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Pull-out capacity of multiple screw fastener connections in cold-formed steel roof battens

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ABSTRACT

Light gauge steel roofing systems of low rise buildings are made of high strength steel roof cladding, battens and purlins/rafters/trusses and fastened with self-drilling screws. Localised failures occurring at these screw connections under wind uplift loading often lead to catastrophic losses of steel roofing systems during severe storm events. Pull-out failures occurring at the two bottom flanges of roof batten to purlin/rafter screw connections is one of them. Multiple screw fasteners connecting the bottom flanges of roof battens to purlins/rafters pull out prematurely from the light gauge steel purlins/rafters. Since the structural behaviour of multiple screw connections differs significantly from the behaviour of single screw connections, the pull-out capacity of multiple screw connections cannot be calculated directly based on the number of screw fasteners. Hence a series of 80 small scale pull-out tests was conducted to investigate the pull-out capacities of two and four-screw fastener connections in roof battens. The pull-out failure loads from the tests were first compared with the pull-out capacities predicted using the design equations in the current cold-formed steel design standards. Suitable design modifications were then proposed to accurately calculate the pull-out capacities of roof battens with two and four-screw connections. This paper describes the details and the results of this study.

1. Introduction

Light gauge steel roofing systems of low rise buildings are often made of high strength steel roof cladding, battens and purlins/trusses in Australia. Self-drilling screws are used to fasten these roof members to each other (Fig. 1). Localised failures at these screw connections often lead to catastrophic losses of steel roof cladding and battens during tropical cyclones, thunderstorms and tornadoes. There are mainly two types of localised failures occurring in thin-walled steel roofing systems: pull-through failures (Fig. 2) and pull-out failures (Fig. 3). In pull-through failures, the screw head pulls through the roof cladding (Fig. 2(a)) or both screw heads pull through the bottom flanges of roof batten (Fig. 2(b)). In pull-out failures, the screw pulls out from roof batten (Fig. 3(a)) or the screws located in both batten bottom flanges pull out from the purlin/rafter/truss located below the batten (Fig. 3(b)). Localised pull-through and pull-out failures of roof cladding to batten connections (Figs. 2(a) and 3(a)) cause severe losses of roof cladding whilst the pull-through and pull-out failures of roof batten to purlin/rafter connections (Figs. 2(b) and 3(b)) cause severe losses of both roof cladding and battens, i.e., the entire roofing system. Therefore, the safety of roof batten to purlin/rafter/truss connections is critical to reduce the level of damage to low rise buildings during extreme wind storms.

Although the localised failures occurring at the roof cladding to batten connection (Figs. 2(a) and 3(a)) were commonly observed in the past storm events [1,2], many detailed research investigations carried out in the past [1–15] have significantly improved the safety of these roof connections. However, this situation has now made the roof batten to purlin/rafter connection the weakest link. The single screw connections (roof cladding to batten) are subjected to a concentric loading whilst the two-screw connections (roof batten to purlin/rafter) are subjected to an eccentric loading. This difference in the loading creates differences in the structural behaviour, failure mode and failure capacities of single and two-screw connections. Therefore, detailed research studies are needed to develop safe design rules for the two-screw connections. Pull-through failures of roof battens have been observed during recent wind storms [16–19]. They have been investigated using both experimental and numerical studies and accurate design equations have been developed [20–25]. Pull-out failures of roof battens occurring between the two bottom flanges and the purlins/rafters (Fig. 3(b)) have also been observed during recent wind storms [16,18]. However, no research studies have been undertaken to investigate these pull-out failures. Hence a series of 60 small scale tests was first conducted to investigate this localised pull-out failure of two-screw connections in this study. In order to increase the batten to purlin/rafter connection capacity, the use of additional screw fasteners (four-screw connections

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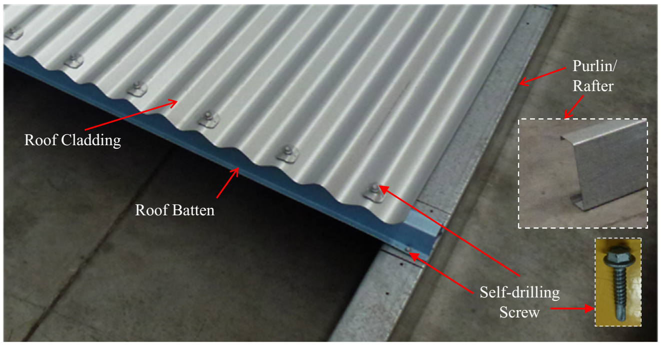

Fig. 1. Typical roofing system.

with two screws on each bottom flange) is commonly recommended. Hence another series of 20 small scale tests was undertaken to investigate the pull-out failure behaviour of four-screw connections.

