Performance Solutions: Is it appropriate to use the overflow equations from AS/NZS3500.1 to design box gutter systems as per AS/NZS3500.3?

Discussion paper by:

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Background

It appears that there is an increasing tendency for building roof drainage designers to use water tank overflow equations from Section 8.4.4 of AS/NZS3500.1:2018 (and its predecessors) to develop box gutter *performance solutions*. This discussion paper examines the suitability of this practice.

Section 8.4.4 – Tank Overflow

The orifice and weir overflow discharge equations provided in Figures 8.4.4.1 (A), 8.4.4.1 (B) and 8.4.4.1 (C) of AS/NZS3500.1:2018 were specifically developed for water tank applications. The overflow equations are applicable in covered tanks with a tranquil and steady water surface profile as shown in Figure 1.

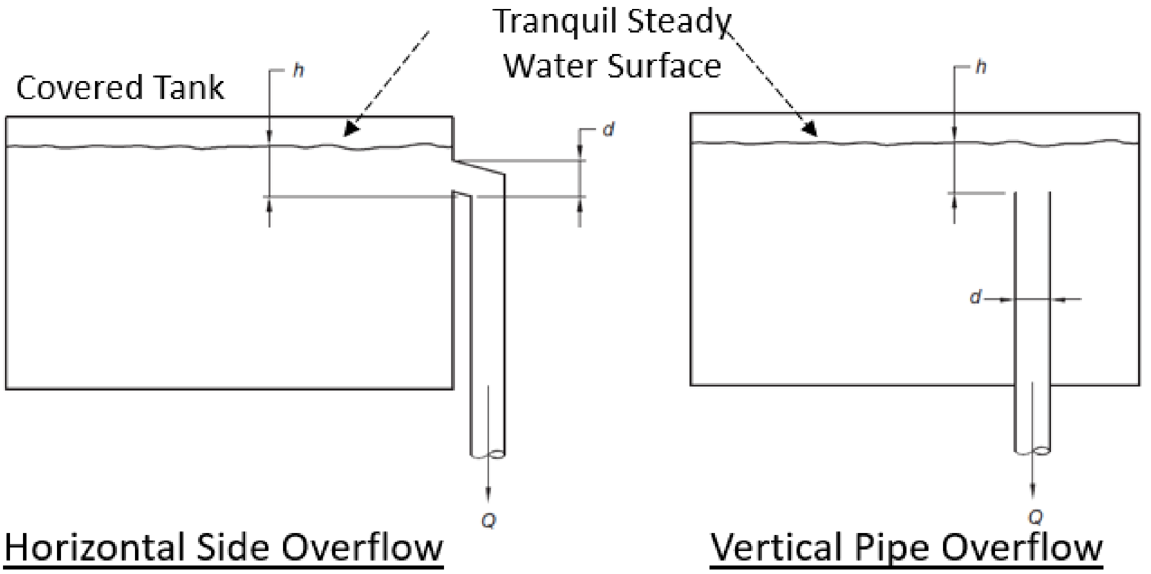

Figure 1 – Tank Diagrams provided in Figures 8.4.4.1 (A), 8.4.4.1 (B) in AS/NZS3500.1

Tank overflow equations 8.4.4.1(2) and 8.4.4.1(4) provided in Figures 8.4.4.1(A) and 8.4.4.1(B) are variations of the historical orifice equation (Eqn. 1) developed by Italian physicist Evangelista Torricelli (1608-1647) in a laboratory research study using a tank with a tranquil and steady water surface. These equations are only valid in situations where the overflow inlet is fully submerged. They are not suitable for box gutter design.

$$Q_o = C_d * A * \sqrt{2gh} \quad \text{...Equation 1}$$

Where:
Q_o = Flowrate through orifice (m^3/s)
C_d = Orifice coefficient (~0.61 for sharp-edged orifice)
A = Cross-sectional area of pipe (m^2)
G = gravity (9.81m/s2)
h = head of water above orifice centroid (m)

Tank overflow equations 8.4.4.1(1), 8.4.4.1(3) and 8.4.4.1(5) provided in Figures 8.4.4.1(A) 8.4.4.1(B) and 8.4.4.1(C) are variations of the historical weir equation (Eqn. 2). These equations are also based on the assumption of a tranquil and steady water surface. These equations are valid in situations where the overflow inlet is not fully submerged, i.e. open-channel flow conditions.

