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STATISTICAL LENGTH EFFECT ON THE LONGITUDINAL COMPRESSION STRENGTH OF AUSTRALIAN RADIATA PINE SOLID SAWN TIMBER

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ABSTRACT: Sawn timber is a heterogeneous material where defects such as knots, local grain deviations, and variations in density and moisture content significantly influence its strength, leading to the statistical length effect. While the impact of length on the longitudinal tensile and bending strength of sawn timber has been extensively studied, research on the longitudinal compression strength remains scarce. This gap restricts the use of sawn timber in compression applications and affects its reliability under compressive loads. To address this, the present study investigates the statistical length effect on the longitudinal compression strength of Australian Radiata Pine sawn timber through experimental and statistical methods. Monte Carlo simulation was employed to model the statistical length effect for 8,816 timber specimens with a cross-section of 35 × 90 mm, graded as MGP10, MGP12, and MGP15. The results revealed a pronounced length effect on compression strength for both the 50th and 5th percentiles, with no significant difference observed between the percentiles. Additionally, the length effect exhibited a slight grade dependence.

KEYWORDS: Sawn Timber, Length Effect, Longitudinal Compression Strength, Monte Carlo Simulation, Radiata Pine.

1 – INTRODUCTION

Sawn timber is extensively used in construction due to its renewable nature, aesthetic appeal, and high strength-to-mass ratio [1]. In Australia, Radiata Pine accounts for the majority of structural sawn timber production, with an annual output exceeding two million cubic meters, while other softwood and hardwood species contribute a smaller portion. During production, sawn timber is graded to assign each piece a specific grade, ensuring it meets the predetermined mechanical properties required for structural design [2]. Australian Radiata Pine is primarily graded into three categories: MGP10, MGP12, and MGP15, in accordance with AS1720.1-2010 [3].

The structural performance of sawn timber is heavily influenced by its inherent heterogeneity. Natural irregularities such as knots, deviations in grain (both global and local), and variations in density and moisture content along the timber's length introduce localized weaknesses. These irregularities significantly impact the strength and reliability of timber members. As the length of sawn timber increases, the likelihood of encountering such irregularities rises, leading to a reduction in the overall strength [4-9].

The weakest link theory has been extensively used to describe the length effect in relation to the mechanical properties of timber. The weakest link theory is effectively illustrated by the classic example of determining the load capacity of a chain composed of n links. The probability that a single link fails under a given

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load x is described by the distribution function $F(x) = P(X \leq x)$. Since the chain operates as a series system, its overall failure is governed by the failure of the weakest link. As the number of links increases, the likelihood of encountering a weaker link also increases. Consequently, the load capacity of the chain is influenced by the number of links. This fundamental concept forms the foundation of the size effect phenomenon observed in the failure of solids [10].

Numerous studies have examined the effect of length on the tensile strength [4-7, 9-19], and bending strength [4, 5, 13, 17, 20-22] of sawn timber, these studies consistently demonstrate that the length effect varies across different timber species and grades. However, research on the length effect in compression strength is scarce. To the authors' knowledge, only one study has addressed this, focusing on the longitudinal compression strength of Canadian softwood species, including Spruce, Pine, and Fir [4]. While this study revealed an overall length effect, the influence of grades was not considered. Furthermore, the compression length effect for Australian Radiata Pine remains unexplored. On the other hand, AS/NZS 4063.1:2010 [23] require random testing to longitudinal compression strength. Consequently, timber boards of the same grade but varying lengths exhibit different characteristic values. This gap in the literature presents a challenge for the use of sawn timber in compression applications, where reliable performance under compressive loads is essential, as well as for the proper characterization of sawn timber. Understanding the length effect in compression is essential for designing safe and efficient timber structures, particularly in applications such as columns, posts, and compression members in trusses. Therefore, this study addresses the current gap in the literature by investigating the length effect on the compression strength of Australian Radiata Pine sawn timber. Combining the weakest link theory with Monte Carlo simulations, the analysis is conducted across three grades: MGP10, MGP12, and MGP15.

2 – MATERIALS AND METHODS

2.1 SAMPLES

Radiata Pine sawn timber boards with cross-section of 35 × 90 mm and graded as MGP10, MGP12, and MGP15, were utilized to produce 8,816 specimens for testing. Each timber board with length of 2,720 mm was segmented into eight serial specimens, each 340 mm in length, following the guidelines of AS/NZS 4063.1:2010 [23]. The details and distribution of boards and specimens for each grade are presented in Table 1.

