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LIMITATIONS AND ERRORS IN THE TORSION SETUP AND FORMLATION OF SHEAR FIELD TEST SPECIFIED IN CURRENT EUROPEAN TEST STANDARD EN 408:2010 FOR TIMBER BEAMS

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ABSTRACT: The current torsion and shear field test method specified in EN 408:2010 [1] for timber beams has evident limitations and minor errors that may lead to significant inaccuracies when measuring sample rotation. The maximum gauge distance specified in the current test standard is still too close to the clamps at both ends. The end effect significantly impacts the rotation of the cross-section where the gauges are located. This paper first presents a study on the minimum gauge distance required to avoid the end effect. Secondly, it reviews various techniques for measuring sample rotation and proposes two potential new approaches for measuring the rotation of samples. Additionally, the shear field test method contains a critical error that could result in substantial miscalculations of the shear modulus.

KEYWORDS: EN408, Torsion test, Shear Field Test, Mechanical properties of timber beam, shear modulus

1 – INTRODUCTION

This study examines the limitations and inaccuracies in the current European standard for evaluating the shear modulus of timber beams. The torsion test setup and the shear field test formulae in EN 408:2010[1] contain inherent flaws that can significantly affect the accuracy of shear modulus measurements. This paper presents an experimental validation of the torsion test setup and addresses errors in the formulae used to calculate the shear modulus from the shear field test. Furthermore, several recommendations are proposed to enhance the reliability of the torsion test setup.

2 – Torsion Test

The torsion test provides a pure shear state and a simpler analytical model, enabling more accurate experimental analysis. As a result, it has been increasingly adopted by researchers to evaluate the shear modulus of structural-size timber and glulam beams [2-16], as well as laminated structural glass beams [17, 18]. However, following the torsion test setup specified in EN 408:2010 may lead to inaccurate shear modulus measurements.

Clause 11 of EN 408:2010 states that the gauges measuring the specimen's rotations should be positioned between two and four times the beam width. For example, in a typical timber joist with a 45 mm width and a 195 mm height cross-section, the gauges must be placed between 90 mm and 135 mm from the beam's end. Inevitably, the end effect significantly influences the rotation measurements. Due to this effect [7], he twist rate varies along the beam length, with its impact diminishing as the distance from the clamps increases. To evaluate the influence of the end effect on beams with different cross-sectional shapes, specimens with depth-to-thickness aspect ratios ranging from 1 to 5 were tested. The results identify the extent of the end-effect impact zones and their correlation with cross-section dimensions. Binocular stereo vision system was developed for this validation.

Test setup

The binocular stereo vision system is able to compute disparity, distance and 3D coordinates of any object by simulating the human eyes. In this system, two cameras simultaneously capture the images of an object from different positions.

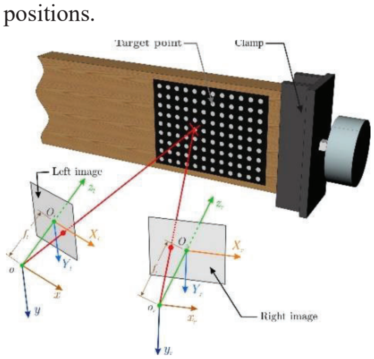

Figure 1 Principle of stereo vision system

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The basic principle behind the employed binocular stereo vision is illustrated in Fig. 1.

An illustration and a photograph of the torsion test setup with a dual stereo vision system used in this study are shown in Fig. 2.:

