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Structural evaluation of castellated timber *I*-joists

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ABSTRACT

A novel timber *I*-joist with a castellated web is presented. While castellated webs are common in steel joists, this concept is new to timber joists. The openings provided by the castellation process provide for the easy passage of services during construction or subsequent remodelling of a building. The manufacturing process is described together with details of tests on twelve 241 mm and eleven 305 mm deep joists. The load–deflection response, failure loads and modes of failure are given. The mean failure moment and shear force for the 241 mm deep joists were found to be 8.2 kN m and 6.0 kN, respectively. The corresponding values for the 305 mm deep joists were 12.5 kN m and 6.9 kN. The predominant failure modes were tension failure in the web at the corner of the openings and shear failure in the web at mid-depth between the openings. The effect of the web openings on the joist stiffness is not significant but the shear capacity is reduced. The reduction in shear capacity compares favourably with the shear capacity of commercial joists of equivalent sizes with circular or rectangular openings.

1. Introduction

Timber *I*-joists are now widely used as primary structural elements in floor and roof applications in residential construction [1,2]. They have a number of advantages over solid lumber joists: by concentrating most of the material away from the neutral axis, the flexural stiffness and load carrying capacity are enhanced; in common with all engineered wood products, they have improved dimensional stability; and they are lighter and easier to handle. In order to minimise construction depth, services are often integrated into floors by passing them through openings in the web.

As web openings result in a reduction in shear capacity, manufacturers of *I*-joists specify limits on the size and location of openings to ensure that the structural integrity of their product is not compromised. There is always the danger that these rules will be contravened during initial construction or subsequent remodelling of a building.

A new castellated timber joist design is proposed that incorporates pre-formed holes in the web, as seen in Figs. 1 and 2. These novel joists will facilitate the installation of services as they can easily pass through the web openings. Other advantages associated with the castellation of the web include enhancement of the flexural capacity due to increased section depth and minimisation of the material waste that occurs when drilling holes. The shear capacity of the joists, on the other hand, is reduced due to the presence of the web openings.

The widespread use of castellated steel beams has led to several studies of their structural performance. A number of different failure modes have been identified for these beams including: shear failure of the tee-sections above and below the holes, shear failure of the web weld at mid-depth, in-plane web buckling and distortional buckling [3,4]. Redwood and Demirdjian [3] carried out tests on four steel castellated joists, all of which displayed buckling of the web-post between the holes. They found that the failure loads were not sensitive to the moment-shear ratio. Zirakian and Showkati [4] investigated the distortional buckling of steel castellated beams. They tested six beams and in all cases the beams underwent lateral buckling accompanied by web distortion. Liu and Chung [5] used a numerical model to investigate the influence of opening shape, opening depth and beam size on the structural performance of castellated steel beams. They found that the load–displacement responses and failure modes were similar for the different sizes and shape openings. The modes of failure reported were shear failure, flexural failure and yielding of the tee-section above and below the holes, and these depended on the loading, the support conditions and the location of the openings.

As the use of castellated webs in timber *I*-joists is a new concept, there have been no studies published on their structural behaviour. The impact of circular and square web openings on the structural performance of timber joists has been examined in a number of studies [6–9]. These researchers have focused mainly on joists with one or two openings. Afzal et al. [6] carried out three-point shear tests on a large number of commercial *I*-joists of two different depths, each having either one or two circular or square web holes located in the centre of the shear span. The percentage reduction in failure load for a particular hole-size to web-depth ratio was found to be independent of joist depth. Square holes were found to have a

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