Using performance-based design to improve understanding and enhance design options for box gutters and downpipes in large buildings

Utiliser la conception basée sur la performance pour améliorer la compréhension et la conception des boites gouttières et les descentes dans les grands bâtiments

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RÉSUMÉ

Une compréhension globale de la performance de gouttières rectangulaires et des tuyaux de descente est essentielle pour s'assurer que la conception du système de drainage du toit d'un bâtiment est efficace. Les systèmes de drainage de toit mal conçus peuvent entraîner des dommages importants sur la structure et le contenu d'un bâtiment. Les codes et normes actuellement appliqués en Australie pour réglementer la conception des gouttières rectangulaires et des tuyaux de descente ont souvent été limités par un manque de travaux de recherche empirique et souvent, ils ne reflètent pas les conditions d'écoulement complexes que subissent réellement les systèmes de drainage de toit. Des solutions de conception basées sur la performance peuvent aider à mieux comprendre et améliorer les options de conception des gouttières rectangulaires et des tuyaux de descente dans les grands bâtiments, en particulier compte tenu des conditions et des changements météorologiques extrêmes, et de l'intensité des précipitations attendues en raison du changement climatique. Un nouveau centre de recherche complet sur le drainage des toitures a été construit récemment à l'Université de la Sunshine Coast en Australie, pour entreprendre des recherches sur la façon dont le test de performance des gouttières, des tuyaux de descente et des systèmes de débordement peut être utilisé pour améliorer la compréhension des conditions hydrauliques lors de précipitations ordinaires ou extrêmement fortes. Ce document décrit le contexte et la méthodologie de la nouvelle étude de recherche.

ABSTRACT

A comprehensive understanding of the performance of box gutters and downpipes is critical to ensure a successful building roof drainage system design. Poorly designed roof drainage systems can result in significant damage to a building's structure and contents. Current codes and standards used to regulate box gutter and downpipe designs in Australia have often been limited by a lack of empirical research studies and they often do not reflect the complex flow environments experienced in real roof drainage systems. Performance-based design solutions can improve understanding and enhance design options for box gutters and downpipes in large buildings, particularly due to the extreme weather events and changes in rainfall intensities expected through climate change. A new, full-scale roof drainage research facility has recently been constructed at the University of the Sunshine Coast in Australia to undertake research into how performance-based testing of box gutters, downpipes and overflow systems can be used to improve understanding of the hydraulic conditions that occur during common and extreme rainfall events. This paper describes the background and methodology of the new research study.

KEYWORDS

Roof drainage, box gutters, downpipes, hydraulic design, stormwater management, extreme weather

1 INTRODUCTION

A building's roof and roof drainage system are the primary means by which rainwater is prevented from damaging both the building's structure and its contents (Jones & O'Loughlin, 1992). Failures of roof drainage systems represent a substantial proportion of insurance claims associated with high rainfall intensity weather events (Spekkers et al., 2014). The successful hydraulic performance of box gutters is important as failure often results in overtopping of gutters and stormwater entering the interior of the building causing damage (Beecham et al., 1995). To operate effectively, roof drainage systems need to be able to discharge water at a flow rate at least equal to the accumulation of water within the system for a given intensity and duration of rainfall (May, 1997; Wright et al., 2006).

Typical box gutter roof drainage systems for buildings with large roof areas consist of a number of important components that can significantly affect their performance (Jones & O'Loughlin, 1992). To ensure successful operation of roof drainage systems it is critical that the design parameters for these components be fully understood and accurately designed. Design parameters include; gutter width, depth and slope; number, position and size of downpipes; rainheads or sumps as transition points between the gutter and the downpipe; and the inclusion of overflow devices in case of primary downpipe blockage.

The design of roof drainage system components is based on the anticipated volume of water entering the system. Evaluated by statistical analysis of rainfall data and the ability of the system components to safely transport water away from the building (Wright et al., 2006; Verdon-Kidd & Kiem, 2015). The hydraulic capacity of the components is typically evaluated by a combination of hydraulic theory and empirical observations.

Current Australian roof drainage system design guidelines rely on a relatively large number of simplifying assumptions for both required capacity and performance ability (Jones & O'Loughlin, 1992). It appears that little or no consideration has been given to flow modifications and interactions between system components. As such, it is possible that much of the overall system performance and hydraulic capacity outlined in current building codes may not have been adequately evaluated or properly verified by experimental observation (May, 1997; Wright et al., 2006;). The codes also only supply guidelines for a limited range of flowrates.

In recognition of the considerable benefits removal of these design restrictions would provide, the Association of Hydraulic Services Consultants Australia (AHSCA) has commissioned a comprehensive research study to be undertaken at the University of the Sunshine Coast. Collaboration between universities and industry partners will ensure project outcomes are scientifically robust and have practical application. Results also provide a comprehensive data set for use nationally and internationally to improve understanding of the hydraulic performance of conventional roof drainage systems.