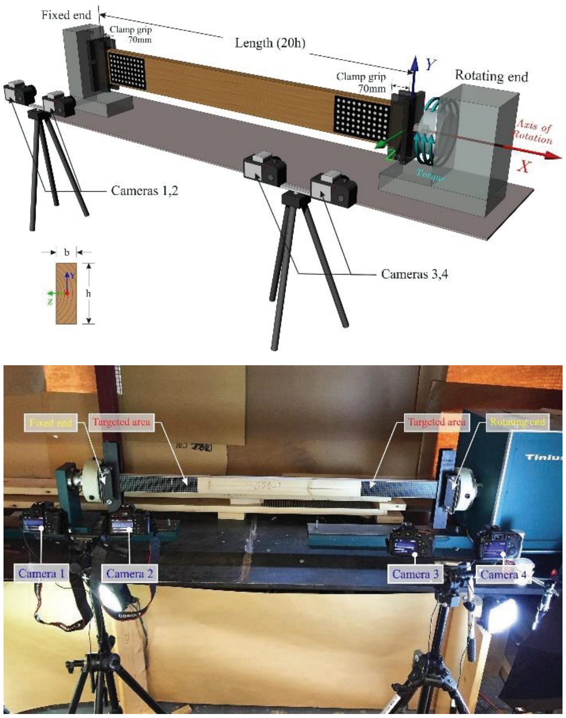
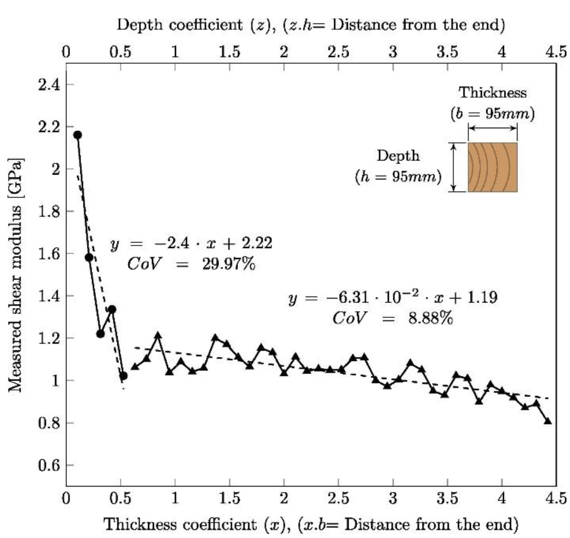
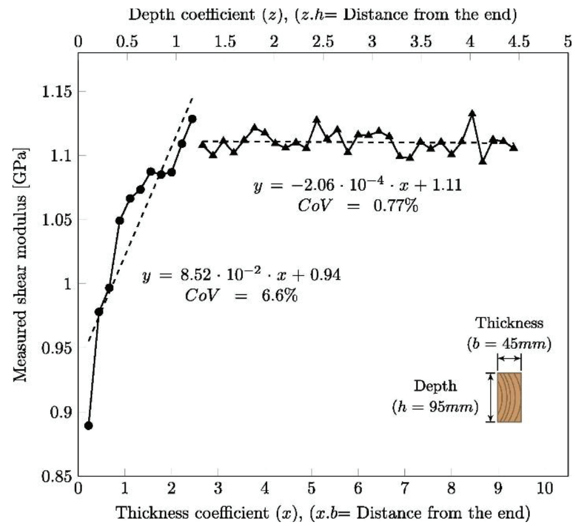
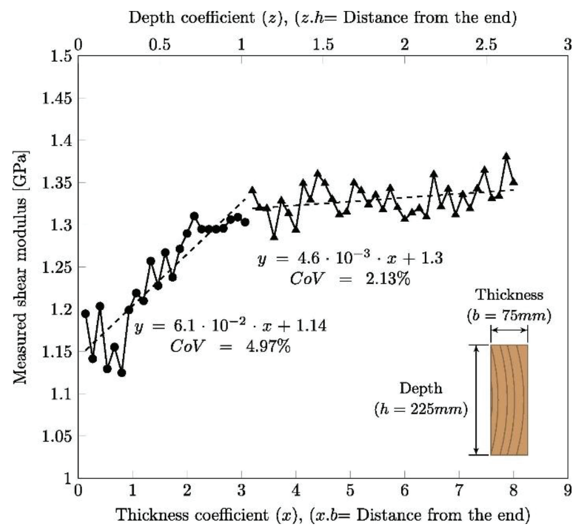


