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Influence of number of finger joints per stud on mechanical performance of wood shearwalls

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HIGHLIGHTS

- The number of finger joints (up to 5–6) in a lumber stud did not affect the mechanical performance of a wood shearwall.
- There was no significant difference in peak racking load between shearwalls fabricated with finger-joined and unjoined studs.
- The failure mode of a shearwall was a combined sheathing nail withdrawal and sheathing nail head pull through.
- Finger-joined studs could be deemed to be equivalent to unjoined studs.

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ABSTRACT

Finger-joined lumber studs are considered equivalent to, and can be used interchangeably with, unjoined lumber of the same grade in residential construction in Canada. However, there have been concerns expressed by engineers and users that there is no data available on the mechanical performance of shearwalls built with finger-joined studs to support this equivalency. This study was intended to address this information gap. Two groups of finger-joined studs were fabricated using 'No. 2 or better' grade spruce-pine-fir (SPF) lumber and a heat resistant polyvinyl acetate (PVA) adhesive. One group had 2–3 joints per stud, while the second group had 5–6 joints per stud. A control group of unjoined 'No. 2 or better' grade SPF lumber was sampled as a reference for comparison between groups. The stud dimensions were 38 mm × 89 mm × 2.44 m. Sheathing used was oriented strand board (OSB) panels with dimensions of 1.22 m × 2.44 m × 12.5 mm. The stud frame was fastened using 12d common wire nails and the sheathing was fastened to the stud frame using 8d common wire nails. A total of 12 shearwall test specimens of dimensions 2.44 m × 2.44 m were fabricated and tested. Test results showed that there was no statistically significant difference in the mechanical performance in terms of peak racking load and stiffness between shearwalls containing finger-joined studs (up to 5–6 joints) and shearwalls containing unjointed studs. The failure mode for each test wall was a combined sheathing nail withdrawal and sheathing nail head pull through. This study provides confirmation that finger-joined studs made using the PVA adhesive in this study could be deemed to be equivalent to unjoined studs in fabrication of shearwalls.

1. Introduction

In Canadian residential construction, finger-joined studs are considered equivalent to unjoined studs and are therefore used interchangeably by builders. The National Building Code of Canada indicates that finger-joined studs manufactured according to NLGA SPS 3 "Special products standard for finger-joined 'vertical stud use only' lumber" [1] are considered equivalent to, and can be used interchangeably with, unjoined lumber of the same grade [2]. Although there are quality control requirements in SPS 3 to ensure that finger-joined studs possess the target mechanical properties and durability, concerns have been expressed by builders that data on mechanical response of shearwalls built with finger-joined studs is not available to support this equivalency. For example, does the number of finger joints in a stud affect the behaviour of a shearwall? The previous study by the authors showed that the ultimate tensile strength of finger-joined lumber decreased to some degree with increasing the number of finger joints per piece of lumber. Therefore, it is particularly critical for the end finger-joined stud in a wall under racking load because it is subjected to a high tensile force when a hold-down connector is present. This study was intended to address this information gap.

There are very limited publications on the racking performance of wood shearwalls consisting of finger-joined studs. Faherty [4] is

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likely the first person who performed a preliminary study on this topic. A total of six walls were tested, three with sawn lumber studs and three with finger-joined studs. Both groups consisted of 2-by-4 Douglas fir (*Pseudotsuga menziesii*) sawn lumber studs, 'No. 2 and Better' grade. The finger-joined studs were assembled with a finger joint profile length of 16 mm. Exposure 1 exterior glue with skid resistant surface was used. The wall dimensions were 2.44 m by 2.44 m with stud spacing of 406 mm on centre. The sheathing used was 1.22 m by 2.44 m oriented strand board (OSB) panels. The nailing spacing was 152 mm along the panel edges and 305 mm at the intermediate studs. A 3 mm gap was maintained between the vertical 2.44 m edges of the OSB panels as per the manufacturer's recommendation. Nails used were 8d duplex common wire. Following ASTM E564-74 [3], Faherty [4] tested two sets of three walls, and measured load, horizontal deformation and diagonal deformation, and found that (1) there was no significant difference in racking performance (in terms of strength and stiffness) between shearwalls using sawn lumber studs and finger-joined studs; (2) there was no observed failure of any stud in either sawn lumber studs or finger-joined studs; and (3) the major failure observed was nail bending and pull through of nail head at the panel corners. However, Faherty did not specify how many joints existed in a single stud.

More recently, Popovski and Ni [5] made their effort to demonstrate that shearwalls made using finger-joined studs produced according to NLGA SPS 3 [1] behaved similar to those made using solid sawn studs of the same grade and species. The wall dimensions were 3.66 m by 4.88 m with a stud spacing of 406 mm. The nail spacing was 152 mm around panel edges and 305 mm on intermediate studs. Common nails, 76 mm long, with a diameter of 3 mm were used for fastening the framing. The 2-by-4 vertical studs were either SPS 3 finger-joined SPF stud grade lumber with 16 mm long fingers, or SPF No. 2 or better solid sawn lumber. Finger-joined studs had an average characteristic number of finger-joints (CNF) of five. Shearwalls were sheathed on one side only using either 13 mm or 9.5 mm thick softwood plywood panels rated for exterior applications. Simpson Strong Tie HD2A hold-downs were used on both ends of a wall. Four types of sheathing configuration were used in the test program. A total of eight walls were tested: one wall was subjected to monotonic lateral loading at a rate of 15 mm/min and the other seven walls were tested following the ISO 16670 cyclic loading protocol specified in ASTM Standard E2126-07 [6]. Popovski and Ni [5] observed that: (1) SPS 3 finger-joined studs could be used as an alternative to solid sawn studs of the same grade in unblocked walls; (2) no tension failures in the studs near the hold-downs were observed in any of the shearwall tests; (3) some stud failures such as splitting were observed in some walls tested at high inter-storey drift levels. However, such failures were mostly related to localized failure of wood rather than the strength of finger joints themselves; and (4) no adhesive failure or multiple finger joint failures were observed. The failure mode of the wall subjected to monotonic loading was influenced by numerous stud-to-sheathing connection failures, such as sheathing tear-out, nail withdrawal and several nail head pull-through failures. Although Popovski and Ni [5] tested the severe scenario of finger-joined studs (CNF = 5), they did not examine the effect of CNF on the performance of walls made of finger-joined studs. Additionally, only one shearwall was tested for each testing condition.

