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Structural capacity of timber I-joist with flange notch: Experimental evaluation

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HIGHLIGHTS

- Notch location and size considerably affect the load carrying capacity of I-joist.
- Load capacity of notched I-joist reduces up to 80% compared to control I-joists.
- Stiffness of notched I-joists is reduced up to 46% compared to control I-joists.
- Crack initiates at the inner bottom corner of the notch of the I-joist.
- Crack propagates towards the bottom flange with an angle ranging from 63° to 77°.

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ABSTRACT

Timber I-joist is a common building construction element in North America and Europe due to its availability and easiness of passing the service conduits and ducts through openings in the Oriented Strand Board (OSB) web of I-joists. However, in order to provide passageway for service conduits and ducts, cuts and notches in the flange of I-joist are frequently made during construction without considering the structural integrity of the system. Flange stiffness is very critical as it provides the flexural strength to the I-joist, hence it is prohibited to cut or notch the I-joist flanges. This study examined ten series of timber I-joists with single flange notch at different locations in two span lengths (12 and 20 ft) and compared with the uncut I-joists to understand the reduction in load capacity, stiffness and failure mechanism of the tested I-joists. A total of 100 I-joist specimens, which included uncut and flange notched I-joists, were tested in this experimental study. It was observed that with the increase in distance of the notch from the support, the load carrying capacity of notched I-joists can even decrease up to 80% in comparison with the uncut I-joists. Moreover, the effects of notch location and notch size were also investigated, and it was found that these notches significantly affect the load carrying capacity of an I-joist.

1. Introduction

Composite timber I-joists are widely used as floor and roof joists in the construction of commercial and residential buildings in Europe and North America. Commonly, these I-joists are made with timber or laminated veneer lumber (LVL) as flange material in combination with Oriented Strand Board (OSB) or Plywood as web materials. These engineered timber I-joists are less expensive, lighter in weight, stronger, and more efficient compared to the solid sawn lumber beams.

According to the manufacturer design guidelines [1,2], the use of flange cut on OSB webbed I-joists are strictly prohibited to use during construction. Cuts and notches in the flange of I-joist are commonly made during construction to facilitate the electro-mechanical systems of the buildings. Some photographs of flange notches in a construction site are shown in Fig. 1. The effect of flange notches on the strength properties (e.g., load carrying capacity, flexural strength, and shear strength) of timber I-joists is not fully understood and current design specifications (CSA-O86) for building construction do not provide any design guideline for I-joists with flange cut and notches [3]. Very few research studies on OSB webbed timber I-joists with flange cut and notch have been conducted [4].

The primary objective of this research paper is to compare the load capacity and stiffness of single flange cut I-joists with those of an uncut I-joist (control specimen). In the current research study, an experimental work was carried out on OSB webbed timber I-joists with flange notches or cuts at different locations along the length as well as two different sizes of flange cuts. A total of 80

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I-joist specimens with flange notched and 20 uncut (control) I-joists were tested in this experimental study to investigate the strength reduction and failure pattern of I-joists with flange notches.

2. Motivation

Very often builders cut the flange of I-joists during the construction phase of a project to accommodate the service conduits and ducts without considering the structural integrity. Eventually, these flange notched I-joists need to be replaced or retrofitted to meet the design requirements, which may affect the project cost, time schedule and safety of the project. Flange notches of I-joists may affect the performance in terms of deflections, load carrying capacity and vibration of the structure. The primary impact of flange notches on I-joists is on the flexural strength as well as the shear strength. The Wood I-joist Manufacturer Association (WIJMA) has a published reference to determine the shear strength of I-joist with web holes, which is well accepted by building code evaluation services as the procedure to evaluate the strength of I-joist with web holes [2]. However, there is no guideline for evaluating the strength of timber I-joists with flange notches.

