Engineering Structures 124 (2016) 64–84

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Development of fragility curves for localised pull-through failures of thin steel roof battens

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ARTICLE INFO

Article history:
Received 30 March 2016
Revised 30 May 2016
Accepted 31 May 2016

Keywords:
Cold-formed steel structures
Light gauge steel roofing systems
Steel roof battens
Wind uplift forces
Pull-through failures
Probabilistic analysis
Monte Carlo simulation
Fragility curves

ABSTRACT

Recent extreme wind events such as tropical cyclones and severe storms have shown that thin steel roof battens fail prematurely at their screw connections to the rafters or trusses. The screw heads connecting the bottom flanges of thin steel roof battens to the rafters or trusses often pull through the roof batten bottom flanges. Since such localised pull-through failures occur in the lower level of roof connections, they often cause the loss of the entire roofing system during extreme wind events. Therefore detailed experimental and numerical studies were conducted at the Queensland University of Technology, and suitable test, design and strengthening methods were developed to accurately design the roof batten to rafter/truss connections and to enhance the roof batten performances under wind uplift loads. However, the levels of possible damages at community level due to the pull-through failures of roof battens are still unknown. Therefore fragility curves were developed in this study to determine the likely level of roof damage during extreme wind events, based on the governing pull-through failures of thin steel roof battens. Detailed probabilistic analyses and Monte Carlo simulations were conducted for this purpose. Fragility curves were also used to evaluate the effects of roof batten span and spacing and, levels of enhancement that could be achieved with the strengthening method proposed for roof battens. This paper presents the details of this study on the development of fragility curves and the results.

1. Introduction

Extreme wind events such as tropical cyclones, tornadoes and thunderstorms often impact the Australian coastal regions significantly. Since the population and residential buildings are highly distributed around the cities located near the coastal regions, the chances of extensive roof damages and associated economic losses due to such extreme wind occurrences are high. In recent times, light gauge steel roofing systems have become more popular in the construction of low-rise buildings with the effective use of thin steel roof sheeting and battens (Fig. 1). However, the high wind uplift loads occurring during extreme wind events often cause catastrophic collapse of roofing systems due to local failures at their screwed connections. In the past, they have failed mostly at the roof sheeting to batten connections (refer Fig. 1). However, extensive research studies were conducted on the localised failures of roof sheeting to batten connections and, suitable design and strengthening methods were developed [1–12]. This situation has now caused the light gauge steel roofing systems to fail at the roof batten to rafter or truss connections (refer Fig. 1).

Localised pull-through failures of thin steel roof battens occurring at the roof batten to rafter or truss connections (Fig. 1) have led to the loss of partial or entire roofing systems (both roof sheeting and battens) during recent extreme wind events [13,14]. The screw heads connecting the thin steel roof battens to the rafters or trusses pull through the bottom flanges of roof battens around the screw head edge (refer Fig. 1). This localised pull-through failure mode indicates that the pull-through failures of roof batten are critical as they occur prematurely prior to the member failures of roof battens. Hence an extensive research study was undertaken to investigate the critical pull-through failures of roof battens using detailed experimental and numerical studies at Queensland University of Technology (QUT), and suitable test and design methods were developed to determine the critical pull-through failure capacities of roof battens [15,16]. A series of two full scale air-box tests and 66 small scale tests (two-span batten tests, cantilever batten tests and short batten tests) was initially conducted using industrial and QUT made roof battens to identify suitable small scale test methods [15]. The main roof batten tests were then conducted in two phases (Phases 1 and 2) using QUT made roof battens and the recommended small scale test methods (Fig. 2). A series of 50 two-span batten tests and 167 short batten tests was conducted in the main roof batten tests and, the effects of screw

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http://dx.doi.org/10.1016/j.engstruct.2016.05.055
0141-0296/