Table 1: Distribution of boards and specimens by grade

Grade	MGP10	MGP12	MGP15
Number of boards	634	328	140
Number of specimens	5072	2624	1120

2.2 TESTING

Each timber specimen was aligned longitudinally and tested under a compression load using a control compression tester (Model: Pilot Smart-Line) as shown in Figure 1. The compression strength was recorded, as depicted in Figure 2, and all data were stored in a database for future analysis.

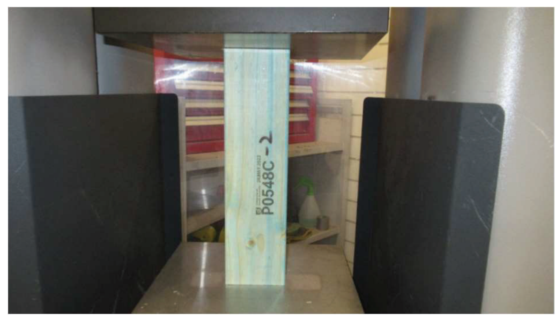

Figure 1. Test setup for measuring longitudinal compression strength.

2.3 ANALYSIS

Based on the weakest link theory, assuming the global strength of timber board with any length associated with the failure of weakest specimen, this assumption hold true for tension failure as well as for compression failure [24]. Monte Carlo simulation was used to estimate the compression strength for various lengths and grades. To achieve this, a Python script was developed to generate random selections, consecutive specimens were randomly selected from each timber board in the database to construct the strength distribution for each length and grade. A two-parameter lognormal distribution, identified as the most suitable for modeling longitudinal compression strength [25], was fitted using method 1 outlined in AS/NZS 4063.2:2010 [26], and the 50th and 5th percentiles were calculated. This process was repeated 5,000 times allowing the construction of 95% confidence interval (CI), Figure 3 shows example of the procedure to estimate 5th and 50th percentiles CI for MGP10 with length of 1360 mm equivalent to four specimens. This method allows only to quantify the statistical length effect due to natural variation of irregularities along the length of sawn timber eliminating other variations as the same material series used to quantify length effect each time.

Finally, Parameter ξ was fitted using (1) to account for the length for both 5th and 50th percentiles [10].

$$f_{c,i} = f_{c,ref} \cdot \left(\frac{l_{ref}}{l_i}\right)^{\xi} \quad (1)$$

Where $f_{c,i}$ is the compression strength for a length l_i and $f_{c,ref}$ is the strength related to the reference length l_{ref}.

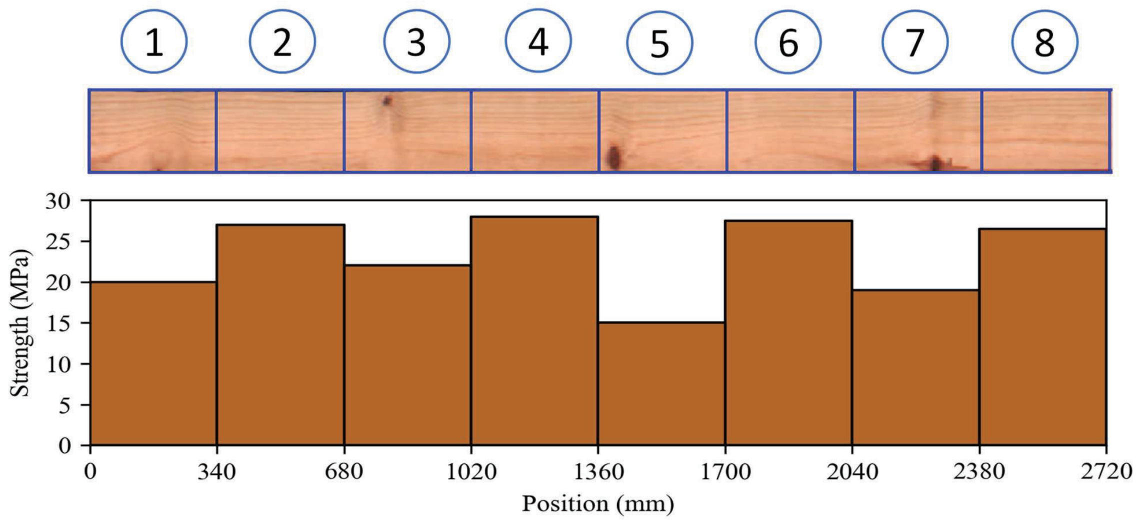

Figure 2. Longitudinal Compression strength variation for timber board.

