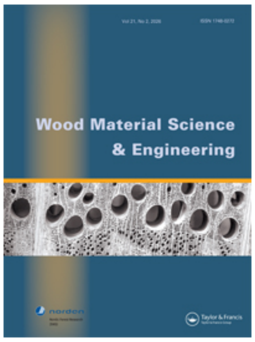


Wood Material Science & Engineering

ISSN: 1748-0272 (Print) 1748-0280 (Online) Journal homepage: www.tandfonline.com/journals/swoo20

Assessment of local stiffness redistribution around knots in round timber under axial compression using digital image correlation

Giorgio Pagella

To cite this article: Giorgio Pagella (20 Mar 2026): Assessment of local stiffness redistribution around knots in round timber under axial compression using digital image correlation, Wood Material Science & Engineering, DOI: 10.1080/17480272.2026.2646317

To link to this article: https://doi.org/10.1080/17480272.2026.2646317

Published online: 20 Mar 2026.

WOOD MATERIAL SCIENCE & ENGINEERING
https://doi.org/10.1080/17480272.2026.2646317

Taylor & Francis
Taylor & Francis Group

BRIEF ORIGINAL

OPEN ACCESS Check for updates

Assessment of local stiffness redistribution around knots in round timber under axial compression using digital image correlation

Giorgio Pagella

Faculty of Civil Engineering and Geosciences, Biobased Structures and Materials, Delft University of Technology, Delft, The Netherlands

ABSTRACT
The local stiffness of a knot in wood can be up to 30 times lower than the longitudinal stiffness of clear wood, as reported in literature and codes. However, it remains difficult to determine the local effect of knots on the stiffness of round timber and to quantify the extent of the surrounding area influenced by this reduction in stiffness. The objective of this study was to experimentally investigate the local redistribution of stiffness around knots in round timber under axial compression using digital image correlation (DIC). By providing full-field strain measurements, DIC enables a detailed characterisation of strain localisation and offers a novel approach to quantify the influence zone of knots. Two spruce piles were tested in compression, and the deformations were obtained on three distinct zones: within the knot, a transition zone, and a clear wood zone. The stiffness in the knot was approximately 1/30 of the clear wood longitudinal stiffness, while the transition zone had a reduction of about 1/15. The study supports the validity of existing design assumptions and of DIC for capturing local stiffness variations in round timber.

ARTICLE HISTORY
Received 18 February 2026
Revised 10 March 2026
Accepted 12 March 2026

KEYWORDS
Round timber; non-destructive testing; digital image correlation; wood features; mechanical properties

1. Introduction

Round timber is widely used in civil engineering for foundation piles, retaining structures, or pedestrian bridges. In this context, timber piles (Figure 1a) are characterised by features such as knots, which can largely influence their stiffness parallel to the grain (Wilkinson 1968, Hoffmeyer 1987, Pagella *et al.* 2022, 2025). Grain deviation induced by a knot locally reorients the fibres, such that within the knot the fibres are oriented approximately perpendicular (approx. 90°) to the longitudinal axis, gradually transitioning toward to 0° with increasing distance from the knot (Figure 1b). This has an impact on the stiffness, where the modulus of elasticity perpendicular to the grain is 30 times lower than that parallel to the grain $E_{c,90} = 1/30\ E_{c,0}$ (CEN 2016). Thus, when a compression load is applied in the axial direction of a pile, only a very small amount of the load is taken up by the knots, since the stress flow follows the stiffer zone parallel to the grain. The effect of wood knots on the stiffness of wooden piles is not easy to quantify, since it depends on the size, number, and distribution of knots. A knot-ratio (KR) is commonly used (i.e. the ratio between the sum of the knot diameters perpendicular to the longitudinal axis of the log, over a 150 mm length, and the circumference of the log in that section), as reported in the draft of the new Eurocode 5 (CEN 2025). In this framework, the objective of this study was to reliably capture the redistribution of stiffness in the vicinity of a knot, by performing displacement-controlled compression tests on round timber specimens and digital image correlation (DIC) to quantify the strain field and identifying the extent of the stiffness influence zone around knots.

2. Materials and methods

The materials comprised two large-scale Norway spruce (*Picea abies*) piles: Pile A (400 mm long, with a diameter of 185 mm, KR = 0.18, biggest knot of 37 mm), and Pile B (720 mm long, with a diameter of 245 mm, KR = 0.1, biggest knot of 32 mm). Both piles originated from a test campaign in Amsterdam (Felicita *et al.* 2024). To replicate submerged in-service conditions for foundation piles, the specimens were stored in water for one week prior to testing to achieve fully saturated conditions (moisture content of 50–60%). A compression test with a displacement-controlled setup was performed to determine the modulus of elasticity ($E_{c,0}$) in accordance with the EN 14251 (CEN 2003). Prior to testing, the specimens were cut parallel at both ends to ensure a uniformly distributed load. Hinged plates were installed at the top and bottom of the specimens to allow rotational freedom during compression and to minimise buckling effects. The loading was applied at a constant displacement rate of 0.02 mm/s. $E_{c,0}$ was also measured from the strains of DIC, between 10–40% load interval as specified in EN 14251. $E_{c,0}$ was also calculated from the load-strain curves measured with linear potentiometers attached to the surface of the piles, spanning 2/3rd of the length of the