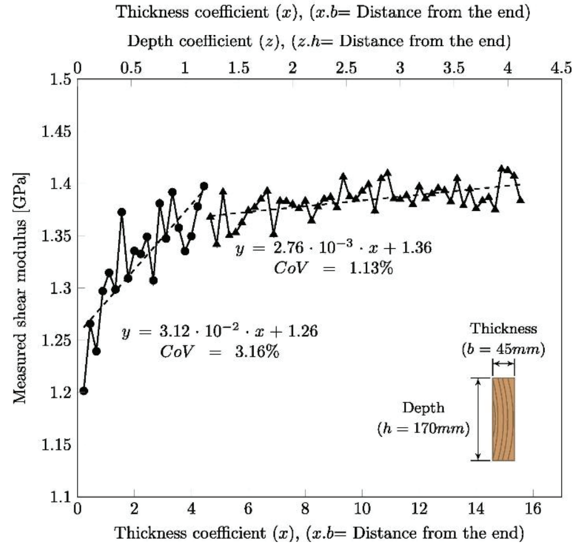
Figure 2 Illustration and phot of the torsion test setup

The dual stereo vision system captures variations in shear modulus at densely distributed measurement positions along the vertical lines marked by black and white dots, starting from the beam's end. The relationship between shear modulus variation and distance from the end was measured for timber beams with cross-section depth-to-thickness aspect ratios ranging from 1 to 5 and is presented in Fig. 3.









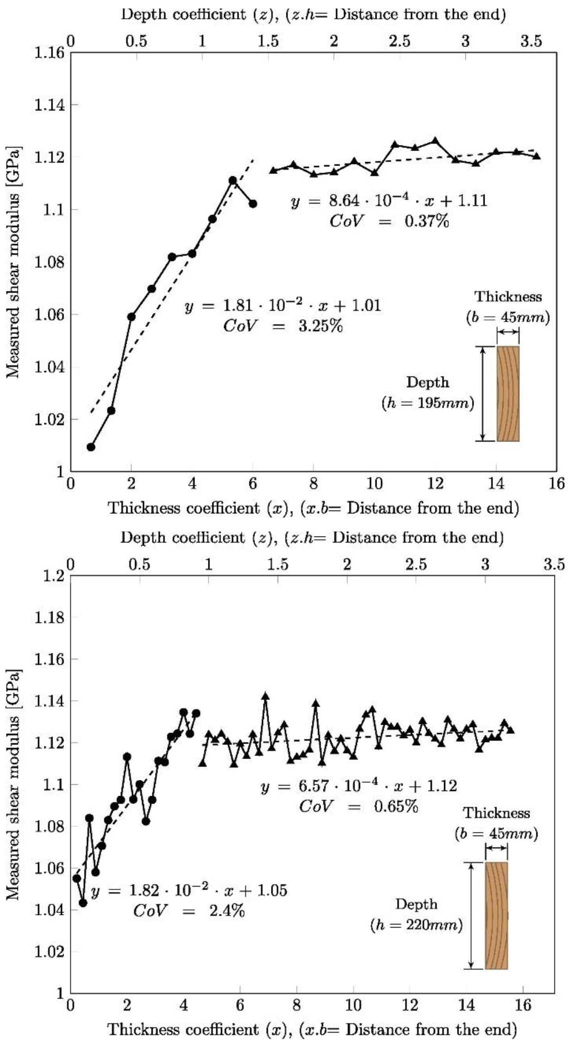


Figure 3 variation of the measured shear modulus of cross-sections with height-to-width aspect ratios ranging from 1 to 5

The test results clearly indicate the presence of two distinct zones. The first, located within 1.0h-1.5h from the beam ends (h being the cross-section depth), exhibits significant variation in the measured shear modulus due to the end effect. This region is referred to as the end-effect zone. Beyond 1.5h from the ends, the measured shear modulus remains nearly constant.

