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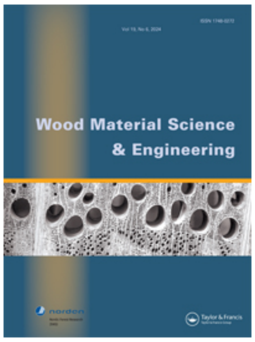

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Small-scale testing of water-saturated wooden discs for determining the strength properties of timber foundation piles

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ABSTRACT
The compressive strength properties of timber foundation piles in Amsterdam were characterised by small-scale compression tests on saturated round wooden discs. The discs were extracted from the head, middle, and tip of five spruce (*Picea abies*) piles dating back to 1727, 1886, 1922, and 2021. Several piles were subjected to underwater bacterial decay, causing a reduction of their load-carrying capacity over time. The amount of decay was determined with micro-drilling measurements. The results of small-scale tests were compared to large-scale axial compression tests to assess the feasibility of retrieving equivalent strength properties, considering the influence of diameters, decay, and wood knots.

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KEYWORDS
Wooden foundation piles; saturated strength properties; wood knots

1. Introduction

The bridges in the historic city centre of Amsterdam are supported by wooden foundation piles, mainly constructed between 100 and 300 years ago (Mirra *et al*. 2024). Nowadays, concerns regarding their potential safety issues have emerged. The piles remain entirely submerged below the water table, exposing them to bacterial decay in anaerobic conditions (Klaassen *et al*. 2005, Mirra *et al*. 2024). Piles degraded by bacteria in anoxic conditions can perform their function for centuries before showing a substantial reduction of the load-carrying capacity, as demonstrated in (Van de Kuilen 2007, Mirra *et al*. 2024, Pagella *et al*. 2024b). To characterise the remaining strength properties of the piles in Amsterdam in relation to bacterial degradation, a large-scale testing campaign was conducted in (Pagella *et al*. 2024b), involving a total of 201 pile segments that were retrieved from two bridges in Amsterdam. The research allowed to assess the remaining short-term compressive strength along the piles in relation to bacterial decay after three distinct periods of service time: 1727, 1886, and 1922. The micro-drilling technique enabled the estimation of the soft shell of each pile, which refers to the degraded outer layer of the cross-section with no remaining strength. Building on the previous works (Pagella *et al*. 2022, Pagella *et al*. 2024b), this paper explores the feasibility of conducting small-scale compression tests on approximately 150-mm-thick discs extracted from the piles. The objective is to determine whether testing wooden discs can reliably replicate the strength properties observed in larger pile segments. This approach aims to reduce the extensive experimental efforts and resources required for testing large-scale pile segments, especially focusing on the most influencing factors on the strength: knots (Hoffmeyer 1987, Zobel and Van Buijtenen 1989, Pagella *et al*. 2022). Testing small sections with and without knots will examine the impact of knots on the strength properties, providing insights to streamline testing while ensuring accuracy in the results.

2. Materials and methods

The materials comprised six full-length tapered Norway spruce (*Picea abies*) piles. Four of these were retrieved from two bridges in Amsterdam, dating back to 1727 (2 piles), 1886 (2 piles), and 1922 (1 piles). One pile was a ‘new’ pile. The piles were ca. 12 meters long, with mean head diameter of 240 mm and a mean tip diameter of 170 mm. Severe decay was identified in the two piles from 1727 and in one pile from 1886, affecting 30–50% of their outer cross-sectional area consistently along each pile, as determined by micro-drilling analysis in (Pagella *et al*. 2024a, 2024b). Low decay was observed in the remaining two piles, one from 1992 and one from 1886, affecting less than 10% of their outer cross-sectional area. Each pile was divided into three parts (head, middle, and tip), from which a segment was extracted (Figure 1(a)) with a length equal to six times its most minor diameter (EN 14251 2003). Adjacent to this segment, two 150-mm-thick discs were sawn (Figure 1(b)): one from a knot cluster area (KW) and the other from a clear wood section (CW), with no knots. During handling and cutting procedures, the specimens were kept submerged in water tanks, aiming at a global moisture content (MC) higher than 60%, well above fibre saturation (EN 14251 2003). The short-term compressive strength ($f_{c,0,wet}$) was determined with large-scale compression tests for 20 saturated pile segments

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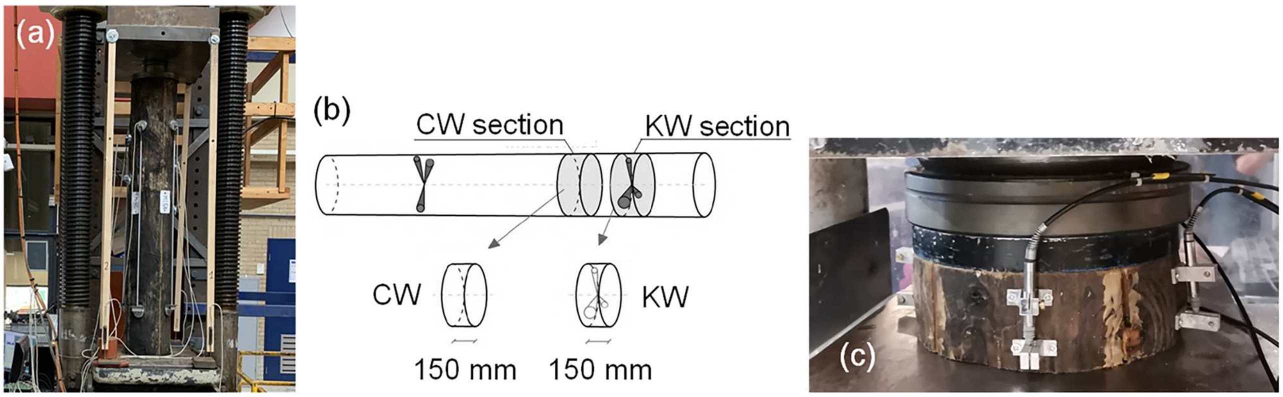

