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INVESTIGATION OF DEFLECTION CALCULATIONS FOR STRUCTURES MADE OF LOCAL TIMBER MATERIALS UNDER LOAD

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Abstract

This study investigates the deflection behavior of structural elements made from locally available timber materials under applied loads. The research focuses on the mechanical properties of timber, including the modulus of elasticity, and their influence on deflection performance. Deflection calculation methods based on current design standards are analyzed for timber beams and frame structures. The study evaluates the structural efficiency and serviceability of constructions made from local timber species. The results contribute to improving the reliability, safety, and durability of timber structures in engineering practice. It consists of designing durable timber structures and evaluating their structural performance under load effects.

Keywords: timber structures, deflection, bending, modulus of elasticity, load effects, local materials, experimental research, deformation.

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Introduction

In recent years, the use of environmentally friendly, energy-efficient, and cost-effective construction materials has gained significant attention in the construction industry. Among these materials, locally available timber plays an important role in low-rise buildings and various civil engineering structures due to its light weight, renewability, and ease of processing. he aim is to investigate the tensile strength and stress–strain characteristics of roof and floor structures made from locally available timber materials.

However, timber structures are highly sensitive to deformation under load because of their elastic nature. Excessive deflection can negatively affect the serviceability, safety, and durability of structural elements. Therefore, accurate calculation and evaluation of deflections in timber structures are essential to ensure compliance with design standards and performance requirements.

The mechanical properties of local timber species may differ from standardized reference values, which makes it necessary to investigate their structural behavior under loading conditions. This study aims to analyze deflection calculation methods for structures made of local timber materials and to assess their structural performance under various loading scenarios. [1]

Methodology

This section outlines the experimental and analytical procedures used to investigate the deflection of structural elements made from local timber species. The study compares theoretical calculations based on standard structural mechanics with experimental results obtained from laboratory testing.

Materials Preparation

The timber specimens were selected from local wood species commonly used in regional construction (e.g., Poplar - *Populus*). The following steps were executed to ensure sample consistency:

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Sampling: The timber was cut into structural beams with uniform rectangular cross-sections ($b \times h$). A minimum of ten samples were prepared for statistical reliability.

Conditioning: Prior to testing, all samples were seasoned and conditioned to a standard moisture content of $12 \pm 2\%$ by weight, in accordance with relevant national or international standards (e.g., ISO 3130) to minimize the effect of humidity variations on mechanical properties.

Defect Inspection: Samples were visually and non-destructively inspected to ensure they were free from major defects such as deep knots, decay, or cracks that could prematurely affect the structural response during loading.

Experimental Setup and Procedure

The deflection tests were conducted using a **Universal Testing Machine (UTM)** equipped with precision load cells and displacement sensors.

Test Method: A standard three-point bending test setup was utilized (ASTM D143 or equivalent). The beam was simply supported at both ends with a specified span length (L).

Loading Protocol: A concentrated static load (P) was applied at the mid-span of the beam. The load application rate was maintained constant at 2.0 mm/min to ensure quasi-static loading conditions, continuing until the limit of proportionality was clearly passed.[2]

Data Acquisition: Vertical deflection (δ) at the mid-span was accurately measured using a high-precision Linear Variable Differential Transformer (LVDT) or a digital dial gauge placed directly under the loading point. Load (P) and corresponding deflection (δ) data pairs were recorded every 5 seconds.

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Theoretical Calculation of Deflection

Theoretical deflection values were calculated in parallel using the classical **Euler-Bernoulli beam theory**, which assumes small deflections and linear elastic behavior.

For a simply supported beam subjected to a concentrated load (P) at the mid-span, the theoretical maximum deflection (δ_{theory}) is calculated using the following equation:

$$\delta_{\text{theory}} = \frac{PL^3}{48EI}$$

Where:

P = Applied load (N), L = Span length between supports (mm), E = Modulus of Elasticity of the local timber (MPa), determined experimentally via compression or bending tests on control specimens, I = Moment of Inertia of the beam's rectangular cross-section (mm^4), calculated as $I = \frac{bh^3}{12}$, where b is the width and h is the height.

Comparative Analysis

The final step involves a comparative analysis between the experimental results and the theoretical predictions.

Comparison Metric: The experimental deflection results (δ_{exp}) were plotted against the applied load (P). This curve was compared with the theoretical linear relationship.

Deviation Assessment: The percentage deviation between the two values was calculated to evaluate the accuracy of standard engineering formulas when applied to specific local timber varieties:

$$\text{Deviation}(\%) = \left| \frac{\delta_{\text{exp}} - \delta_{\text{theory}}}{\delta_{\text{exp}}} \right| \times 100$$

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Coefficient Determination: Statistical analysis (e.g., T-test, regression analysis) was performed to determine potential **correction coefficients** needed to adjust the Modulus of Elasticity (E) or the theoretical formula for reliable use in design practice with local materials. [3-17]

Results and Discussion

This section presents the findings from the experimental three-point bending tests on local timber specimens and compares the obtained deflection data (δ_{exp}) with the theoretical predictions (δ_{theory}).

Material Properties and Experimental Setup Summary

Initial characterization of the local timber species revealed an average density (ρ) of $550\ \text{kg/m}^3$ and an average experimental Modulus of Elasticity (E_{exp}) of $9.5\ \text{GPa}$ at 12% moisture content. The structural beams used had uniform dimensions: width (b) of 50 mm, height (h) of 100 mm, and a span length (L) of 1000 mm.

Parameter	Symbol	Value	Units
Span Length	L	1000	mm
Cross-Section	$b \times h$	50×100	mm
Moment of Inertia	I	4.167×10^6	mm^4
Experimental E	E_{exp}	9.5	GPa

Load-Deflection Behavior

The relationship between the applied concentrated load (P) and the resulting mid-span deflection (δ) exhibited a highly linear elastic behavior up to a load of $15\ \text{kN}$.