This study was aimed at providing the firsthand information on the mechanical performance of a shearwall made of finger-joined studs. To achieve this goal, the following two issues were addressed: (1) a comparison of the load-deformation behaviour of shearwalls built with unjoined studs with that of shearwalls built of finger-joined studs; and (2) an evaluation of the potential influence of the number of finger joints on load-deformation response of shearwalls built with finger-joined studs.

2. Materials and methods

2.1. Material sampling

The studs used to construct the shearwalls were sampled at the Abitibi-LP plant at St. Prime, Quebec, Canada. This plant produces finger-joined studs conforming to the requirements of SPS 3 [1]. The finger joints were bonded using a polyvinyl acetate (PVA) adhesive that meets the heat resistance adhesive (HRA) requirements of SPS 3. All studs sampled were 'No. 2 or better' grade SPF lumber. The dimensions of the studs were 38 mm × 89 mm × 2.44 m. Three groups of test specimens were sampled, as listed in Table 1. It is noted that only half of lumber in Group B was used in this study and the other half for another purpose of research.

Following sampling, the studs were shipped to the Wood Science and Technology Centre, the Univeristy of New Brunswick in Fredericton, New Brunswick, Canada. The lumber was conditioned at 20 ± 2 °C and 65 ± 2% relative humidity for three weeks to equalize the moisture content to a target value of 12%. 24 sheets of 1.22 m × 2.44 m × 12.5 mm OSB sheathing conforming to CSA standard O325 [7] were purchased at a local building supplies store for the shearwall sheathing.

2.2. Determination of modulus of elasticity of lumber

The apparent modulus of elasticity (MOE) of each lumber piece was measured using the bending flat-wise centre point loading technique outlined in ASTM D4761-11 [8]. A known concentrated load was applied using free weights at the mid-span of a test lumber specimen. The deflection was measured under the load at the bottom face of the lumber specimen using a linear variable differential transformer (LVDT). The span-to-depth ratio deviated from that specified in the standard because the stud length was 2.44 m. Therefore, the maximum possible span-to-depth ratio was 56:1, which was less than that specified in the standard. The test span used was 2.13 m. The ends were supported using a roller at one end and a pivot at the other end. The MOE was therefore calculated.

The purpose of performing the flat-wise MOE tests was to sort and group the studs based on MOE values so that the extreme values were removed and the average MOE and standard deviation of the studs for each shearwall were approximately equal. Sorting the studs into groups with similar MOE values minimized the effect of stud quality on shearwall performance.

2.3. Construction of test walls

Each test wall was constructed according to the details shown in Fig. 6 of ASTM E72-10 [9]. This standard is the most commonly used test method for determining wood-frame building systems such as walls and floors in North America. The shearwall test specimens were 2.44 m × 2.44 m. Corner posts were nailed together with three spacers per post. The spacers were made from plywood and were 89 mm × 305 mm × 19 mm. A single sole plate and a double top plate were fastened to the studs using 12d common nails. Top and bottom plates were the same type of lumber used in the vertical studs for each wall. Stud spacing was 406 mm and the sheathing was 1.22 m × 2.44 m × 12.5 mm OSB panels. Two sheets of OSB oriented vertically were fastened to one side of the stud frame. OSB was oriented vertically since the majority of the previous tests were performed with vertical sheathing. Also, vertical sheathing is common practice in construction. A 3 mm gap was maintained between the two adjacent sheets of OSB as per manufacturer's installation instructions. OSB panel sheathing was fastened to the stud wall in accordance with the National Building Code of Canada [2] which specifies 51 mm nails at 150 mm spacing at panel edges and 300 mm at intermediate supports. 12d common wire nails were used to fasten the stud frame and 8d common wire nails were used to attach the sheathing to the stud frame. Care was taken not to penetrate the heads of the 8d common wire nails through the surface layer of the sheathing. Fig. 1 is an illustration showing how the test wall frame was constructed and the location and direction of the applied lateral load. The symbols (d_V, d_D, d_S and d_R) indicate the placement of the deflection gauges, which is described in the following section. Three wall specimens of each construction group were fabricated according to the ASTM E72-10 [9], producing a total of nine walls in this study.

Table 1
Sample size for test groups.

Test group	Type of stud	Number of lumber pieces	Number of walls tested
A	Finger-joined 2 × 4 studs with 2–3 joints per stud (typical situation)	56	3
B	Finger-joined 2 × 4 studs with 5–6 joints per stud (severe scenario)	126	3
C	Unjoined 2 × 4 studs (control)	50	3