2 AUSTRALIAN BUILDING CODES AND STANDARDS

2.1 Development

The Building Code of Australia standard (AS 3500.3) governs the design of box gutter roof drainage systems in Australia and New Zealand. The code is based on empirical observations and hydraulic theory developed by K.G Martin (1965) as part of the Division of Building Research of the Commonwealth Scientific and Industrial Research Organisation (CSIRO). This work is heavily influenced by the methods and empirical observations of research conducted at the British Building Research Station, in the 1950's and 1960's, to develop the design solutions in British Standards. Many of the equations used by Martin are largely utilised without modification for Australian conditions (Martin, 1973). The influence of gutter slope on roof drainage performance was introduced into design graphs in AS/NZ 3500.3, following experimental work by Martin and Tilley (1968). In 1973 the CSIRO published a report designed to incorporate factors in roof drainage system design relevant to an Australian context (Martin, 1973). The standard was then revised in 1990, 1998, 2003 and 2015 in recognition of knowledge gaps and additional data obtained from experimental observations conducted in the 1990's (Beecham et al., 1995, Jones & Kloti, 1999).

2.2 Limitations

Limitations to design solutions for box gutters specifically stated in AS 3500.3 are gutter slopes to be in the range of 1:40 to 1:200, maximum design flow of 16 L/s and maximum downpipes size of 150 mm x 150 mm for rectangular downpipes, or 150 mm in diameter for circular downpipes. These small downpipe sizes can cause significant limitations to the building industry. A lack of appropriate research data is the rationale given for the existence of these limitations (AS/NZ 3500.3, 2015). Other limitations are due to the experimental methods used to develop the standards testing the performance of components in isolation and on a reduced scale to that experienced in practise. Advances in the understanding of complex flow dynamics and pressure gradients that manifest across roof drainage systems under varying flow conditions have identified the potential inadequacies of these methods (Lucke & Beecham, 2010; Reichstetter & Chanson, 2012).

3 STUDY APPROACH

This research will take an empirical approach to evaluating the performance of various configurations of roof drainage systems with internal box gutters, overflows and downpipes across a range of simulated rainfall intensities and conditions. Configurations to be evaluated will include a variety of gutter widths and gradients in conjunction with a range of sizes and shapes of typical and innovative overflow devices and downpipes. Key parameters evaluated in real-time across different parts of the system include flow rate, flow velocity, downpipe pressures and gutter water levels.

Figure 1 – Full-scale experimental roof drainage research facility at the University of the Sunshine Coast.

A full-scale roof drainage research facility (Figure 1) has been constructed for use in the study. The test facility has been designed to simulate realistic flow conditions for buildings with large roof areas. Inflow into the gutter via the roof sheeting can be programmed to simulate any design storm hydrograph. The maximum flow rate of the test rig is 80 L/s. This allows for the hydraulic performance of drainage system configurations to be tested using rainfall data from historical rainfall events, or from predicted future extreme events. The maximum length of the box gutter section is 25 m. The gutter in comprised of two halves that can be adjusted separately or combined to act as a single length. The roof sheeting and gutter slopes of the test rig are fully adjustable (up to 1:40). The height of the test rig is seven meters. The research focus is on the following critical hydraulic design considerations including:

- hydraulic waves;
- unintended and intended creation of siphonic conditions in downpipes;
- identification of appropriate “freeboard”;
- flow type transitions on the flow rate of various outlet and overflow configurations; and
- performance of sumps in high velocity discharges.

4 OUTCOMES

If roof drainage systems are capable of operating more effectively and with greater capacities than current design standards allow, then this increases unsustainable building practices and construction costs. However, the potential for increased system capacities must be carefully balanced against any potential increases in the risk of failure and subsequent damage (Wright & Jack, 2013).

This experimental research will assist in more accurate evaluation of the hydraulic capacity of conventional roof drainage systems and it will provide greater insight into how hydraulic performance may change with predicted increases in rainfall intensities resulting from climate change. The recent updating of Australian design storms has already resulted in greater predicted rainfall values for many locations irrespective of the potential effect of climate change on extreme rainfall events (Green et al., 2014).

Anticipated outcomes of this research study include:

- demonstrated viability of significantly increased gutter and downpipe flows;
- additional overflow options and related gutter sizing options for each overflow configuration;
- provision of design options to exclude sumps; and
- testing of larger downpipes (up to 300 mm diameter and 250 mm x 200 mm).

5 SUMMARY

The Australian hydraulic services industry has noted that the current roof drainage design standard has a variety of limitations that hamper the construction industry. This research project will involve a comprehensive investigation into capacities and performance of roof drainage systems, both within, and beyond the specifications of the current standard (AS/NZ 3500.3). The research outcomes will provide significant rationale for revision of the standard to be undertaken, or be used to validate performance based design submissions. It will also improve our understanding of how existing drainage systems performance may vary under greater rainfall intensities than they were designed for.

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