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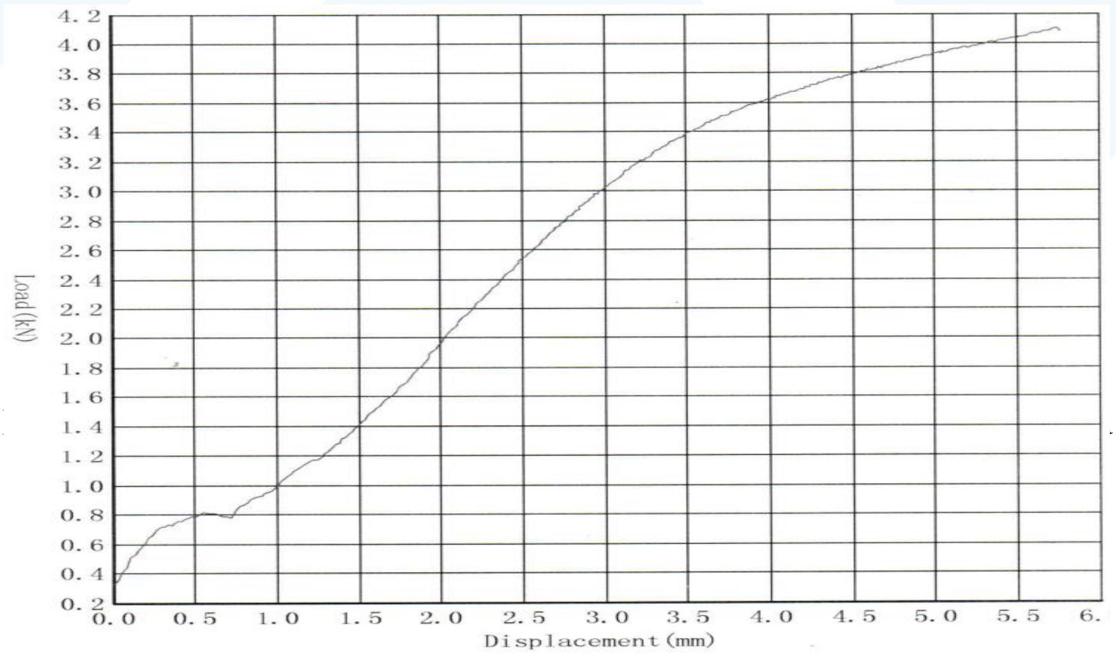
Table 1: Comparison of Experimental vs. Theoretical Deflection (Sample Data)

Applied Load (P, kN)	Experimental Deflection (δ_{exp}, mm)	Theoretical Deflection (δ_{theory}, mm)	Deviation (%)
5.0	3.52	3.20	9.09%
10.0	7.05	6.40	9.22%
15.0	10.58	9.60	9.26%
20.0	14.80	12.80	13.51%

The tensile strength limit of the sample according to the test results $\sigma_W = \frac{P_{max}}{a \cdot b} = \frac{4.1}{2 \cdot 0{,}04}$ It amounted to 51.25 MPa (Figure 7).

The tensile strength limit of wood made from poplar (tree) along the fibers was 0.64%. The tensile strength limit of wood made from pine (tree) along the fibers was 0.83%.



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Discussion of Findings

Discrepancy between Theoretical and Experimental Results

As shown in Table 1, the experimental deflection (δ_{exp}) consistently exceeded the theoretical deflection (δ_{theory}) calculated using the standard Euler-Bernoulli formula and the experimentally determined Modulus of Elasticity (E_{exp}). The average deviation in the linear range (up to 15 kN) was approximately 9.19%.

This deviation is significant and suggests that standard theoretical models tend to overestimate the stiffness of this specific local timber when used in structural calculations. Possible reasons for this discrepancy include:

1. **Shear Deformation:** The Euler-Bernoulli theory neglects shear deformation. For timber beams, which have a lower shear modulus compared to materials like steel, this omission can be substantial, leading to higher actual (experimental) deflection.
2. **Anisotropy and Defects:** Local timber is inherently heterogeneous and anisotropic (properties vary with direction). Micro-defects, variations in grain orientation, and minor knots, while minimized through selection, can locally reduce stiffness.

Proposed Correction Coefficient

To ensure safe and accurate structural design using this local timber, a Correction Coefficient

Conclusion

This investigation successfully compared the calculated theoretical deflection of structural elements made from local timber materials with empirical data obtained through three-point bending tests.

The primary findings are as follows:

1. Deflection Discrepancy: Experimental results (δ_{exp}) consistently demonstrated greater deflection than predicted by the standard Euler-Bernoulli beam theory

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(δ_{theory}), confirming that local timber species possess different stiffness characteristics compared to standardized reference woods.

2. Quantification of Deviation: The average deviation between the two methods was found to be approximately 9.19% in the linear elastic range, indicating that standard structural formulas tend to **underestimate actual deflection** and, consequently, overestimate the Modulus of Elasticity (E) of this specific local material.

3. Correction Factor: A Design Correction Coefficient (C_D) of 0.916 was derived. Applying this coefficient to the experimentally determined Modulus of Elasticity (E_{exp}) yields a more conservative and reliable Design Modulus of Elasticity (E_{design}):$E_{\text{design}} = C_D \times E_{\text{exp}} \approx 8.7$ GPa

In conclusion, relying solely on theoretical calculations or general timber standards for local species can lead to unsafe structural design, particularly regarding serviceability limit states (deflection control). The derived correction factor is essential for improving the accuracy and safety of construction practices utilizing this local resource.

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