

Full length article

New test and design methods for steel roof battens subject to fatigue pull-through failures



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ABSTRACT

Thin steel roof claddings and battens are widely used in low rise buildings all around the world. However, they are vulnerable to premature connection failures when subjected to severe wind uplift actions such as those induced by cyclones and storms. Current design methods exclusively depend on full scale prototype roof tests. This paper proposes an alternative design method using a simple equation for thin-walled steel roof battens subjected to fatigue pull-through failures, developed through a series of small scale cyclic wind load tests of roof battens. Since an acceptable small scale connection test method is not available for fatigue pull-through failures of roof battens, various types of small scale connection tests were initially examined to propose the most suitable test method. For this purpose, a series of constant amplitude cyclic tests was conducted using three different small scale test methods (short, cantilever and two-span battens), for a commonly used steel roof batten. Test results showed that the present state of knowledge based on static pull-through studies could lead to the use of a wrong test method in fatigue pull-through studies. This paper has used the cyclic test results from the selected small scale test method to propose a fatigue pull-through design equation. The use of the proposed design equation will lead to conservative outcomes for roof battens and will enable safe roof batten design without the need for full scale cyclic tests of prototype roof assemblies.

1. Introduction

Low-pitched roofs made of light gauge steel roof claddings and battens are vulnerable to premature pull-through failures during severe wind events such as cyclones and storms. Fig. 1 shows the two critical connections in a steel roof that are susceptible to pull-through failures. The first is the cladding to batten connection which connects the roof cladding to batten and the second is the batten to rafter/truss connection which connects the roof batten to rafter/truss in a building. The wind uplift load on the roof cladding is first transferred to battens via cladding to batten connections and then to rafter/truss via batten to rafter connections. As the cladding and battens are made of thin, high strength steel with low ductility, their connections are likely to fail under cyclic wind uplift loading due to pull-through failures. Post-cyclone investigations and past research studies have revealed that low cycle fatigue cracking around the screw fastener holes is the reason for the pull-through failures [1,2], and the possibility of such fatigue pull-through failures is high in a low-pitch low-rise building roof near the eaves and ridges where the suction wind pressure is extremely high [3].

In the past, fatigue pull-through failures were limited to cladding to batten connections as shown in Fig. 2(a). It occurs when the cyclic wind

uplift loading creates radial fatigue cracks in the roof cladding around the fastener holes, allowing the screw fastener to pull through the roof cladding. Many research studies [4–6] have investigated the fatigue pull-through failures of cladding to batten connections and improved the roof design to overcome the fatigue pull-through failure. Due to such improvements, fatigue pull-through failures have now moved to the next weakest connection, i.e. batten to rafter/truss connection [7]. A wind tunnel study conducted by Ginger [8] also confirmed that not only the cladding to batten connections, but also the batten to rafter/truss connections experience the same kind of cyclic wind uplift loading and thereby prone to fatigue pull-through failures. Therefore, this paper focuses on the premature fatigue pull-through failures in the vicinity of batten to rafter/truss connections.

The fatigue pull-through failures in the batten to rafter connections occur when the cyclic wind uplift loading generates fatigue cracks around the batten to rafter screw heads and lets the screw fasteners to pull through both bottom flanges of the roof batten as shown in Fig. 2(b). Although the batten pull-through failure is similar to the cladding pull-through failure, the failure mode is different since the cladding pull-through failure is typically due to severe cracking of cladding originating from the screw hole whereas the batten pull-

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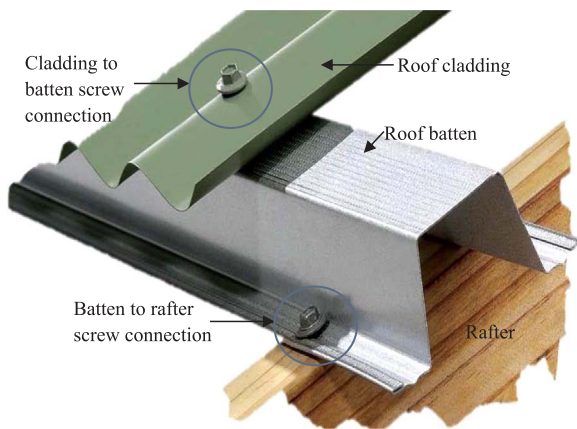


Fig. 1. Typical roof connections.

through failure is due to tearing around the screw head [9]. Due to this difference, the design and test methods/guidelines developed for the cladding to batten connection pull-through failure cannot be used for batten to rafter connection pull-through failures [10]. Considering this, Sivapathasundaram and Mahendran [10,11] developed new design equations to determine the static pull-through capacities of cold-formed steel roof battens. However, they did not consider the effects of cyclic wind loading and the resulting fatigue pull-through failures. Currently available design capacity tables provided by the roof batten manufacturers also do not specify the static and fatigue pull-through failure capacities.