$$Q_w = C_d * b * \sqrt{2g} * h^{1.5}$$ …Equation 2

Where:
Q_w = Flowrate over weir (m^3/s)
C_d = Weir coefficient (varies significantly depending on shape of weir)
b = width of weir (m)
G = gravity (9.81m/s2)
h = head of water above orifice centroid (m)

Box Gutters

As discussed above, the orifice and weir overflow discharge equations provided in Section 8.4.4 of AS/NZS3500.1:2018 are applicable for use in water tanks with a tranquil and steady water surface profile. Roof drainage box gutters are long, straight, drainage components designed to convey roof runoff longitudinally and discharge it freely from the end of the box gutter into a sump below. Box gutters are subjected to spatially varied flow conditions and accordingly have extremely complex flow variation throughout the length of the gutter and at the outlet. This circumstance becomes even more complex where opposing flows of a gutter share an outlet and or overflow.

Box gutters conveying roof water to sumps clearly have no resemblance to tanks, nor do they have a tranquil steady water surface profile. It is a dubious practice to use tank overflow equations to design overflow provisions for box gutter systems. It is also inappropriate to develop an overflow solution in isolation, without due consideration of the varying water profile in the box gutter.

Box gutters of building roof drainage systems are subjected to very different operational conditions than those of a covered tank, or the laboratory-based model that was used to develop the equations in question. Roof drainage systems are designed to operate effectively during intense storm events where the inflow rates into the box gutters can fluctuate greatly. This often produces highly unsteady hydraulic flow conditions (spatially varied flow) which results in significant water level changes within the gutters. These unsteady hydraulic flow conditions can also cause the location of the maximum water level within the gutter to change continually during a storm event (Figure 2). The deepest part of the water profile in a gutter is rarely at the outlet and therefore, sizing the outlet (or overflow) without identification of the deepest part of the flow is fundamentally flawed.

Figure 2 – Flow in 300mm wide box gutter showing varying maximum depth locations

The highly complex unsteady flow conditions that occur in box gutters makes it very difficult to hydraulically model and no mathematical formulae can reliably predict the maximum water depths in gutters with consideration to varying gradients and encompassing a multitude of outlet configurations. Physical testing is the only reliable method to accurately determine the full range of flow conditions that is likely to occur in a box gutter conveying roof water during a storm event in different configurations.

Much research and hydraulic testing was undertaken on box gutter systems during the development of AS/NZS3500.3:2018 (and its predecessors). This research determined minimum box gutter depths, and a range of other factors required to ensure roof drainage water is conveyed safely in the box gutter to the sump without the risk of gutter overtopping, flooding or building damage. The outcomes of this, and other research studies, are incorporated in the *general method* for box gutter design procedures outlined in Figures 3.7.4(A), 3.7.4(B) and 3.7.4(C) in AS/NZS3500.3:2018. Using unrelated water tank overflow equations from Section 8.4.4 of AS/NZS3500.1:2018 to design hydraulically complex box gutter systems is clearly not a suitable *performance solution* alternative.

Overflow Sumps

AS/NZS3500.3:2018 requires box gutters to discharge primary flows freely from the end of the gutter, in the direction of flow, into a sump which has overflow provisions at least equal to the total design flow. Three alternative sump overflow designs are available in AS/NZS3500.3:2018 namely, *rainhead*, *sump/side overflow* device and *sump/high capacity overflow* device. The overflow of the *rainhead* device is a low-set weir in the direction of gutter flow, that discharges directly to the atmosphere. The overflows of the *sump/side* and *sump/high capacity* devices discharge though weirs connected to an overflow channel/duct, and an overflow pipe, respectively.

In the *general method*, the downpipe sizes required to safely drain the design flows from the three alternative sump overflow designs in AS/NZS3500.3:2018 are calculated using variations of the orifice equation (Eqn. 1). However, roof drainage system sumps do not generally experience a tranquil and steady water surface during operation, rather, they experience highly turbulent hydraulic conditions such as those shown in Figure 3.

Figure 3 – Highly turbulent hydraulic conditions in sumps receiving box gutter inflows

As discussed, box gutter system sumps experience highly turbulent hydraulic conditions and water level variations during normal operation. These water level variations affect the discharge rate through the downpipe. AS/NZS3500.3:2018 allows for these highly turbulent hydraulic conditions and water level variations in sumps by increasing the typical sump depth.