CONTACT Giorgio Pagella g.pagella@tudelft.nl Faculty of Civil Engineering and Geosciences, Biobased Structures and Materials, Delft University of Technology, Delft, 2628CN, The Netherlands

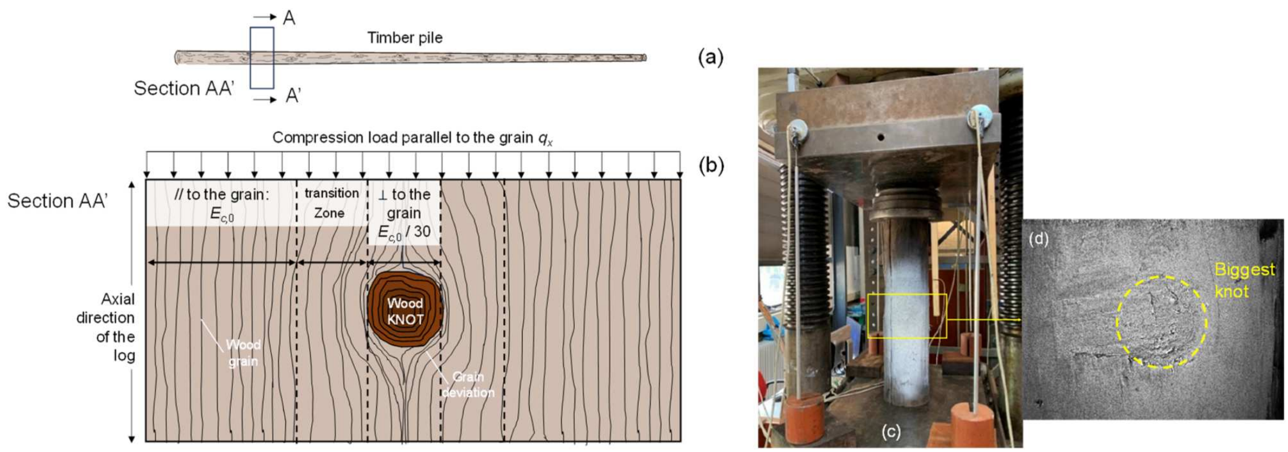
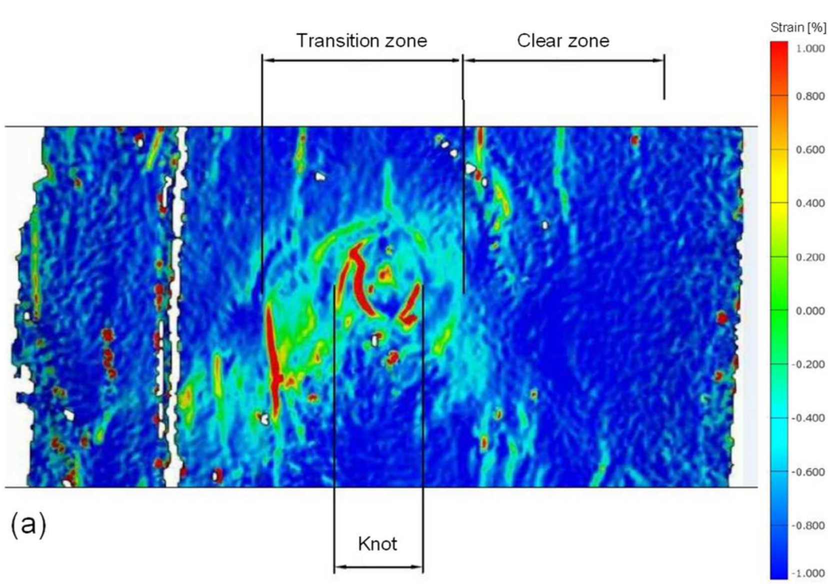


Figure 1. Test procedure: (a) timber pile, (b) section of timber pile with knot and assumption of modulus of elasticity ($E_{c,0}$) zones depending on fiber deviation, (c) test-setup of a pile segment equipped with linear potentiometer and DIC, and (d) zoom in around the biggest knot.

specimens, to validate the accuracy and applicability of DIC in measuring $E_{c,0}$. DIC equipment was employed to monitor deformation within a 135×100 mm^2 area surrounding the biggest knot within the knot cluster of each pile (Figure 1c). This region was prepared with a white base coat and a random black speckle pattern. Images were captured using two cameras and two LED lamps equipped with polarising filters. The cameras were calibrated to an accuracy of 0.035 pixels. Data processing and analysis were performed using Zeiss Inspect Optical 3D. Images were recorded at 3-second intervals throughout each test. Using DIC, three distinct regions around the knot were analysed (Figure 1b): (a) Within the knot – where fibres are oriented perpendicular to the load direction in a circular pattern; (b) Transition zone – the area adjacent to the knot where fibres deviate from the longitudinal direction; (c) Clear wood zone – the region sufficiently distant from the knot, where fibres are aligned with the longitudinal axis and exhibit an inclination of less than 5°.