Due to the unavailability of fatigue pull-through capacity design equations for roof battens, the current design method depends entirely on large scale prototype roof testing based on a Low-High-Low (LHL) cyclic loading sequence recommended by the National Construction

Code of Australia (NCC) [12]. Prototype roof panels must be tested to a design cyclone which is simulated by the multi-level fatigue loading sequence such as the LHL loading sequence as suggested by Mahendran [13]. The roof assemblies must be tested by including roof cladding, its immediate supporting members such as roof batten and rafter and their connections. Besides, the test should be repeated multiple times, considering the variability of structural components. Therefore, it is desirable to eliminate this complex, expensive and time consuming LHL prototype testing by developing a simple fatigue design equation and/or a small scale isolated connection test method. However, a standard test method or set-up is not available to conduct such small scale isolated connection tests that are suitable for assessing the fatigue pull-through capacities of steel roof battens. The test method proposed by Sivapathasundaram and Mahendran [9] to conduct the static pull-through failure studies may not be suitable for fatigue pull-through failure studies as the failure modes and the wind actions that cause the failures are different.

Therefore, as the first step of developing a suitable design equation for the fatigue pull-through failure of roof battens, this study initially focused on determining a suitable small scale test method that simulates the fatigue pull-through failures of batten to rafter connections by considering all the influential factors. For this purpose, 0.75 mm thick G550 steel (minimum tensile strength of 550 MPa) industrial roof battens (G550-0.75 batten) were used (Fig. 3). The study then focused on developing a simple design equation to determine the fatigue life of the G550-0.75 battens by means of a cyclic test series conducted using the selected small scale test method. In the past, a fatigue life approach based only on the applied cyclic load magnitude was used for this purpose. Beck and Stevens [14] was the first who used such an approach to investigate the fatigue behaviour of steel roof cladding. They used a series of constant amplitude cyclic loading tests and produced a cyclic load amplitude versus fatigue life (number of cycles to failure) curve, which is commonly known as the S-N curve to predict the fatigue

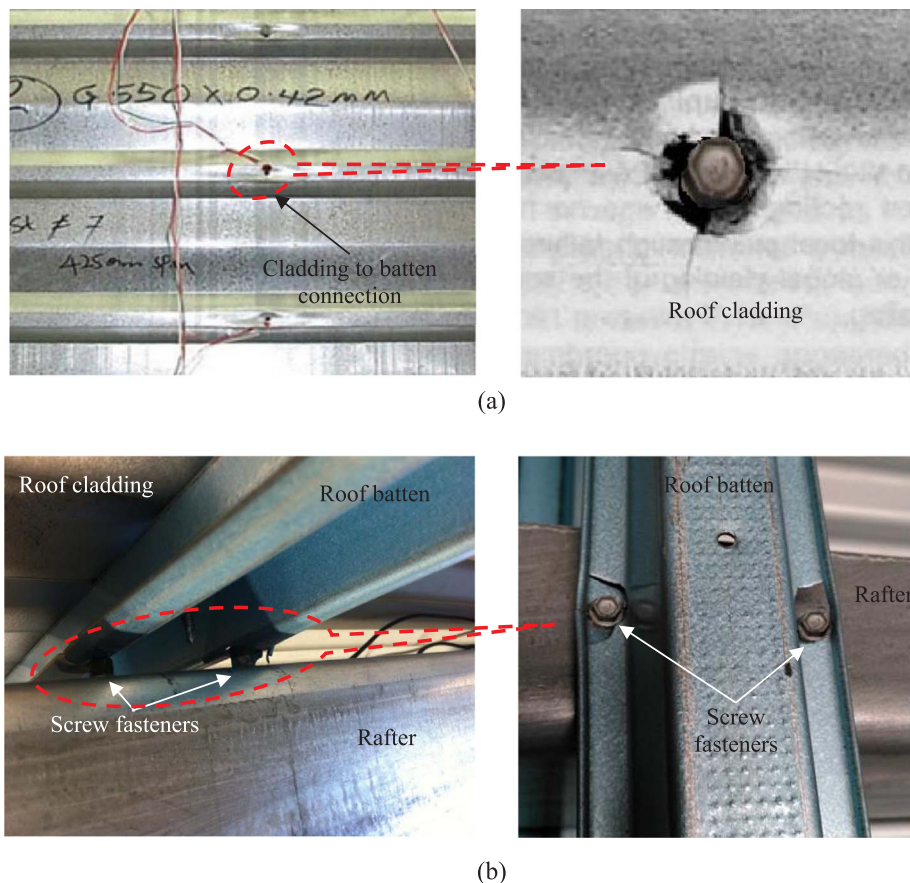


Fig. 2. Pull-through failures: (a) Cladding to batten connection [15]; (b) Batten to rafter connection.

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