Research undertaken during the development of AS/NZS3500.3 determined that a significant increase of sump depth was required to ensure the required flowrate through the downpipe was achieved. These findings are incorporated in Figures I3 and I4 of AS/NZS3500.3 to allow for turbulent flow conditions that occur during operation.

No research has been published that investigates the suitability of using the water tank overflow equations from Section 8.4.4 of AS/NZS3500.1 to develop performance solutions for box gutters, sumps or overflows. It is therefore inappropriate to use these equations to design *performance solutions* for box gutters, sumps, or overflows.

<u>Other Issues for Consideration</u>

As discussed above, there are numerous hydraulic theory explanations as to why it is inappropriate to use water tank overflow equations to develop *performance solutions* for box gutter systems. However, there are also other related and relevant issues that should be considered in the development of *performance solutions* for box gutter systems. These are discussed below.

Building roof drainage systems are highly complex hydraulic systems that contain different components including rainwater, box gutters, sumps, outlets, overflow devices, weirs and pipes. All these components interact with each other and they <u>cannot be designed in isolation</u>. Effective roof drainage system design must consider all components of the system acting together to ensure roof water is conveyed safely away from the building without the risk of gutter overtopping, flooding, or building damage.

Roof drainage box gutter systems designed using the general design methods outlined in Figures 3.7.4(A), 3.7.4(B) and 3.7.4(C) in AS/NZS3500.3 consider the interaction of all drainage components operating together. However, performance solution designs often do not consider these effects.

Environmental conditions can also influence the performance of roof drainage systems. High winds and intense rainfalls that often occur during storm events can cause significant wave actions in box gutters of roof drainage systems. Waves can also form in some gutter configurations due to the proximity of the outlet (or overflow) to vertical faces, such as the return ends of the gutter. These gutter waves can travel along the length of the box gutters effectively varying the anticipated location of maximum gutter water depth and potentially cause overtopping and building flooding.

Box gutter systems designed using the general design methods in AS/NZS3500.3 allow for this potential wave action by applying sufficient freeboard values which were obtained from physical testing research studies. The height and speed of the waves vary with the flow rate of the gutter and its configuration. As flow is increased, additional freeboard may be required, and this is particularly evident in flow rates above those presented in AS/NZS3500.3.

Wind can also cause leaves, branches, plastic bags and other debris to be blown into the box gutters and sumps of roof drainage systems. This debris can potentially cause partial, or full blockages of drainage components resulting in overtopping of the gutters. Box gutter systems designed using the general design methods in AS/NZS3500.3 allow for potential blockage of the primary downpipe by requiring a separate overflow device that has at least the same capacity as the primary system.

Box gutters that are installed with changes in direction (i.e. not straight) can also dramatically increase the potential for blockages to occur and this practice is specifically prohibited in AS/NZS3500.3. The hydraulic resistance introduced by changes in direction (corners) is significant and outside the scope of AS/NZS3500.3.

<u>Conclusion</u>

This paper has examined the practice of using water tank overflow equations from Section 8.4.4 of AS/NZS3500.1:2018 to develop box gutter *performance solutions* in lieu of complying with the AS/NZS3500.3:2018 general method requirements for box gutter system design.

The author concludes that this practice is unacceptable. This is mainly due to the significant differences in operational hydraulic conditions between covered tanks and box gutter systems exposed to the elements.

The AHSCA Research Foundation recently concluded a four-year comprehensive research study using physical modelling to investigate and validate the hydraulic behaviour of a variety of new box gutter outlet and overflow devices. Their research outcomes included 12 new fully-tested box gutter overflow devices that can be used as performance solutions where AS/NZS3500.3 overflow solutions are not suitable, or where required flowrates are above 16L/s. Designers requiring box gutter performance solutions are advised to contact their local, fully accredited and trained AHSCA member to discuss their requirements.

Hydraulic modelling and the estimation of spatially varied flow in box gutters is extremely complex. These complexities are multiplied with varied outlet configurations, primary gutter flow requirements and additional overflow paths.

It is recommended that regulators, building surveyors/certifiers, council and property owners insist that any “Performance Solutions” related to box gutters be undertaken by an appropriately trained professional using formulae and methodologies developed by research specifically relevant to box gutters.