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Withdrawal capacity of threaded rods embedded in timber elements

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HIGHLIGHTS

- The withdrawal capacity of threaded rods embedded in timber elements was studied.
- Theoretical and experimental methods were used.
- In general, theoretical and experimental results are in good agreement.
- A nearly linear relation between withdrawal capacity and embedment length was observed.

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ABSTRACT

In the present paper, the withdrawal capacity of threaded rods embedded in timber elements is investigated using both theoretical and experimental methods. A theoretical approach based on Volkersen theory, assuming a bi-linear constitutive law is developed. Moreover, an experimental investigation of withdrawal of threaded rods from glulam elements is presented. Results for specimens covering a wide range of varying embedment lengths and rod-to-grain angles are provided. The agreement between theoretical estimations and experimental results is good. A nearly linear relation between embedment length and withdrawal capacity, predicted by the theoretical approach, is validated by the experimental results.

1. Introduction

1.1. Background

Threaded connectors, mostly self-tapping screws, have recently shown a great potential as reinforcements [1–4], in axially loaded timber-to-timber connections [5,6] and in moment resisting connections [7–10]. In general, connections with axially loaded threaded connectors show high withdrawal capacity and stiffness. Long threaded rods and self-tapping screws may, to some extent, play the same role in timber structures as reinforcement bars do in concrete structures. When placed with an inclination to the grain direction, they can arrest cracks which may form along the grain, and thus transfer stresses across cracks and retain the structural integrity of timber elements. Due to their length, their withdrawal capacity and stiffness are not significantly affected by local defects (knots, cracks etc.). Furthermore, connections with rods screwed into timber elements are less prone to construction quality issues, less brittle and offer greater fire-protection than connections with glued-in-rods. They may also facilitate a high degree of pre-fabrication and hence contribute to easy and fast erection on construction sites. Finally, ductile connections can be achieved with these connectors, using the principle of capacity design [10].

During recent years, a significant amount of research has been performed on the withdrawal of self-tapping screws and threaded rods embedded in timber elements [9,11–23]. This research has focused almost exclusively on withdrawal capacity, neglecting withdrawal stiffness. Withdrawal stiffness is a part of the current investigation, and theoretical and numerical estimations along with experimental validation are presented in an accompanying paper, see [24]. The influence of important parameters, such as embedment length, diameter and angle between the rod axis and the grain direction, on withdrawal capacity, has been sufficiently investigated only for screws with relatively small diameters. Results available for withdrawal of large diameter threaded rods are limited to rods installed parallel or perpendicular to the grain and to rods with relatively short embedment lengths [9,12,14–16,19]. As for available theoretical models [15,16,19],

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they are based on the application of classical Volkersen [25] theory to axially loaded connectors [26], assuming a linear constitutive law between shear stress and withdrawal displacement. These models have been validated by experimental results only for rods with relatively short embedment lengths, and only for rods inserted parallel to the grain.

Some existing models for calculating the withdrawal capacity are based on application of regression models on experimental results [12,14,17,20,23]. This approach is also adopted by Eurocode 5, EC5 [27]. However, EC5 provides no means of determining the distribution of stresses and displacements, nor the withdrawal stiffness. Moreover, EC5 imposes a limitation to the angle between rod-axis and grain direction ($\geqslant 30°$), leading to a lack of guidelines for threaded rods embedded in small inclinations to the grain direction.

1.2. Outline

A theoretical approach for estimating the withdrawal capacity of axially loaded connectors embedded in timber elements is developed in the present paper. This approach is based on classical Volkersen theory [25] for axially loaded connectors [26], using a bi-linear constitutive law. In addition, an experimental investigation of withdrawal of threaded rods from glulam elements is presented. The parameters of this investigation are the embedment length and the rod-to-grain angle. The experimental withdrawal capacities of specimens with a wide range of these parameters are compared with the theoretical estimations.

2. Theoretical approach

2.1. Theoretical basis

An axially loaded connector embedded in a timber element is shown schematically in Fig. 1a. The embedment length is denoted l and the length of the part of the connector that is not embedded in the timber element is denoted l_0. The angle between the connector axis and the grain direction is denoted α. The outer thread diameter and the core cross-sectional area of the connector, are denoted d and A_s respectively. The withdrawal force is denoted P. Axis x_e is defined with its origin at the entrance point of the connector, pointing downwards. Depending on the provided support, three main types of loading conditions may be considered as shown in Fig. 1b; pull-push, pull-pull and pull-shear loading conditions.

