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New pull-out capacity equations for the design of screw fastener connections in steel cladding systems

Mayooran Sivapathasundaram, Mahen Mahendran*

Queensland University of Technology (QUT), Brisbane, Australia

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ABSTRACT

In recent times, the roofing systems made of thin and high strength steel roof sheeting and battens or purlins are predominantly used in the construction of low-rise buildings. However, such thin steel roofing systems continue to fail frequently at their screw fastener connections during high wind events such as storms and cyclones due to inadequate connection capacities. Localised pull-out failures occurring at the thin steel roof sheeting to batten or purlin connections have been the root cause for extensive loss of roofing systems under high wind uplift loads over many years. Such premature connection failures often cause partial or even complete loss of steel roofing systems and, thus allowing rainwater to cause severe damage to building contents. Therefore a detailed experimental study was conducted to investigate the pull-out failures occurring at the steel roof sheeting to batten or purlin connections. One hundred and eighty-seven small scale pull-out tests were conducted for this purpose using a range of screw fastener sizes and many thicknesses of thin steel roof battens and purlins. This paper presents the details of this experimental study and the pull-out capacity data obtained from the tests. It then presents suitable design equations and capacity reduction factors to accurately determine the pull-out capacities of screw fastener connections commonly used in steel roofing systems. In the development of design equations, 592 pull-out capacity data obtained from another experimental study at the Queensland University of Technology were also used. The new design equations can also be used for the screw fastener connections in steel wall cladding systems subject to high wind suction loads.

1. Introduction

In recent times, the roofing systems made of high strength and thin steel roof sheeting and battens or purlins are predominantly used in low-rise building construction due to the many benefits associated with the use of cold-formed steel as a construction material. Roof battens or purlins span over multiple rafters or trusses and, their bottom flanges are fixed to the rafters or trusses by using self-drilling screw fasteners. Thin steel roof sheeting is fixed to the top flanges of roof battens or purlins using closely spaced self-drilling screw fasteners (Fig. 1). The combination of external suction wind pressure and internal positive wind pressure leads to high wind uplift loads on these light gauge steel roofing systems during high wind events such as storms, tornadoes and cyclones. These high wind uplift loads must be transferred safely via roof sheeting to batten or purlin connections first. However, they often cause premature failures of these roof connections, which lead to extensive loss of steel roofing systems. This allows rainwater to enter the building during high wind events and to severely damage its contents.

Two types of localised roof connection failures commonly occur at the roof sheeting to batten or purlin connections, known as pull-through failure and pull-out failure. In the pull-through failure, the screw fasteners connecting the roof sheeting to batten or purlin pull through the thin steel roof sheeting (Fig. 2). The screw fastener head pulls through the roof sheeting by causing a splitting fracture at the screw fastener hole in the roof sheeting (Fig. 2). This connection failure was commonly observed in the past storms and cyclones [1,2]. However, detailed research investigations undertaken in the past [1–12] have developed suitable test and design methods for pull-through failures and enhanced the safety against this failure. The use of suitable cyclone washers has further increased the pull-through capacity of roof sheeting to batten or purlin connections [7,13]. However, this has then lead to the loss of steel roofing systems due to the other localised roof connection failure, the pull-out failure. In the pull-out failure, the screw fasteners connecting the roof sheeting to batten or purlin pull out from the thin steel roof battens or purlins (Fig. 3). Recent wind damage studies [14,15] have highlighted the occurrences of such localised pull-out failures, which caused partial or even complete loss of steel roofing systems.

* Corresponding author.
E-mail address: m.mahendran@qut.edu.au (M. Mahendran).

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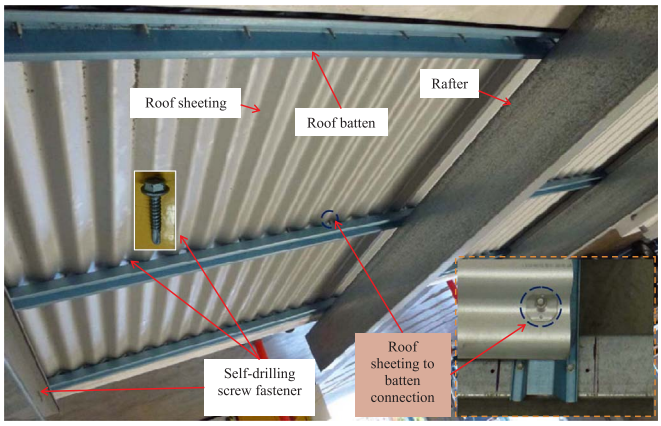

Fig. 1. Typical roof connections.