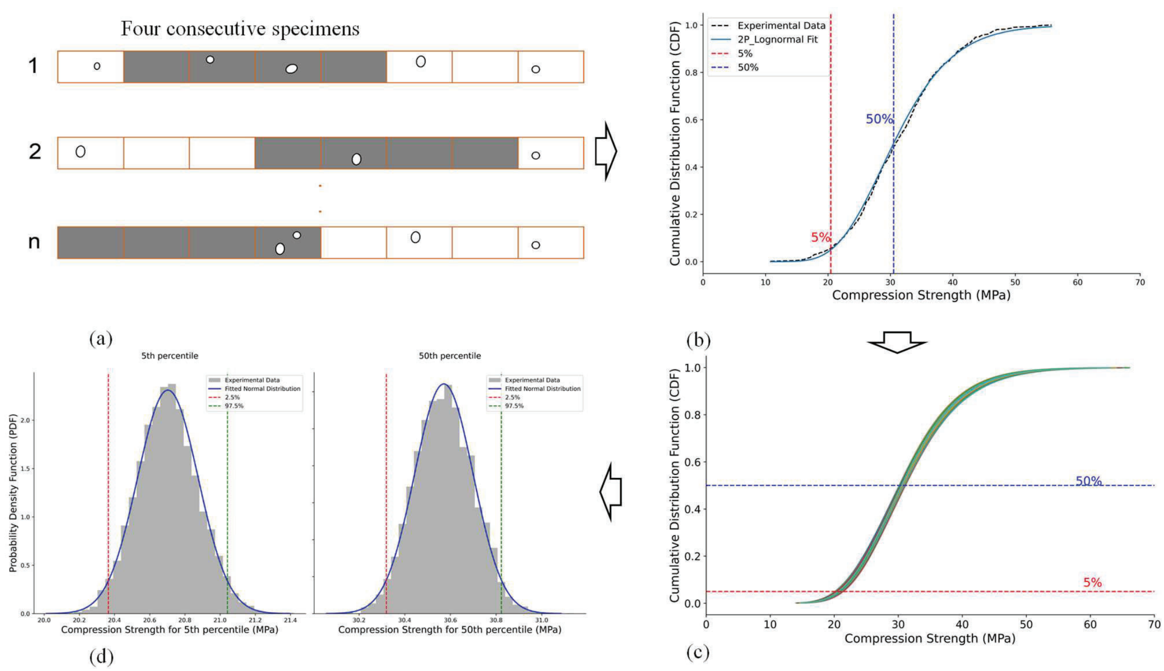

Figure 3. Diagram illustrating the procedural steps: (a) selection of random consecutive specimens, (b) fitting a two-parameter lognormal distribution, (c) repeating the process 5,000 times, and (d) constructing 95% confidence interval (CI) for 5th and 50th percentiles.

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3 – RESULTS AND DISCUSSION

This section presents the results of the Monte Carlo simulations and statistical analyses conducted to evaluate the longitudinal compression strength of MGP10, MGP12, and MGP15. The analysis focuses on the behavior of the 5th and 50th percentiles across varying lengths, the estimation of the ξ parameter to model strength reduction trends, and a comparison of the performance of Australian Radiata Pine with other softwood timbers.

Figure 4 and Figure 5 Present the longitudinal compression strength of the 5th and 50th percentiles respectively, with 95% CI for one to four specimens, based on the Monte Carlo simulation, for MGP10, MGP12, and MGP15, results revealed a clear trend of strength reduction as the length increases. However, to predict the parameter ξ, the compression strength for all grades were normalized, then the mean values of 5,000 Monte Carlo simulations for each length and grade was fitted to (1). The proposed ξ parameter values were 0.122, 0.108, and 0.109 for MGP10, MGP12, and MGP15, respectively, at the 5th percentile as shown in Figure 6. At the 50th percentile, the ξ values were 0.127, 0.115, and 0.111 for MGP10, MGP12, and MGP15, respectively as shown in Figure 7, The coefficient of determination (R^2) for all fitted data was 0.99, indicating an excellent fit. The results indicate no significant difference in strength reduction between the two percentile levels. For example, the difference in strength when doubling the length between the 5th and 50th percentiles for MGP10 is only 0.4%. On the other hand, there was slight grade dependence. For instance, when doubling the length at the 5th percentile, the difference between MGP10 and MGP15 was only 0.8%, while it was 1.2% for the 50th percentile. To complete the comparison, it was found that the compression length effect of Australian Radiata Pine timber is slightly higher than that of Canadian softwood timber [4], in the case of MGP10, doubling the length resulted in a 2% greater reduction in strength compared to Canadian softwood for both 5th and 50th percentiles. Finally, the proposed shape parameters for a two-parameter lognormal distribution were 0.24 for MGP10, and 0.2 for MGP12 and MGP15. The proposed shape parameters can be used to construct the cumulative distribution function (CDF) for A two-parameter lognormal distribution combined with either 5th or 50th percentiles in AS 1720.1-2010 [3]. This CDF can be applied in stochastic structural design purposes.

