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Performance of toe-nail connections under realistic wind loading

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ABSTRACT

Using recently developed pressure loading actuators (PLA), ramp and realistic fluctuating wind loads are applied to toe-nail connections which are typically used in wood-frame residential construction. The failure capacity from the ramp and fluctuating wind load tests are found to be similar, and are comparable to capacities reported in the literature. However, under realistic wind loading, the toe-nail connections are found to fail in increments with the majority of the damage to the connection occurring intermittently at the peak pressures so that it takes many peaks for a connection to fail. In addition, the effects of construction defects, in this case missing nails, were also examined in order to determine the reduction in capacity. Considering the wind loads on a typical house, estimates for failure wind speeds were obtained, assuming a factor of safety, and compared to ASCE 7-05 wind regions.

1. Introduction

Roof failures are commonly observed in extreme wind events, including roof-to-wall connections (RTWC) and sheathing in residential wood-frame housing. In addition to life safety issues, failure of a roof or its components can cause significant water ingress, with subsequent damage to the building contents, substantially increasing the insured losses [1]. Furthermore, with all or part of the roof missing, the walls are more susceptible to collapse which can become a significant life safety issue. Toe-nails are the most common type of RTWC in North America. While it is now common to use hurricane straps in hurricane prone regions such as Florida and the Gulf Coast of North America, in new construction, there are still a large number of existing structures with toe-nail connections as the primary hold down for the roof structure. Moreover, in non-hurricane regions toe-nails are still used in new construction as the primary roof-to-wall connection. These regions are susceptible to extreme wind events, such as tornadoes and downbursts, which are capable of causing complete roof failures, a recent example of which is discussed in [2].

The capacity of toe-nail connections to uplift loads has been the subject of several studies, including those by [3–6]. These tests applied load at a constant displacement rate (typically 2.54–6.35 mm/min) and measured the force required to keep the connection moving at the set rate. These tests are nominally static and quite different from the highly fluctuating loads generated by real winds. Experiments conducted by [6] on in situ connections did apply a form of cyclical loading, although a maximum of only three loading cycles were used. The cycles were applied at a low displacement rate of 2.54 mm/min and the end of a cycle was based on a displacement threshold. The loading from these tests was also significantly different from that induced by real wind loads where there are a large number of cycles and the loads can double or increase more than that in less than a second and decrease just as quickly. The mean maximum withdrawal capacity from these studies is in the range from 1130 N to 2840 N, depending on the type, number of nails, age of the connection, type of wood, and the wood moisture content. To date there has been no study to document the effects, if any, that cyclical or realistic wind loads have on the withdrawal performance of toe-nailed RTWC. Hysteretic behavior and reduction of the failure capacity when subjected to cyclical shear loads, have been tested and implemented in finite element models of entire structures, e.g., [7], primarily for studies involving earthquake loading. The current study examines the withdrawal behavior of toe-nail connections under realistic wind uplift loads and compares the response to that found from static testing.

2. Experimental setup

Toe-nailed RTWC are tested using a load control approach with the test rig shown in Fig. 1. The loads are applied to the specimen by controlling the pressure inside of the blue airbag, which is then mechanically attached to the toe-nail specimen, as shown in inset A of Fig. 1. The toe-nail connections consist of two 0.61 m long 2×4 segments, representing a typical portion of a top-plate for wood-framed stud walls, mounted at either end to load cells to measure

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