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Experimental studies of thin-walled steel roof battens subject to pull-through failures

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ABSTRACT

Despite the increasing usage of thin and high strength steel roof battens in the roof structures of low-rise buildings, recent cyclones and storms have shown that they prematurely fail at their screw fastener connections to the rafters or trusses due to the screw heads pulling through the batten bottom flanges. Such pull-through failures can lead to catastrophic failures of the entire roofing systems as observed during recent high wind events. Therefore a detailed experimental study consisting of both small scale and full scale tests was undertaken to investigate the pull-through failures of roof battens under wind uplift loading in relation to many critical parameters such as screw fastener tightening, roof batten geometry, batten thickness, steel grade, screw fastener head size and screw fastener location. Effects of underside surface and edge details of the screw fastener head, and screw fastener types were also considered. This paper presents the details of the tests conducted in this study and the pull-through failure load results obtained from them. Finally it presents the details of suitable design rules and capacity reduction factors developed in this study that can be used to accurately determine the design pull-through capacities of steel roof battens under wind uplift loads.

1. Introduction

In recent times, lightweight building construction using thin-walled and cold-formed steel members has become more popular in many countries. This is due to the increased research efforts on the performance of the entire cold-formed steel building systems [1], isolated members [2,3] and their connections under the required design actions. Lightweight roofing systems made of thin and high strength steel roof sheeting and battens are part of this construction in low-rise buildings. However, the critical load combination of external wind suction and internal wind pressures that occur during high wind events such as cyclones, tornadoes and storms often dislocate these lightweight roofing systems partially or even completely. Past wind damage and research investigations have shown that such severe roof failures have occurred predominantly due to the premature failures of roof connections [4].

There are two types of connections in the roofing systems. The first connection is between the roof sheeting and the top flange of the roof batten section and this is mostly referred to as roof sheeting to batten connection (Figs. 1 and 2(a)). The second connection is between the bottom flange of the roof batten section and the truss or rafter and this is commonly referred to as roof batten to truss or rafter connection (Figs. 1 and 2(c)). In the past, the roof sheeting to batten connection has often failed and lead to severe failures of the roof structures during high wind events. Among the roof sheeting to batten connection failures, the screw fastener head that connects the roof sheeting to the top flange of roof batten pulled through the thin roof sheeting in most cases and this localised failure is commonly referred to as pull-through failure (see Fig. 2(a)). In other cases, the screw fastener pulled out from the roof batten, and this is referred to as pull-out failure (see Fig. 2(b)).

Past research [5–16] has investigated the roof sheeting to batten connection failures in detail and developed suitable design rules to accurately determine the connection capacities. These extensive research efforts have greatly aided to enhance the structural safety and design of the roof sheeting to batten connections. However, severe roof failures have continued to occur, and in fact more severely in recent times as they now fail locally at the next level of screw fastener connections of roof battens to the rafters or trusses. Most of these localised connection failures were observed in the form of pull-through failures occurring at the bottom flanges of roof battens as shown in Fig. 2(d). These connection failures can cause catastrophic failures of the entire roofing systems by dislocating both roof sheeting and battens as observed during recent cyclones and tornadoes [17,18].

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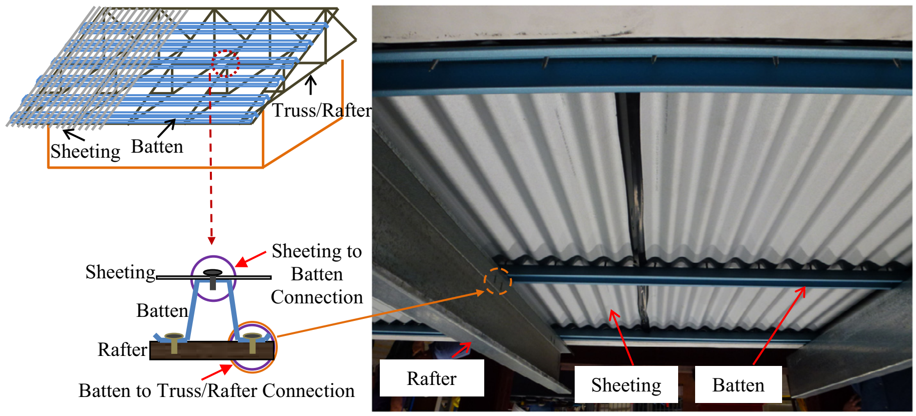

Fig. 1. Typical steel roof structure and its connections.