Figure 1. Test set-up: (a) compression test of large-scale pile segments, (b) extraction of 150 mm thick discs from a clear wood (CW) section and a section with knots (KW), and (c) small-scale compression test of a disc with knots.

(Figure 1(a)), explained in detail in (Pagella et al. 2024b), and with small-scale compression tests for 40 wooden discs (Figure 1(c)). The discs were loaded to failure within approximately 5 minutes, with a displacement-controlled set-up. The influence of the knots on $f_{c,0,wet}$ between the KW and CW discs, was studied considering an equivalent strength (EQ $f_{c,0,wet}$) of the discs, derived from the ratio between the maximum force reached in compression ($F_{c,0,test}$) and their average sound cross-sectional area (Pagella *et al.* 2024b), assuming that zero remaining strength is assigned to the degraded outer layer of the cross-section (Mirra *et al.* 2024, Pagella *et al.* 2024b). The presence of knots was calculated with the knot ratio (KR), i.e. the ratio between the sum of the knot diameters perpendicular to the longitudinal pile axis and the pile circumference.

3. Results

EQ $f_{c,0,wet}$ and KR for CW and KW discs were moderately correlated (Figure 2(a)). In particular, for KR > 0.1, the knots had an influence up to 30% on the compressive strength. For KR < 0.1, no significant difference was found between EQ $f_{c,0,wet}$ KW and CW discs. Considering this, the short-term strength of discs was very similar to that of larger pile segments (Figure 2(b)), independently of the amount of decay. Figure 2(c) shows the strong correlation between $f_{c,0,wet}$ of pile segments and discs, considering both CW and KW discs for KR < 0.1, and only KW discs for KR > 0.1.

4. Conclusions

This study conducted small-scale compression tests on 40 saturated wooden discs extracted from spruce foundation piles of varying service lives to determine their compressive strength relative to different knot ratios (KR). The results obtained from the wooden discs were compared with compression tests performed on full-scale pile segments. The compressive strength determined for the discs was very well aligned with that of the more significant pile segments. For KR > 0.1, the knots can influence the compressive strength by up to 30%. Thus, the strength properties of wooden piles can be accurately assessed using small-scale tests of wooden discs with knots (KW) extracted from the pile section with the highest KR. This method of small-scale testing of discs can be effectively adopted for characterising the strength properties of large-scale pile segments in Amsterdam, considering the presence of knots. This could considerably reduce the extensive experimental efforts of testing large-scale pile segments while providing accurate results for the short-term compressive strength of wooden foundation piles.

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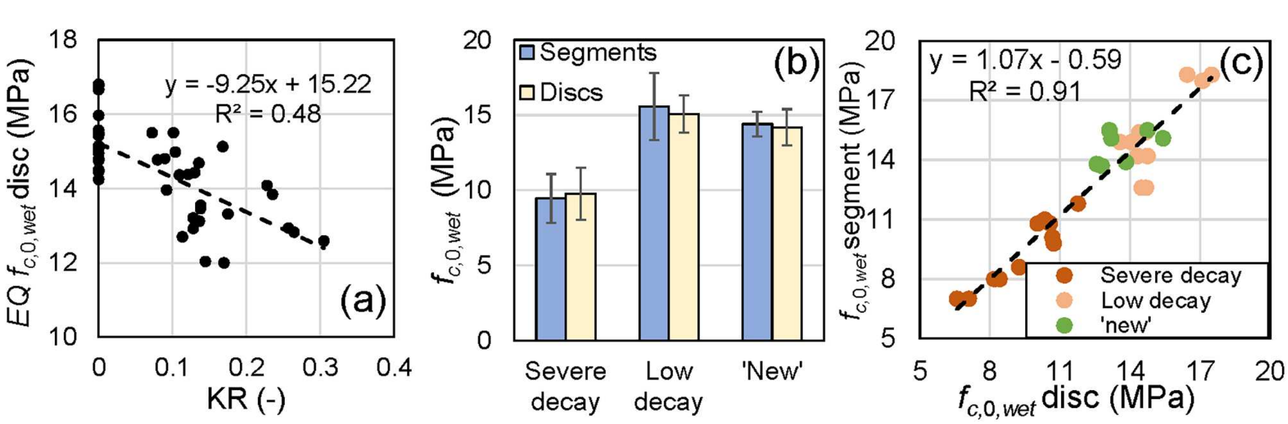

Figure 2. (a) relationship between EQ $f_{c,0,wet}$ discs and KR, (b) comparison between $f_{c,0,wet}$ of the pile segments and discs, and (c) relationship between $f_{c,0,wet}$ of the pile segments and discs for severe decay, low decay, and new wooden piles.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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