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Withdrawal stiffness of threaded rods embedded in timber elements

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HIGHLIGHTS

- The withdrawal stiffness of threaded rods embedded in timber elements was studied.
- Theoretical, numerical and experimental methods were used.
- The specimens exhibited high withdrawal stiffness.
- In general, theoretical and experimental results show good agreement.

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ABSTRACT

In the present paper, the withdrawal stiffness of axially loaded threaded rods screwed into timber elements is investigated using theoretical, numerical and experimental methods. The theoretical approach is based on the application of classical Volkersen theory on axially loaded connectors. An experimental investigation of withdrawal of threaded rods from glulam elements is presented. The parameters of this investigation are the embedment length and the angle between the rod axis and the grain direction. The theoretical and numerical estimations are compared to the experimental results.

1. Introduction

1.1. Background

Connections with long threaded rods screwed into timber elements can be a strong alternative to dowel-type connections and connections with glued-in-rods. Recently, threaded connectors, mostly self-tapping screws, have 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, axially loaded threaded connectors show high withdrawal capacity and stiffness. Due to their length, their withdrawal capacity and stiffness are not significantly affected by local defects (knots, cracks, etc.). Connections with threaded connectors screwed into timber elements, are less prone to construction quality issues, less brittle and offer greater fire-protection than connections with glued-in-rods. Furthermore, they may allow a high degree of prefabrication and hence contribute to easy and fast erection on site.

Withdrawal stiffness is the necessary parameter for the calculation of the rigidity of joints with threaded connectors [6,9]. In general, joints with high rigidity enhance service-ability of structures. By introducing joints with rotational rigidity in the ends of beam elements, a more optimized moment distribution can be achieved [11,12] leading to a more economical design, enhanced robustness and enhanced vibrational performance [13]. Joints with rotational rigidity can also enhance the sideway stability of timber arches [14].

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 [9,15–28]. However, this research has almost exclusively focused on withdrawal capacity and not on withdrawal stiffness. A theoretical model for the estimation of withdrawal stiffness has been presented in [23,28]. However, it has only been validated by experimental results for relatively stocky threaded rods (i.e. rods with short embedment

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length compared to their diameter) and only for rods inserted parallel or perpendicular to the grain direction.

The withdrawal stiffness of self-tapping screws or threaded rods has not been fully investigated, as the effect of parameters such as the embedment length and rod-to-grain angle have not been explored. The lack of available methods and experimental results is also reflected in modern timber design codes like Eurocode 5, EC5 [29], which provides no guidelines for the calculation of withdrawal stiffness and stress distributions of axially loaded connectors.

1.2. Outline

In the present paper, the withdrawal stiffness of axially loaded threaded rods screwed into timber elements is investigated. A theoretical approach based on the application of Volkersen theory on axially loaded connectors is used to estimate the withdrawal stiffness and the stress and displacement distributions. Moreover, 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. Results for specimens covering a wide range of these parameters are presented. Finally, numerical models are employed for the analysis of the specimens. The theoretical and numerical estimations are compared to the experimental results.

2. Theoretical approach

2.1. Elastic analysis

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 mechanical behaviour of the connector and the wood is assumed to be linear-elastic with moduli of elasticity denoted E_s and $E_{w.\alpha}$ respectively (the modulus of elasticity of wood depends on α). 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 [30] applied on axially loaded connectors [31]. According to [31], all shear deformation is assumed to occur in an infinitely thin shear layer while the core of the connector and surrounding wood are assumed to be in states of pure and uniform 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 surrounding 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 axial stresses in the core of the connector and in the wood are denoted $\sigma_s(x_e)$ and $\sigma_w(x_e)$ respectively.

Fig. 1c shows the stress state of an infinitesimal thin slice dx_e of an embedded connector and the surrounding wood. Due to the withdrawal force, a shear stress, $\tau(x_e)$ is developed in the interface between the timber element and the outer thread surface of the connector. As depicted in Fig. 1c, the displacement of the shear zone is denoted $\delta(x_e)$ and is equal to the relative displacement between the displacement of the connector, $u_s(x_e)$ and the displacement of wood, $u_w(x_e)$:

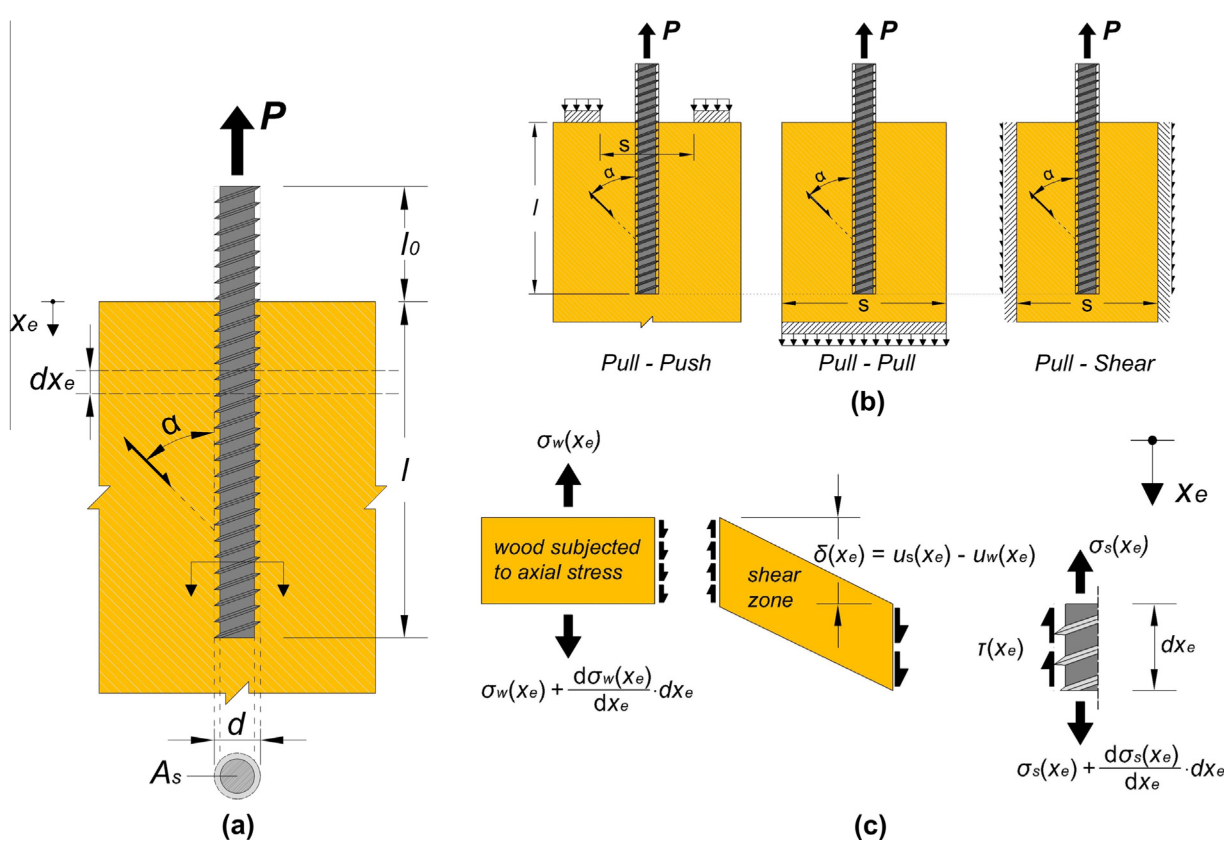

Fig. 1. Axially loaded connector: (a) geometric features (b) loading conditions (c) stress state of an infinitesimal small slice dx_e.