AN ALGORITHM FOR THE SHEAR CHECK OF DOWELLED CONNECTIONS WITH COMBINED MOMENT AND LATERAL LOADING

Panagiotis Patlakas¹, Andrew Thompson²

ABSTRACT: Moment-resisting connections with dowel-type fasteners require verification of their shear strength to prevent splitting. This can be of particular importance when lateral forces are also present. Guidance towards the design of such connections is available to structural designers and follows established procedures. However, while this is effective for standardised orthogonal connections, the calculations become complex when non-standard geometries are implemented. This paper describes an algorithm for the automation and parameterization of shear strength calculations for any moment-resisting connection geometry in a 2d plane. In addition the implementation of this algorithm in the Java programming language, and its embedment in the timber design software, Teretron, is presented.

KEYWORDS: Moment-resisting connections, shear, algorithm, software

1 BACKGROUND

Moment-resisting connections are often employed in timber design, especially in larger structural systems where rigidity is required. The design of such connections in practice typically relies on the calculation of the ductile strength of the connection, based upon the individual capacity of a fastener within a group. A number of assumptions are made in the design, including the assumption that members act as rigid elements. Concerns with regard to brittle failure (shear and/or splitting of the timber) are typically dealt with indirectly, via the adoption of a number of construction requirements prescribed in the design codes. Eurocode 5 provides guidance on edge, end, and spacing distances, as well as specifying pre-drilling as a requirement for nail-type fasteners of a diameter above 6 mm and timber with characteristic density greater than 500 kg/m³ [1].

However, when moment-resisting connections are subjected to both moments and lateral forces, the minimum design requirements do not cover all possibilities of brittle failure. The connection needs to be checked analytically against splitting, as shear forces are developed in boundary areas where the forces induced in the fasteners due to moment are of opposite direction to the lateral forces induced in the fasteners due to the shear forces perpendicular to the grain of member (Figure 1).

Figure 1: Boundary area that should be checked against splitting forces

Porteous and Kermani have provided detailed guidance to designers for the calculation of such forces in connections where the fasteners are arranged in a rectangular grid and the members are perpendicular to each other [2]. This methodology is effective and can be extended to other geometries and arrangements. However, even slight changes in the geometry (such as members at an angle) or the fastener arrangements (such as a non-rectangular grid), complicate the process, making it both time consuming

¹ Panagiotis Patlakas, Southampton Solent University, East Park Terrace, Southampton, UK. Email: panagiotis.patlakas@solent.ac.uk
² Andrew Thomson, University of Bath, Claverton Down Bath, UK. Email: ab3ajt@bath.ac.uk
and error prone in the context of a professional practice. As such, the development of an algorithmic method which automates the task and enables the designer to specify non-conventional arrangements and geometries could have significant applicability. Such a method is presented in this paper.

2 METHODOLOGY

2.1 CONNECTION MODELLING

The modelling of the connection is based on the conditions on individual fasteners. Each fastener \( i \) is represented by a 2x1 matrix \( V_i \) with \( x, y \) coordinates that are taken from the centre of inertia of the connection.

The lateral force on each fastener is represented by a collection of 2x1 matrices, each representing the horizontal and vertical force component in a specific coordinate system.

Firstly, the lateral forces in each fastener due to each design action are calculated in the universal (“real-world”) coordinate system.

As shear is relevant to the orientation of each individual member, additional matrices are used to describe these lateral forces in the coordinate system of each member. Rotation matrices are developed for each member based on its angle with the horizontal. The previously calculated location and force matrices are then multiplied with the rotation matrices to produce the final force matrices.

2.2 SHEAR CALCULATION

The process begins from the fastener furthest to the centre of inertia from the left, via a simple evaluation of the location matrix. Starting from this \( x_{\text{min}} \), a nested for loop is written to cover the entire connection area, at a step \( d \) where \( d \) is the diameter of the fastener. This loop identifies cross-section with fasteners with force components perpendicular to the grain of the member, where splitting might occur due to shear.

In C style pseudocode, this loop can be summarized as:

```c
for (x = x_{\text{min}}; x <= x_{\text{max}}; x = x + d) {
    total shear F = 0
    build a fasteners array
    identify the fasteners (if any) that fall in this line
    if fastener needs to be checked for shear
        add to the fasteners array
    for (fastener : fasteners) {
        get force component perpendicular to the grain from matrix \( F_{m,i} \)
        add to total shear F
    }
    calculate shear stress \( \tau \) in this line
    check shear against the shear strength of the member in that position
}
```

3 RESULTS

3.1 IMPLEMENTATION IN SOFTWARE

Teretron® is a software application for structural timber design to Eurocode 5 [3]. The methodology described here has been implemented in the software, using the Java programming language (version 7 SE).

The implementation followed standard techniques of Object-oriented Programming (OOP). Each fastener is described by a custom-made Fastener class, while all matrices described in Section 2 are implemented as arrays.

The methodology was successfully implemented in Teretron®. The software output has been tested in three stages; against manually calculated case studies, against procedural implementations in Excel, and with unit testing via JUnit [4]. All checks have indicated successful implementation. A worked example is presented in this paper.

4 CONCLUSIONS

The method presented here allows for greater design freedom with regard to the design of moment-resisting connections. It is also indicative of the gains that can be achieved by developing algorithms for structural timber design. Timber has typically lagged behind concrete and steel with regard to the available software for structural design despite the complexity inherent in timber structures due to the anisotropic nature of the material.

With regard to the algorithm presented in this paper, future work will focus on the expansion of the methodology to include semi-rigid connections.

REFERENCES