Based on these findings, it can be concluded that the gauges used to measure rotation in a torsion test should be placed at least 1.5h away from the beam ends - significantly farther than the current specification in EN 408, particularly for beams with slender cross-sections. Additionally, the test results reveal that the ratio of the end-effect zone length to depth varies less than the ratio of the end-effect zone length to thickness (b, the cross-section thickness), as illustrated in Fig. 4. Therefore, it would be more appropriate for EN 408 to reference depth rather than thickness when specifying gauge placement.

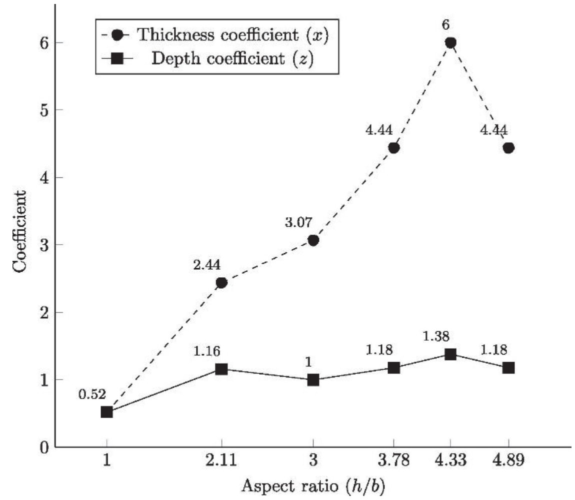


Figure 4 Span of end effect for the tested specimens

Recommendations for torsion test setup

1. This research has concluded that the distance between the gauge sections and the supports as specified in the EN 408 for the torsion test setup, is not sufficient. This distance is not far enough to avoid the impact of the end effect, which will bring in unnecessary errors in the measurement for the cross sections with high aspect ratio.
2. Contradicted to EN 408, our research has indicated that it is more appropriate to use the depth as the referencing dimension to specify the required minimum distance.
3. Look into the test results of this experimental research, a minimum distance of 1:5h can be observed. This agrees with the previous numerical and analytical studies.
4. The gauges and rotation measuring system illustrated in EN 408 are not well designed. The circular gauge may not rotate the same angle as the specimen due to the possible warping in the cross-section. In addition, the LVDTs used in the system will not be able to handle a slightly larger rotation.
5. The proposed non-destructive and non-contact photogrammetry technique has proven to be an efficient yet a precise way of measuring the surface rotation in multiple locations simultaneously.
6. the shear field test method contains a critical error that could result in substantial miscalculations of the shear modulus.

3 – SHEAR FIELD TEST

The shear field test is another method specified in EN 408 Clause 11.2 for determining the shear modulus of timber beams. However, the formula provided in EN 408 contains a critical error—it significantly overestimates the shear modulus, effectively doubling its calculated

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value. As a result, using this incorrect shear modulus in practical engineering design would lead to a severe underestimation of a timber structure's torsional response. This could compromise structural safety, potentially causing excessive torsional deformations, reduced load-bearing capacity, and even structural failure in extreme cases.

The formulae provided in EN408 for computing the shear modules is shown below:

$$G_{tor,s} = \alpha \frac{h_0}{bh} \frac{\left(V_{s,2} - V_{s,1}\right)}{\left(w_2 - w_1\right)} \tag{1}$$

The correct formulae should be read as:

$$G_{tor,s} = \alpha \frac{h_0}{2bh} \frac{\left(V_{s,2} - V_{s,1}\right)}{\left(w_2 - w_1\right)} \tag{2}$$

The shear field test concept is also widely used in diaphragm or "picture frame" tests for cross-laminated timber (CLT) [19-21]. However, some previous studies contain errors in the assumption of diagonal displacements, incorrectly presuming that the two diagonal displacements (Δ/2, as shown in Figs. 5–6) are equal.