3. Results

Figure 2a presents the DIC strain analysis in the elastic range during the compression test on Pile A. Some local disturbances are visible around the knot, mainly due to surface irregularities. A white line appears on the left side of the knot, corresponding to a surface indentation that could not be properly captured by the DIC system. In the clear wood zone, the strain field is relatively uniform. Figure 2b shows $E_{c,0}$ values of piles A and B in the three analysed zones. In the transition zone surrounding the knot, the fibre inclination leads to a local reduction in stiffness with $E_{c,0}$ ranging from 1/12 and 1/15 of $E_{c,0}$ in the clear zone. Within the knot itself, the lowest stiffness values were recorded, approaching 1/30 of the clear wood $E_{c,0}$, thereby confirming the expected reduction in stiffness perpendicular to the grain. $E_{c,0}$ values measured with DIC corresponded with those measured with linear potentiometers, with variations up to 10%.



(b)

	Zone	mean $E_{c,0}$ (MPa)
Pile A	Clear	3800
	Transition	260
	Knot	130
Pile B	Clear	3500
	Transition	280
	Knot	120

Figure 2. DIC strain analysis: (a) Pile A, example of strain redistribution around the knot analysed with DIC, and (b) $E_{c,0}$ values from DIC of Piles A and B.

4. Conclusions

A substantial redistribution in the modulus of elasticity around knots in round timber was experimentally observed. The lowest stiffness values occurred within the knot region, where the modulus of elasticity was approximately 1/30 of the clear wood value, while the transition zone surrounding the knot exhibited values of approximately 1/12–1/15 of the clear wood stiffness.. These results confirm the expected stiffness reduction caused by fibre deviation and quantify the extent of the transition zone between the knot and the surrounding clear wood.

The use of digital image correlation (DIC) enabled the measurement of strain distributions and proved to be an effective method for capturing local stiffness variations around knots. The modulus of elasticity values derived from DIC showed good agreement with those obtained from linear potentiometers, with deviations within 10%, confirming the reliability of the optical measurement technique. It should be noted that only two specimens were tested in this study, which limits the statistical representativeness of the results. In addition, factors such as surface irregularities of the timber and local buckling of the pile were not explicitly accounted for and may influence the stiffness evaluation when using DIC.

Despite these limitations, the results obtained from both specimens were consistent and demonstrate the potential of DIC for investigating the local mechanical behaviour of timber, revealing that the reduction in stiffness associated with knots extends beyond the knot itself into a surrounding transition zone. The findings provide a basis for future experimental studies with a larger number of specimens, which could further refine the characterisation of stiffness redistribution around knots in round timber.

Acknowledgements

The Authors gratefully acknowledge the funder, the city of Amsterdam, and student Quinten van Vliet, for conducting the tests.

Author contributions

CRediT: **Giorgio Pagella:** Conceptualization, Data curation, Formal analysis, Methodology, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

Disclosure statement

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

Funding

This work was supported by city of Amsterdam.

References

CEN, 2003. *Structural round timber – test methods*. Brussels: European Committee for Standardization (CEN).

CEN, 2016. *Structural timber- strength classes*. Brussels: CEN.

CEN, 2025. Draft of the new Eurocode 5 2025. NEN-EN 1995-1-1 (2025) Eurocode 5: Design of timber structures – Common rules and rules for buildings – Part 1-1: General. NEN, Delft, The Netherlands.

Felicita, M., *et al*., 2024. Assessment of in-situ stress distribution and mechanical properties of wooden foundation piles instrumented with distributed fiber optic sensors (DFOS). *Case Studies in Construction Materials*, 20, pp. 1-6. doi:10.1016/j.cscm.2024.e03139.

Hoffmeyer, P., 1987. The role of grain angle, knots, tension wood, compression wood, and other anomalies on the mechanical properties of wood. Technical University of Denmark. Byg Report No. TR-183.

Pagella, G., *et al*., 2022. Influence of knots and density distribution on compressive strength of wooden foundation piles. In *Eighth International Conference on Structural Engineering, Mechanics and Computation, Cape Town, South Africa*.

Pagella, G., *et al*., 2025. Characterization of the mechanical properties of saturated spruce (Picea abies) and pine (Pinus sylvestris) foundation piles. *Journal of Building Engineering*, 108, Article 112836. doi:10.1016/j.jobe.2025.112836.

Wilkinson, T.L., 1968. Strength evaluation of round timber piles. Forest products laboratory, U.S.D.A. Forest service, U.S. Department of agriculture. Madison Wisconsin U.S.A. Research paper FPL 101, 1968.