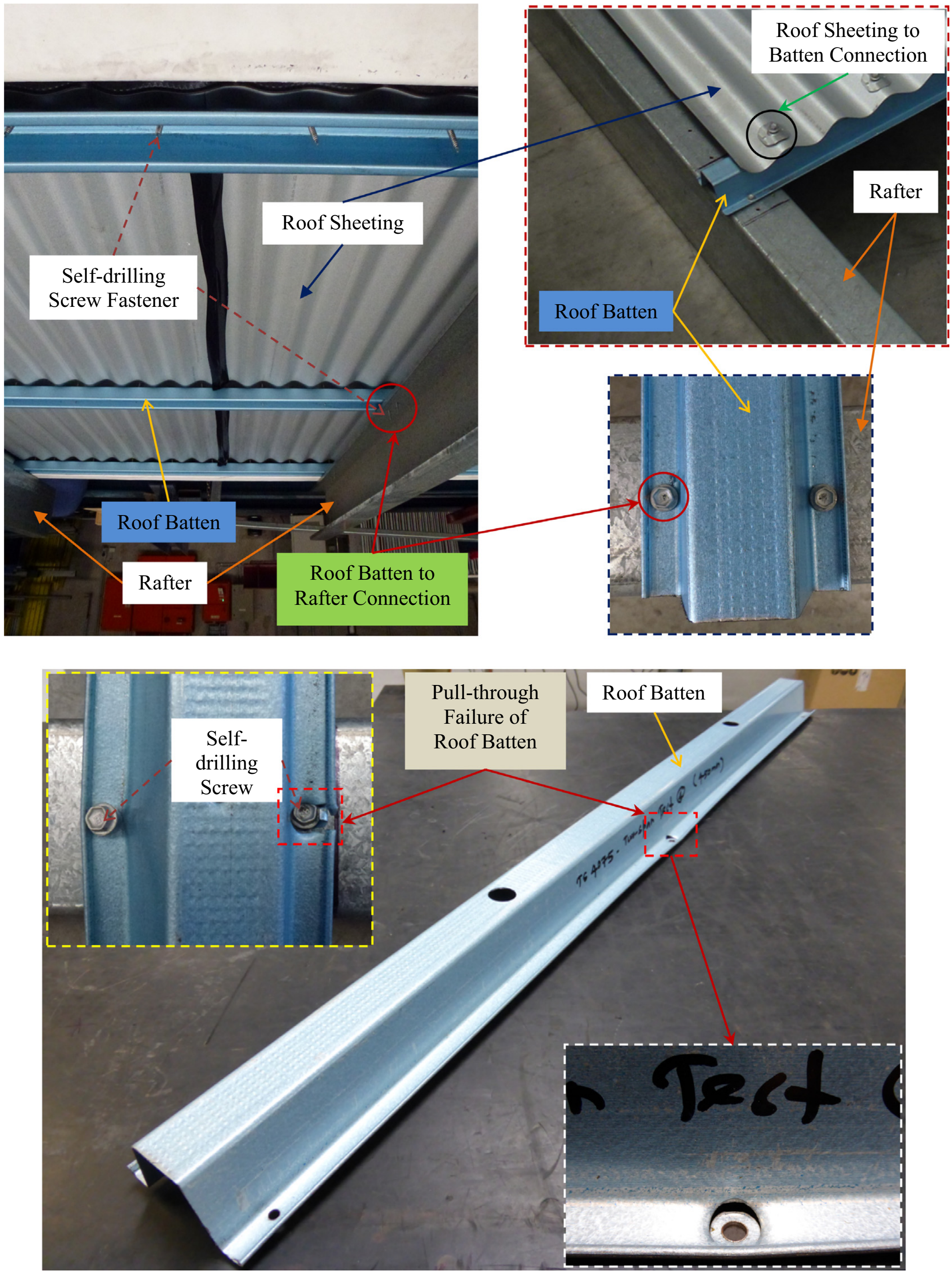

Fig. 1. A typical roof batten to rafter connection and localised pull-through failure of thin steel roof batten.

fastener tightening, batten height, web angle, steel grade, batten thickness, screw head diameter, batten bottom flange width and screw fastener location on the pull-through failure capacity of roof batten were evaluated. Since the pull-through capacity design rules presented in the current design standards significantly overestimate the pull-through failure capacities of roof battens, suitable design rules were first developed based on the test results [16]. In addition, finite element models of two-span and short battens were also developed and validated using the test results. They were then used to conduct parametric studies and, a large roof batten pull-through capacity database was developed by combining both test and numerical results. Based on them, design rules were developed and recommended to accurately determine the pull-through failure capacities of roof battens under wind uplift loads [17]. Further, the strengthening methods recommended and used by the roof batten manufacturers and builders to delay or prevent the roof batten to rafter or truss connection failures were also investigated and, a suitable strengthening method was proposed to enhance the roof batten performance under high wind loads [17].