3. Literature review

Until today no research work has been carried out to determine the load capacity and stiffness of I-joists with flange notches or cuts at the top flange subjected to flexural compression force. Although, Hindman and Loferski [4] did carry out a pertinent study to investigate the improved load capacity and stiffness of flange cut I-joists retrofitted with cold formed steel reinforcers in relation to uncut control I-joists, they did not perform any test to determine the capacity and stiffness of un-retrofitted flange cut I-joists. Their study shows that the strength and stiffness of reinforced/repaired flange cut I-joists are lower than those of the uncut or control I-joists by 40% and 33%, respectively. Before studying the retrofitting technique it is important to understand the behavior of flange notched I-joists.

Most of the previous research studies were carried out on the timber I-joists with web holes rather than with flange notch or cut. An experimental study and finite element modeling was conducted by Zhu et al. [5], Guan and Zhu [6] and Zhu et al. [7] and they found that stress concentrations occur around the web opening. They also observed that fractures were formed in tension zones around the opening of the OSB web and the cracks developed towards the beam flanges in a direction roughly at 45° to the beam axis. Later, Zhu et al. [8] conducted both experimental investigation and finite element analysis to investigate the buckling behavior of OSB webbed I-joists and found that good correlations exist between analytical and experimental results.

Pirzada et al. [9] predicted the strength of timber I-joists with web holes by applying fracture mechanics based on the Finite Area Method (FAM). Afzal et al. also conducted an experimental study to evaluate the I-joist strength with web holes [10]. Morrissey et al. [11] conducted an experimental and analytical investigation with excess web openings. Finite-element analyses of all test configurations were conducted to understand the effects of web openings (circular and square) on the stiffness, stress distributions around openings, and ultimate failure mechanisms. They observed that square web openings are more critical than the circular web openings for load carrying capacity due to the occurrence of stress concentration at the corner of the square opening. The load carrying capacity of I-joists with circular web openings was 45% lower than that of the control I-joists, whereas for I-joists with square openings, it was 53% lower than that of the control I-joists.

Fig. 1. Flange notch at construction site.

4. Testing of timber I-joists with a single flange cut

Two different span lengths of I-joists were tested: 12 and 20 ft. These joists were produced by an I-joist manufacturer (AcuTruss Industries Limited) in Kelowna, Canada. The I-joists were produced with a 9.5 mm thick OSB web and 38 mm by 63 mm lumber flanges as shown in Fig. 2. Test set-up and specimen dimensions were selected by strictly following the provisions of ASTM-D5055 [12] and WIJMA guideline [2]. According to the manufacturer (NASCOR) Specifier Guideline [13], the maximum allowable span (simple) is 20 ft for the I-joists with the selected cross sectional geometry. The test setup and loading diagram are shown in Fig. 3. To prevent lateral buckling of tested I-joists a sufficient number of lateral supports were provided during testing as shown in Fig. 3(b). A total of 5 series of I-joists for each span length, i.e., a total of 100 specimens were tested with and without flange notches (2 notch sizes at 3 different locations).

Table 1 shows the different configurations of flange cut I-joists tested including the distance of the cut from the support of the beam (L_e), span length (L), dimensions of the flange cut ($b \times d$), and number of samples. The locations of the flange notch were selected as per the most common scenarios experienced by the I-joist installation and manufacturing industry. I-joist manufacturing industry usually faces the notch related problems within 600 mm (2 ft) from the end support due to the presence of floor drains of sewer and sanitary pipes and conduits. Here, the specimens are designated as 12-A-01, 20-M-10, etc. The first two digits of the specimen name denote the span length (in ft). The letters of the specimen name denote the series number (A, F–I, K–N). The last two digits (–) denote the specimen number (01–10). Load–deflection response was measured continuously during the entire test. The deflection was measured in two different methods; an

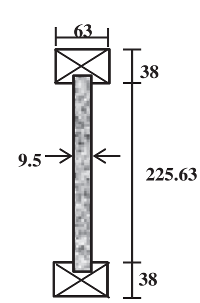

Fig. 2. Cross section of tested I-joists (dimensions are in mm).