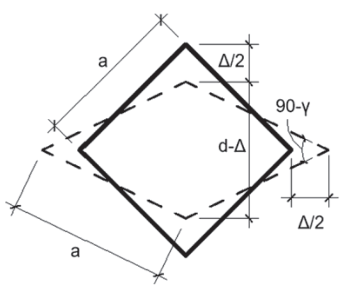

Figure 5 Notation for the evaluation of shear strain c in the centralregion of the panel [19]

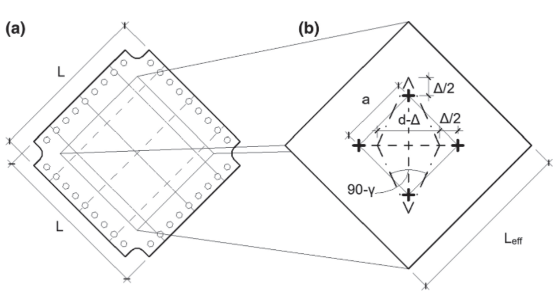

Figure 6 CLT panel of size L × L in picture test [21]

In reality, the diagonal displacements along these two directions are not equal, as demonstrated in Fig. 7. The formulae derived in these studies are therefore based on a mathematically incorrect assumption.

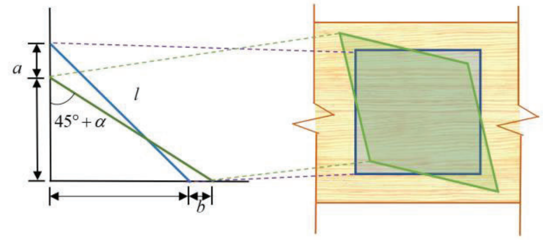

Figure 7 Diagonal displacements of a CLT diaphragm test

Using basic trigonometric derivation, the diagonal displacements can be accurately calculated using the following formulae:

$$\begin{cases} a = \left(\cos 45° - \cos(45° + \alpha)\right) l \\ b = \left(\sin(45° + \alpha) - \cos 45°\right) l \end{cases} \tag{3}$$

Clearly, $a \neq b$. The difference between the two diagonal displacements at varying rotation angles is plotted in Fig. 8.

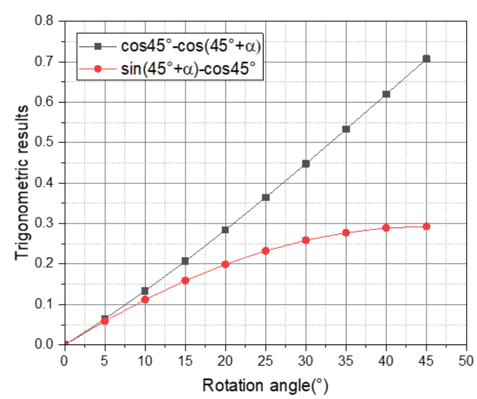

Figure 8 Differnce of two diagonal displacements

As shown in Fig. 8, assuming equal diagonal displacements introduces a continuously increasing distortion in shear modulus calculations as shear force increases. This could lead to significant inaccuracies in structural analysis and design.

Correct formula derivation for computing shear modulus from the shear field test

To derive the correct formula for calculating the shear modulus from the shear field test, a simply supported beam is used as an example. The relevant dimensions and terms are defined in Fig. 9.

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The local to global average shear stress ratio

The overall average shear stress across the cross-section at position x, where the shear field test measurement is taken, is defined as follows:

$$\tau_0(x) = \frac{V(x)}{bh} \tag{4}$$

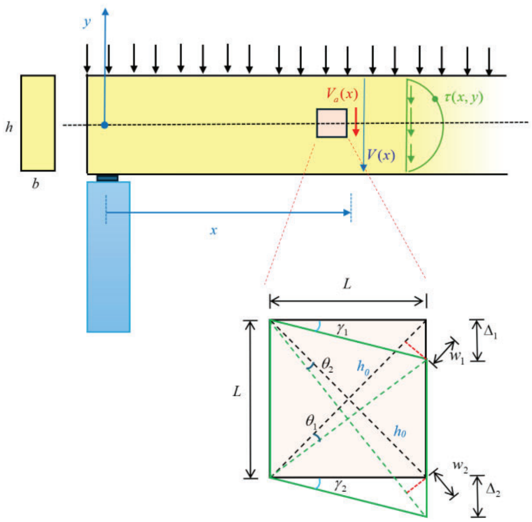

Figure 9 Shear field test setup

The shear stress distribution at position x and y is given by the following equation:

$$\tau(x, y) = \frac{V(x)}{2I}\left(\frac{h^2}{4} - y^2\right) \tag{5}$$

where I is the moment of inertia of the cross-section. Based on Eq. (5), the average shear stress along the shear field block edge (length L) can be computed as:

$$\tau_a(x) = \frac{V_a(x)}{bL} = \frac{\int_{-\frac{L}{2}}^{\frac{L}{2}} \tau(x, y) b dy}{bL} = \frac{6V(x)}{h^3 bL}\left(\frac{h^2}{4}L - \frac{L^3}{12}\right) \tag{6}$$

The local-to-global average shear stress ratio is then defined as follows:

$$\alpha = \frac{\tau_a(x)}{\tau_0(x)} = \frac{\frac{6V(x)}{h^3 bL}\left(\frac{h^2}{4}L - \frac{L^3}{12}\right)}{\frac{V(x)}{bh}} = \frac{3}{2} - \frac{L^2}{2h^2} \tag{7}$$

The local to global average shear stress ratio

According to the definition of shear strain and the geometrical relationships specified in Fig. 9, the shear strain of the shear field block can be expressed as:

$$\gamma = \frac{\gamma_1 + \gamma_2}{2} = \frac{\sqrt{2}\left(w_1 + w_2\right)}{2L} = \frac{\sqrt{2}w_i}{L} \tag{8}$$

Where $w_i = \frac{w_1 + w_2}{2}$ is used to match the terminology in EN 408.

Computing the shear modulus

The shear modulus derived from the shear field test results is given by:

$$G_{tor,s} = \frac{\tau_a(x)}{\gamma} = \frac{\alpha\tau_0(x)}{\frac{\sqrt{2}w_i}{L}} = \frac{\alpha\frac{V(x)}{bh}}{\frac{\sqrt{2}w_i}{L}} = \frac{\alpha LV(x)}{\sqrt{2}bhw_i} \tag{9}$$

Substituting L with h_0 gives:

$$G_{tor,s} = \frac{\alpha\frac{h_0}{\sqrt{2}}V(x)}{\sqrt{2}bhw_i} = \frac{\alpha h_0 V(x)}{2bhw_i} \tag{10}$$

In a four-point bending test, the shear field block is typically positioned within the shear zone, where the shear force remains constant, i.e., independent of x. The shear modulus is then computed using measurements from two different shear force levels within the elastic range, resulting in:

$$G_{tor,s} = \frac{\alpha h_0 V}{2bhw_i} = \frac{\alpha h_0 (V_2 - V_1)}{2bh(w_2 - w_1)} \tag{11}$$

This study demonstrates that the EN 408 formula for calculating the shear modulus from the shear field test contains an error that doubled the value of the shear modulus. By re-deriving the equation, the correct formulae have been provided, ensuring a correct and accurate computation of shear modulus. These findings highlight the necessity of revising EN 408 to improve the accuracy and reliability of structural analysis and design for timber beams.

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4 – CONCLUSION

This study critically evaluates the accuracy of shear modulus determination methods in EN 408:2010, focusing on the torsion test setup and shear field test formulae. Experimental validation using a dual stereo vision system has demonstrated that the end effect significantly influences rotation measurements in the torsion test, particularly for beams with high aspect ratios. The findings indicate that the current gauge placement recommendation in EN 408 is insufficient, and a revised minimum distance of 1.5h from the beam ends is necessary to obtain accurate shear modulus values. Additionally, the shear field test formula in EN 408 was found to overestimate the shear modulus by a factor of two due to a fundamental mathematical error. By re-deriving the correct formula, this study provides a more reliable approach for determining shear modulus. These findings necessitate a revision of EN 408 to enhance the accuracy of timber structure design and analysis.

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