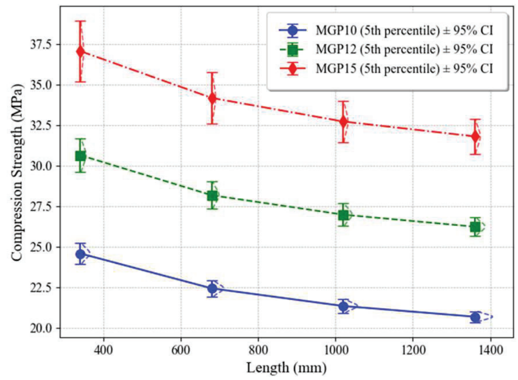

Figure 4. 5th percentile Compression Strength for one to four specimens with 95% CI.

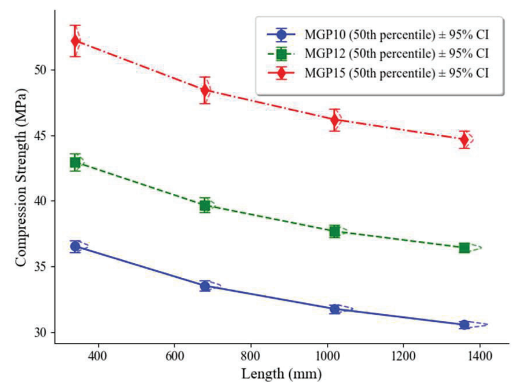

Figure 5. 50th percentile Compression Strength for one to four specimens with 95% CI.

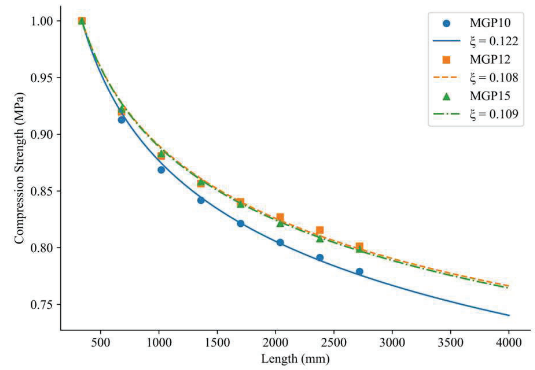

Figure 6. Fitted values of Parameter ξ for the 5th Percentile.

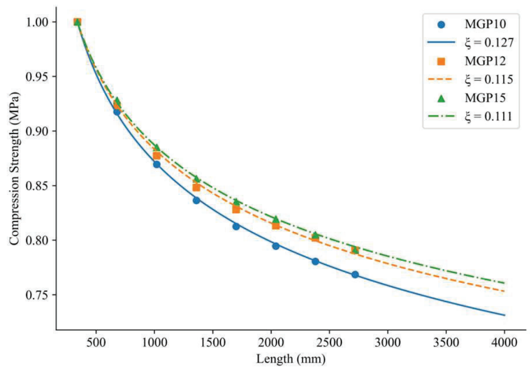

Figure 7. Fitted values of Parameter ξ for the 50th Percentile.

4 – CONCLUSION

This study examined the statistical length effect on the longitudinal compression strength of Australian Radiata Pine sawn timber for grades MGP10, MGP12, and MGP15. Monte Carlo simulations, combined with the weakest link theory, were used to analyze 8,816 specimens, confirming a clear reduction in compression strength with increasing length. The ξ parameter, which quantifies the rate of strength reduction, exhibited consistent values across the 5th and 50th percentiles, with only minor variations observed among timber grades.

The ξ values at the 5th percentile were 0.122 for MGP10, 0.108 for MGP12, and 0.109 for MGP15, while at the 50th percentile, the ξ values were 0.127 for MGP10, 0.115 for MGP12, and 0.111 for MGP15. The findings indicate that strength reduction trends are similar between the two percentile levels, with minimal differences in the rate of reduction. Additionally, a slight grade dependence was observed, where higher-grade timbers exhibited marginally lower reductions in strength with increasing length. A comparative analysis with Canadian softwood timber revealed that Australian Radiata Pine experiences a slightly greater length-dependent reduction in compression strength. In the case of MGP10, doubling the length resulted in a 2% greater strength reduction compared to Canadian softwood.

Furthermore, the proposed shape parameters for the two-parameter lognormal distribution is 0.24 for MGP10, 0.2 for MGP12, and 0.2 for MGP15, provide a reliable basis for modelling CDF. This study enhances the understanding of the compressive behavior of sawn timber, contributing to more reliable structural design methodologies.

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