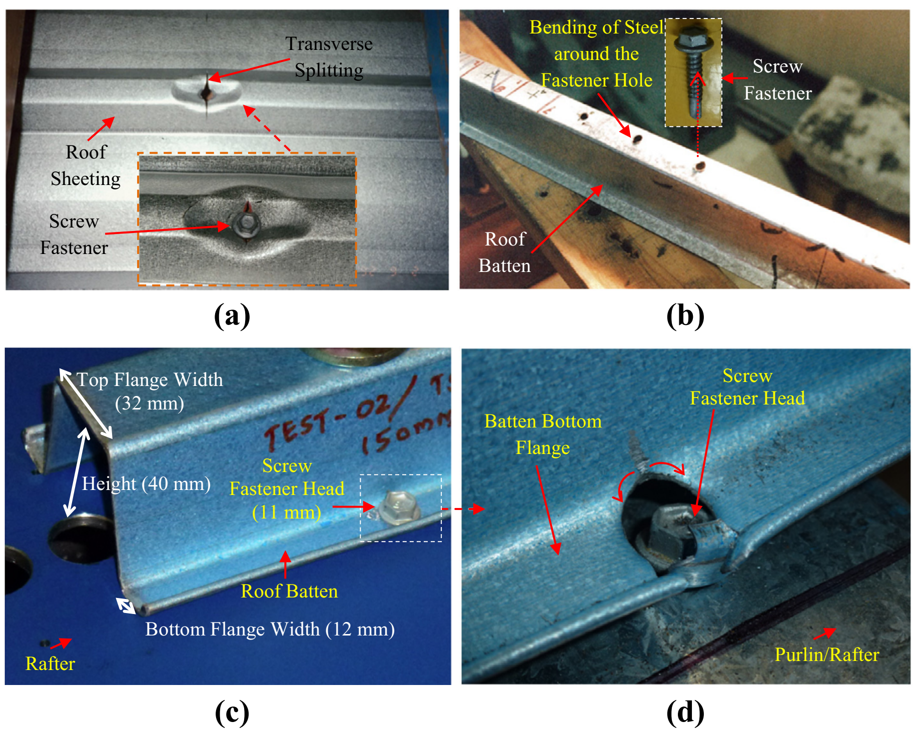

Fig. 2. Roof connection failures: (a) Roof sheeting pull-through failures. (b) Pull-out failures. (c) Roof batten to rafter connection and (d) Roof batten pull-through failures.

Despite the severity of roof batten to rafter/truss connection failures, they have not yet been researched well. In addition, this localised pull-through failure of roof battens associated with a tearing fracture around the screw fastener head (Fig. 2(d)) substantially differs from the previously investigated pull-through failures of roof sheeting to batten connection that are mostly related to transverse splitting of thin steel roof sheeting at the screw fastener hole (see Fig. 2(a)). Since these pull-through failure mechanisms differ significantly, the design rules developed for roof sheeting pull-through failures cannot be used to determine the pull-through capacities of roof battens. Therefore this research has investigated the pull-through failures of thin steel roof battens by undertaking an extensive experimental study under simulated static wind uplift loads. It included investigating the effects of many critical parameters such as screw fastener tightening, roof batten geometry, batten thickness, steel grade, screw fastener head size, screw fastener location, underside surface and edge details of the screw fastener head and screw fastener types. This study has lead to the development of suitable design rules and capacity reduction factors that can be used to determine the design pull-through capacities of roof battens more accurately. This paper presents the details of this experimental study and the results.

2. Experimental study

A typical roof structure has a multi-span roof batten system subjected to a uniformly distributed wind uplift load transferred to its top flange via roof sheeting screw fasteners at 100–200 mm intervals (Fig. 1). The wind uplift loading on the roof batten creates both a tensile force in the screw fasteners that connect the batten bottom flanges to the rafters or trusses and a bending moment in the batten cross section. The pull-through failure of roof battens occurs mainly under these two actions. Therefore a two-span batten system is considered adequate to represent the multi-span batten systems in laboratory testing. Since this research is likely to