Mahendran and Tang [11] conducted a series of single screw pull-out tests (592 tests) at QUT using a range of screw fasteners and many thicknesses of roof battens and purlins. They used steel thicknesses of 0.4 to 3.0 mm made of steel grades of G250 to G550 (minimum yield strengths of 250 to 550 MPa) and, Teks (10 g to 14 g) and T17 screw fasteners. Their test results indicated that the design equations presented in the cold-formed steel standards overestimated the pull-out capacities of single screw connections significantly (unsafe predictions). Hence they proposed an empirical design equation for the pull-out capacities of single screw connections. However, since their design equation was not developed in a non-dimensional format and did not include some of the new screw fasteners such as roof zips, cyclonic roof zips and batten zips, a series of single screw pull-out tests (187 tests) was undertaken by Sivapathasundaram and Mahendran [26] at QUT by including a wide range of screw fasteners and many thicknesses of roof battens and purlins. They used steel thicknesses of 0.55 to 1.5 mm made of steel grades of G450 to G550 and, Teks (10 g to 14 g), T17, roof zips, cyclonic roof zips and batten zips screw fasteners. They developed a new pull-out capacity design equation by combing all the available test

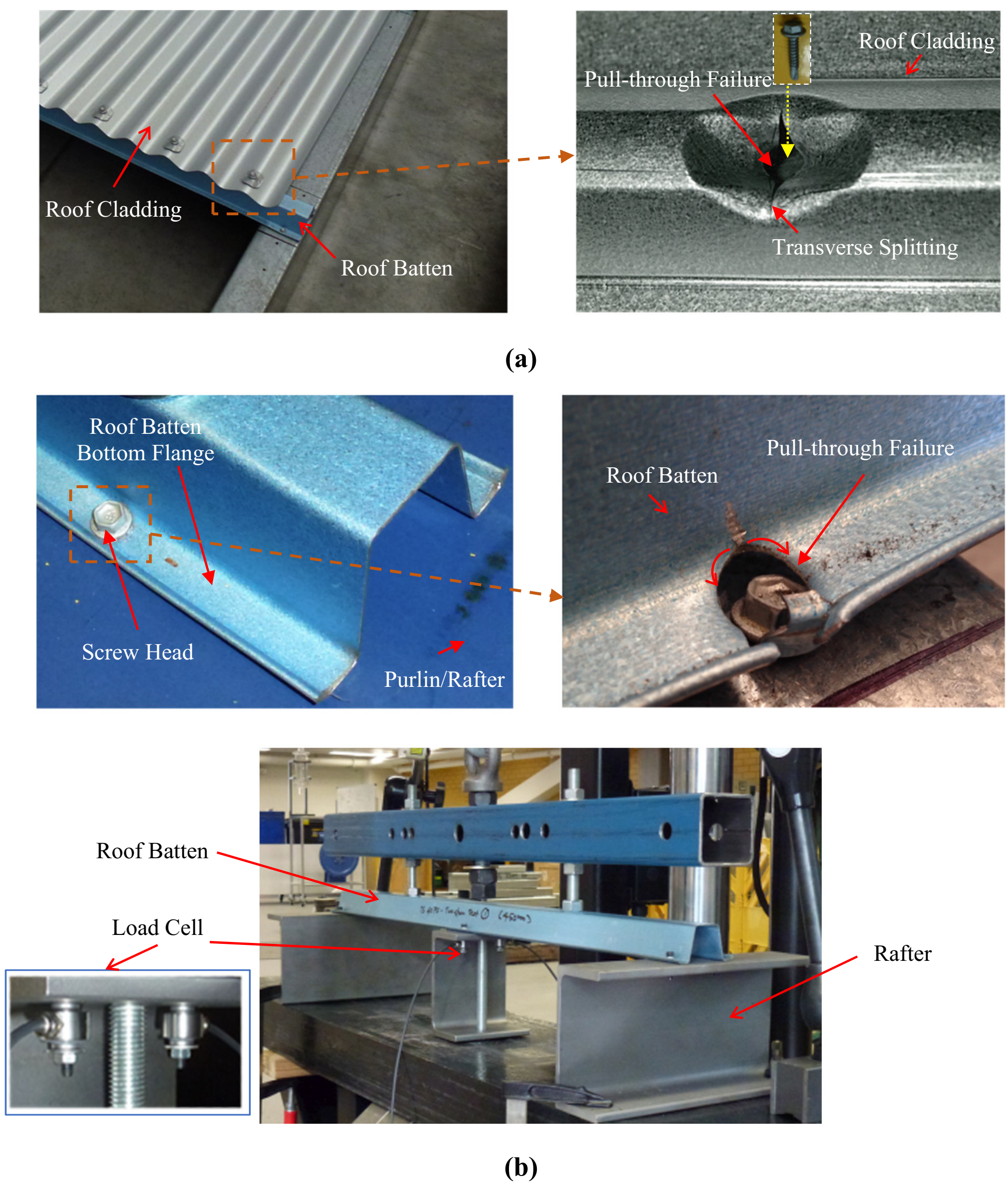

Fig. 2. Pull-through failures of (a) roof cladding to batten connections and (b) roof batten to purlin/rafter connections.