an effective value from laboratory and NLT testing work.

From the previous example – if WC2 was located at the end of a branch that is 4.5 metres long then this adds an additional 3 seconds to the travel time and the sequence timing would now be as follows;

WC1 flushed at time 0

WC2 flushed at time 0 + (8-3) = 5 seconds

WC2 would therefore need to be flushed 5 seconds after WC1

2.4 Pass criterion

Any of the following indicates a failure of the system.

- A pressure in excess of 375 Nm^{-2} when measured above the lowest WC to be used in the test.

- An evacuation of the water trap seal due to siphonage (below the limit -25%)
- A gurgling sound from water trap seals (due to negative pressures)
- Air Bubbling through a water trap into the toilet bowl
- Water being pushed through the water trap seal into the appliance.

A reasonable method needs to be employed to observe the water trap seals on the lowest floor where a WC flush has occurred and the floor above and below if possible. A visual inspection can help, however, other means would be beneficial. For example, the recording of system pressures near the base of the stack under surcharge conditions. Proprietary engineered options for the determination of system seal performance are also available and should be considered for this test. Automatic detection methods may also be used where a non-destructive air pressure wave can be used to map the location of compromised traps.[5]

Pressure transducers with data logger should be encouraged and a test log of pressures recorded. This would be beneficial for forensic analysis of problems at a later date.

3. Real world test (NLT system)

The above procedure was used to calculate the test sequence of up to three WC flushes at the National Lift Tower test facility in Northampton UK. The approximate version of the calculations were used to time the WC flushes over a distance of 33 m on the test rig shown below in Figure 3. Note that the trace for a single flush with no steady flow is indicative of the pressures in the system if WCs were flushed at the same time. (dispersed flow). The pressure trace shown is what was observed at the base of the stack when a large flow of is stopped by a valve, and is what is being simulated by the test procedure.
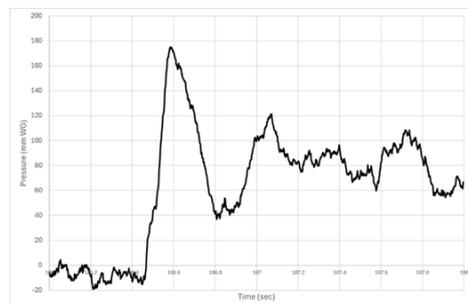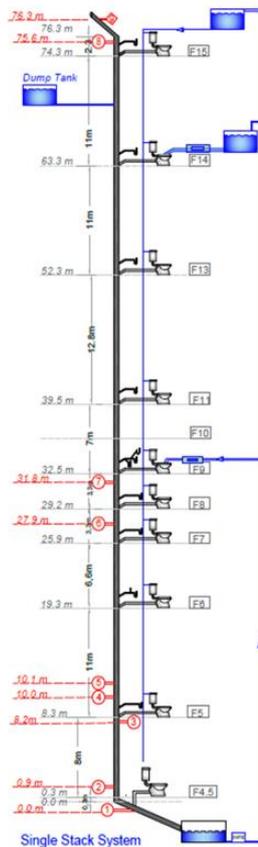
Pressure rise at the base of the stack as recorded – due to a complete blockage of the passage to air due to a surcharge

Figure 4- System used for test validation.