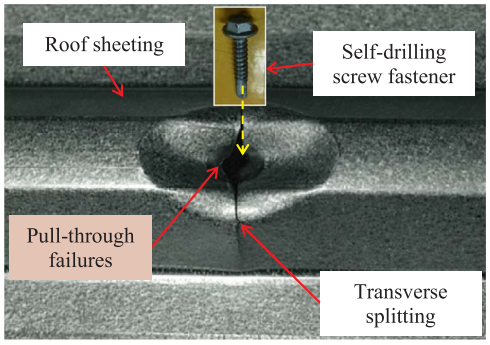

Fig. 2. Roof sheeting pull-through failures.

Mahendran and Tang [16] conducted an extensive experimental study involving 592 pull-out tests at the Queensland University of Technology. However, their study did not include some of the new screw fasteners, which are increasingly used at present, while their proposed design pull-out capacity equation format was considered inadequate for inclusion in steel design standards. Therefore, a detailed experimental study was conducted using a range of screw fastener types and sizes (Table 1) and many thicknesses of steel roof battens and purlins (0.55 and 0.75 mm thick battens, and, 1.0, 1.2 and 1.5 mm thick purlins) made of three high strength steels G450, G500 and G550 (Table 2). One hundred and eighty-seven small scale pull-out tests were undertaken for this purpose. This paper presents the details of this experimental study conducted to investigate the behaviour of roof battens and purlins subjected to pull-out failures. It proposes suitable design equations and capacity reduction factors to accurately determine the pull-out capacities of screw fastener connections in thin steel roof battens and purlins. In the development of design equations, 592 pull-out capacity data obtained from Mahendran and Tang's [16] study were also used.

Table 1
Screw fastener details.

Screw fastener group	Screw fastener type	TPI	p (mm)	d (mm)	d_1 (mm)	DD (mm)
Teks	10g-16	16	1.59	4.73	3.51	3.85
	12g-14	14	1.81	5.39	3.99	4.70
	12g-24	24	1.06	5.42	4.32	5.12
	14g-10	10	2.54	6.38	4.61	5.15
	14g-14	14	1.81	6.18	4.79	4.98
	14g-20	20	1.27	6.17	4.95	5.98
T17	10g-12	12	2.12	4.86	3.25	0.00
	12g-11	11	2.31	5.60	4.07	0.00
	14g-10	10	2.54	6.38	4.61	0.00
Zips	M6-11	11	2.31	6.00	4.20	3.10
	12g-11	11	2.31	5.30	4.18	3.20
	14g-12	12	2.12	6.38	4.58	3.80

Note: TPI – threads per inch, p – pitch, d – thread outer diameter, d_1 – thread inner diameter and DD – thread drill point diameter.

2. Experimental study

Since the pull-out failures are localised to the screw fastener hole region as shown in Fig. 3 and the full scale test methods are time consuming and expensive, small scale test methods were preferred. Although the current test standards [17,18] also suggest small scale test

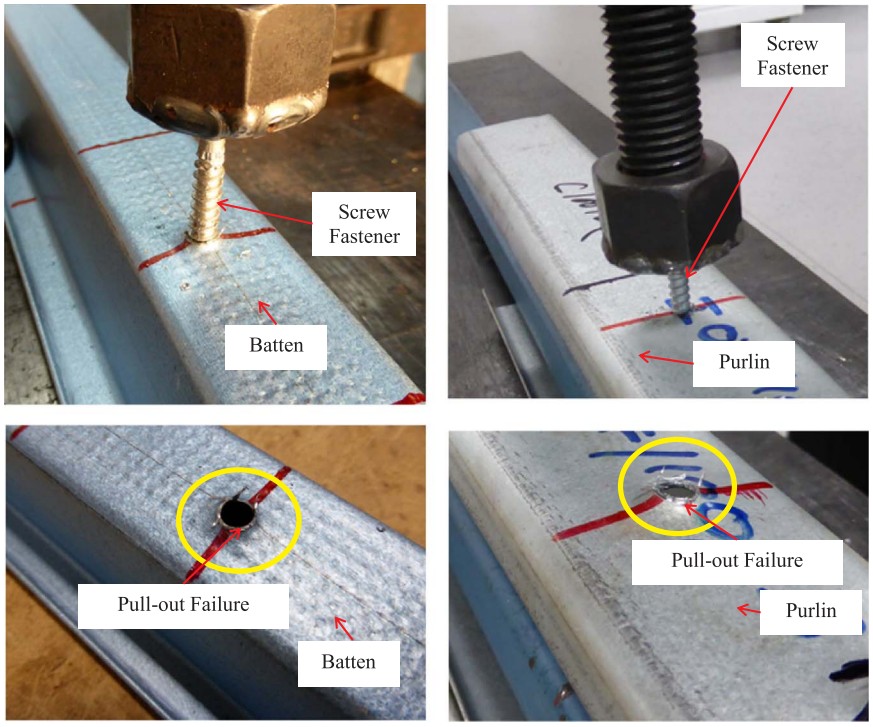

Fig. 3. Roof sheeting to batten or purlin connection pull-out failures.