The theoretical approach is based on classical Volkersen theory [25] applied on axially loaded connectors [26]. According to [26], all shear deformation is assumed to occur in an infinitely thin shear layer while the connector and surrounding wood are assumed to be in states of pure axial stress. In the present approach, all shear deformation is assumed to occur in a shear zone of finite dimensions while, another zone of the wood with cross sectional area A_w is in a state of pure and uniform axial stress. In reality, parts of these two zones overlap.

The withdrawal force imposes a shear stress $\tau(x)$ in the interface between the timber element and the outer thread surface of the connector. The displacement of the shear zone is denoted $\delta(x)$ and is equal to the relative displacement between the displacements of the connector, $u_s(x)$, and the wood, $u_w(x)$:

$$\delta(x) = u_s(x) - u_w(x) \tag{1}$$

The relation between the interface shear stress, $\tau(x)$, and the displacement of the shear zone, $\delta(x)$, is approximated as bi-linear, instead of the real non-linear relation, as shown in Fig. 2. A similar approach can be found in [28]. The idealized, bi-linear constitutive law is described by the following expression:

$$\tau(x) = \Gamma_e \cdot \delta(x), \quad \delta(x) \leqslant \delta_e = f_w/\Gamma_e \tag{2a}$$

$$\tau(x) = f_w - \Gamma_f \cdot (\delta(x) - \delta_e), \quad \delta(x) > \delta_e = f_w/\Gamma_e \tag{2b}$$

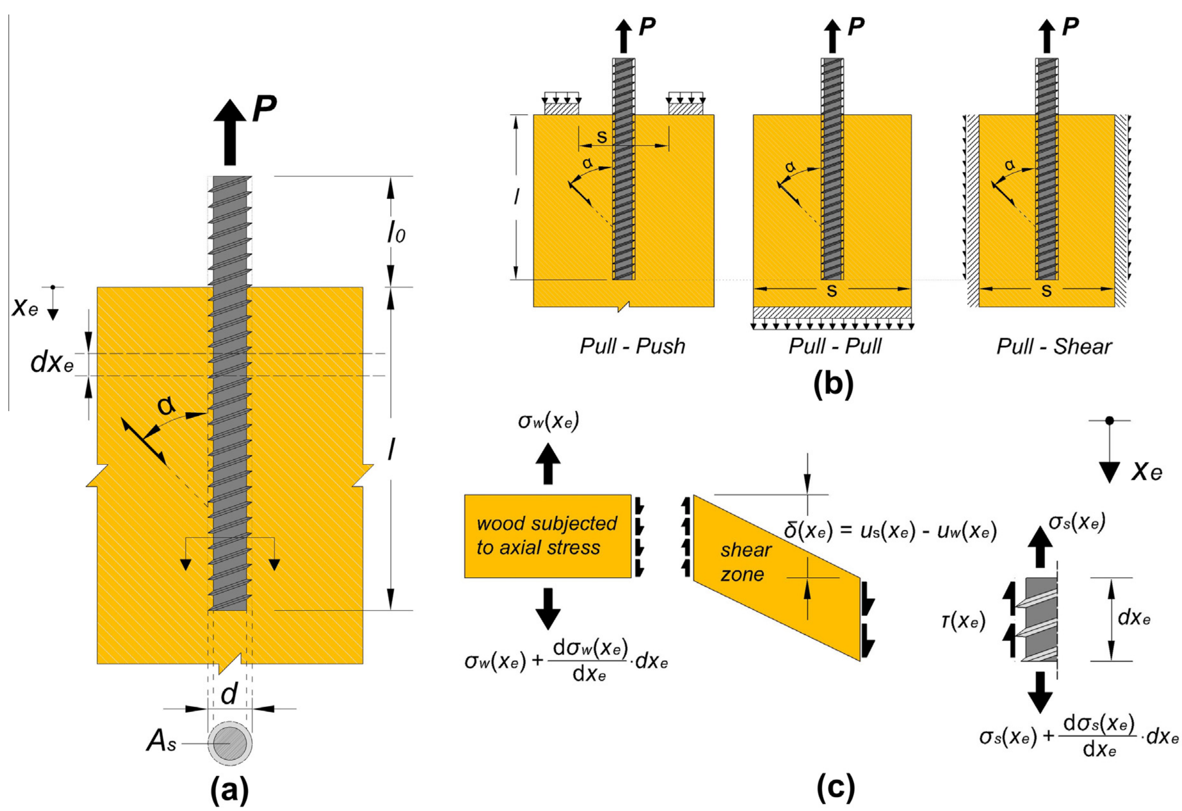

Fig. 1. Axially loaded connector: (a) geometric features, (b) loading conditions and (c) stress state of an infinitesimal small slice dx_e.