4. Results

The following are recorded traces from the NLT using the calculation process above. The aim is to ensure that a single pressure spike of sufficient magnitude is observed at the base of the stack in order to stress test the system. Figure 5 is illustrative of the pressure trace when a single flush is discharges from 32.5 m up the system. No real pressure is recorded. Figure 6 and 7 show pressure traces associated with different combinations of flows from a pseudo-steady flow of 2l/s and additive WC flushes whose timing is calculated using the equations set out above. The 3 flush test in Figure 7 clearly shows a spike of similar magnitude as that shown in Figure 4.
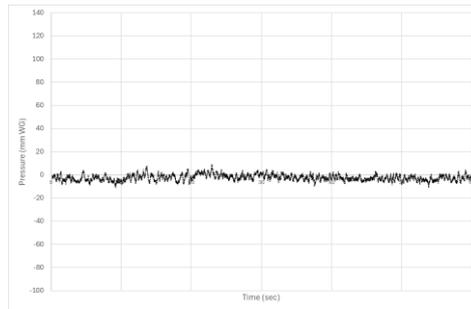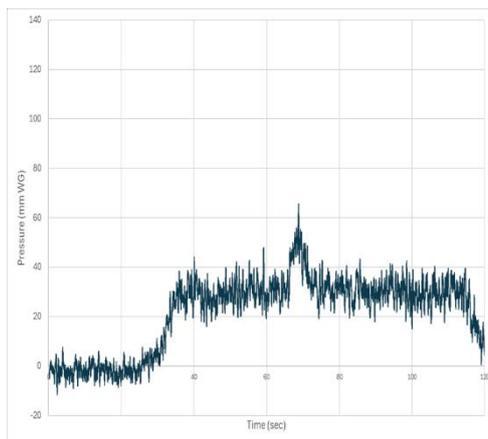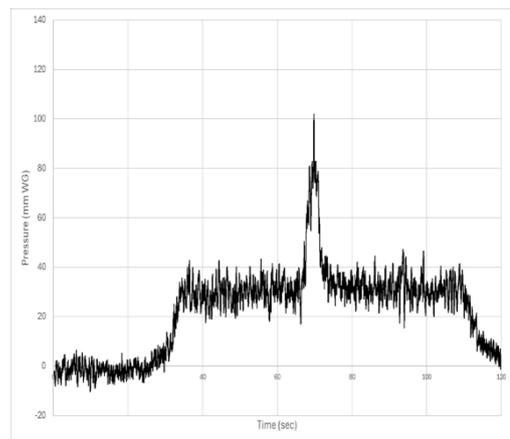

Figure 5 A single flush from 32.5m. The impact on the pressure at the base of the stack is imperceptible – this is similar to the pressure trace observed when multiple toilets are flushed at the same time.

(a)   (b)

Figure 6 (a) A single flush on top of a 2l/s steady flow rate. steady flow of 2l/s from floor 32.5 m plus a flush from floor 29.5m . (b) Two flushes timed to join together and give a larger pressure rise at the base of the stack - steady flow of 2l/s from floor 32.5m plus flush from 29.5m and flush from floor 8.3m
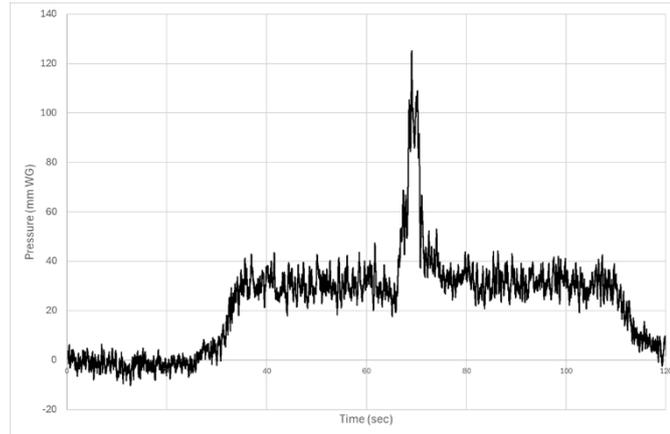
Figure 7- Steady flow of 2l/s plus flush from floor 29.5m and flush from floor 8.3m and floor 5m

5. Conclusions

The measure of success for this method is that a single pressure transient can be recorded at the base of the stack in order to stress the system under full load conditions. The pressure trace in Figure 7 confirms this. A drainage system needs to be able to deal with positive and negative pressure rises in order to function properly. Current guidance does not suggest a meaningful way to test system performance under realistic air pressure conditions (particularly for positive pressures). The method described in this paper provides a way to calculate a sequence of WC flushes in a tall building in order to create similar conditions at the base of the stack to those experienced under a Jowkowsky pressure rise (due to surcharge in the main collection drain for example).

6. Acknowledgements

7. References

[1] BS EN 12056-2 (2000) 'Gravity Drainage systems inside Buildings. Sanitary Pipework, Layout and Calculatioin', in. London: BSI.

[2] Wyly RS, Eaton HN. (1961) Capacities of Stacks in Sanitary Drainage Systems for Buildings.

[3] Wyly RS.(1964) Investigation of the Hydraulics of Horizontal Drains in Plumbing Systems.

[4] Swaffield (2010). Transient Airflow in Building Drainage Systems. Taylor and Francis

[5] Kelly DA, Gormley M. Automatic detection of depleted fixture trap seals using the reflected wave technique. Build Serv Eng Res Technol. 2014;35(3).

8. Author

Michael Gormley is Professor of Public Health and Environmental Engineering at the School of Energy, Geoscience, Infrastructure and Society at Heriot-Watt University. His research specialisms are: mathematical modelling of air and water flows in building drainage systems, infection spread via bioaerosols and product development.