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# PULL-OUT STRENGTH OF GLUED-IN STEEL ROD PERPENDICULAR TO THE GRAIN IN SPRUCE-PINE GLULAM TIMBER

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**ABSTRACT:** This study presents pull-out tests of glued-in steel rod installed perpendicularly to the grain in Spruce-Pine glulam timber. The tested specimens indicate that the embedded length and the steel grade influence the anchorage behaviour and capacity. Results showed that a well design anchor can exhibit a ductile failure mode. Experimental results are also compared to theoretical models and to pull-out strength of glued-in steel rod parallel to the grain to investigate the relation between these pull-out strength capacities.

**KEY WORDS:** Glued-in rods, pull-out strength, glulam, experimental testing.

## 1 INTRODUCTION

Connections in glulam timber structures must transfer shear and moment between structural members and present a ductile failure. Glued-in rods used as connections transfer shear and moments by pulling-out the rods anchored in timber members. This study investigates and compares the influence of the anchorage length and the steel grade on the behaviour and failure mode of glued-in rods installed perpendicularly to the grain of Spruce-Pine glulam timber. New pull-out test setups will be discussed as experimental tests are carried out. The experimental results will be compared with theoretical models and with pull-out strength of glued-in steel rod parallel to the grain.

## 2 EXPERIMENTAL INVESTIGATION

### 2.1 SPECIMENS

42 specimens having a surface section of 160 x 130 mm and respecting the required edge distance proposed by Simonin [1] to avoid wood splitting were fabricated for pull-out testing. The steel rod is installed in the middle of that surface. The specimens were divided in 6 series of 7 specimens to study different embedded length and steel grade of the anchored rod. The depth of the samples and number of lamellas were chosen according to the selected embedded length for each series presented in Table 1. The diameter of the steel rod ($d_r$ in Figure 1) is 15.9 mm (5/8 in) and the diameter of the hole ($d_h$ in Figure 1) is 19.0 mm (3/4 in). This generates a glued joint thickness (e in Figure 1) of 1.6 mm.

***Table 1:*** *Dimensions of the tested specimen series*

| Series | Timber depth | Number of lamellas | Embedded length (mm) | Steel grade |
|---|---|---|---|---|
| 150A | 243 | 7 | 150 | A307 A |
| 150B | 243 | 7 | 150 | A193 B7 |
| 220A | 243 | 7 | 220 | A307 A |
| 220B | 243 | 7 | 220 | A193 B7 |
| 300A | 347 | 10 | 300 | A307 A |
| 300B | 347 | 10 | 300 | A193 B7 |

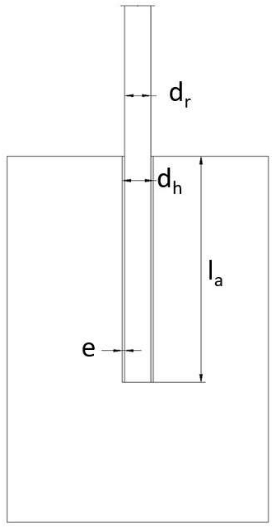

***Figure 1:*** *Specimens with indicated ($l_a$) embedded length, ($d_r$) rod diameter, ($d_h$) hole diameter and (e) glued joint thickness.*

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## 2.2 MATERIALS

The wood used for the tested specimens is Spruce-Pine glulam timber grade 20f-EX. This grade is commonly used in Eastern Canada for members resisting to both flexure and axial compression.

The mechanical characteristic properties of this material, according to CSA 086-19 [2] are: bending strength, $f_b$, of 25.6 MPa, shear strength, $f_v$, of 1.75 MPa, compressive strength, $f_c$, of 25.2 MPa, compressive strength perpendicular to the grain, $f_{cp}$, of 5.8 MPa, tensile strength perpendicular to the grain, $f_{tp}$, of 0.51 MPa and Young modulus, E, of 10 300 MPa. The density of the material is taken as 495 kg/m$^3$.

ASTM A193-B7 [3] and ASTM A307-A [4] steel grades were used for pull-out testing. The specified tensile strength, $f_u$, of ASTM A307 steel was 413.7 MPa. The specified yield strength, $f_y$, and tensile strength, $f_u$, of ASTM A193-B7 steel were 723.9 MPa and 861.8 MPa, respectively. The aim of using two different steel grades is to experience different failure modes for a given embedded length. Experimental tests make it possible to determine the required embedded length to avoid wood brittle failure.

The adhesive used in this study is a bi-component polyurethane [5] and its mechanical properties are shown in Table 3. This adhesive was designed to avoid debonding failure.

***Table 2:*** *Adhesive properties (MPa) [5]*

| $f_t$ | $f_c$ | $f_v$ | E |
|---|---|---|---|
| 25 – 30 | 79.9 | 2.4 – 3.8 | 1 560 |

## 2.3 PULL-OUT TESTS SETUP

Most of pull-out tests in the literature have been conducted on glued-in rods installed parallel to the grain with a « pull-pull » test setup as it best represents stresses in a beam-column connection. To determine pull-out strength perpendicular to the grain, « pull-pull » test would require glulam timber sections with too many lamellas. Different alternative setups were investigated. Tlustochowicz [6] proposed using a « pull-pile foundation » test setup. When the rod is pulled-out from the wood specimen, the reaction is transfer along the pre-installed screws to the external resisting frame. This setup reduces compressive stress confining the anchorage area compared to only support the top surface of the timber specimen. This experimental setup is shown in Figure 2 and was initially selected for this research.

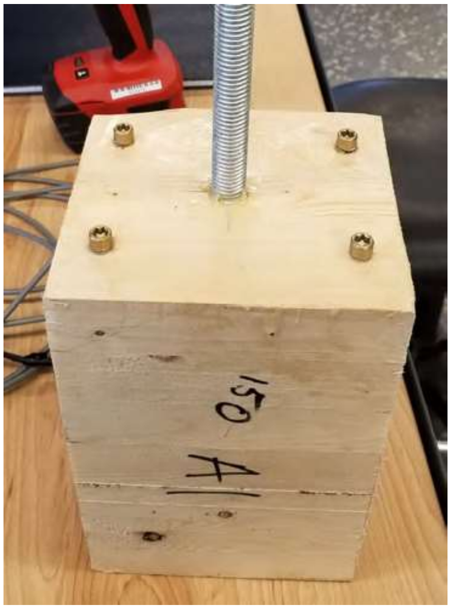

***Figure 2:*** *« Pull-Pile foundation » specimen*

As illustrated in Figure 3, the first pulled-out tests exhibited splitting of the wood through the screws instead of pull-out failure. Due to the influence of the screws on the failure mode, this testing setup was not further considered.

***Figure 3:*** *Failure by splitting through the screws.*

To avoid splitting failures through the screws, a « pull-push » setup was used. A teflon layer (see Figure 4) was installed between the specimens and the reaction steel plate to minimize friction between these two interfaces and confinement of the anchorage.

***Figure 4:*** *Teflon layer for « pull-push » tests.*

Figures 5 and 6 present the complete setup used for pull-out tests. As illustrated, the steel rod is pulled-out upward while a reaction steel plate was installed above the specimens to carry vertical reaction downward.

***Figure 5:*** *Experimental setup*

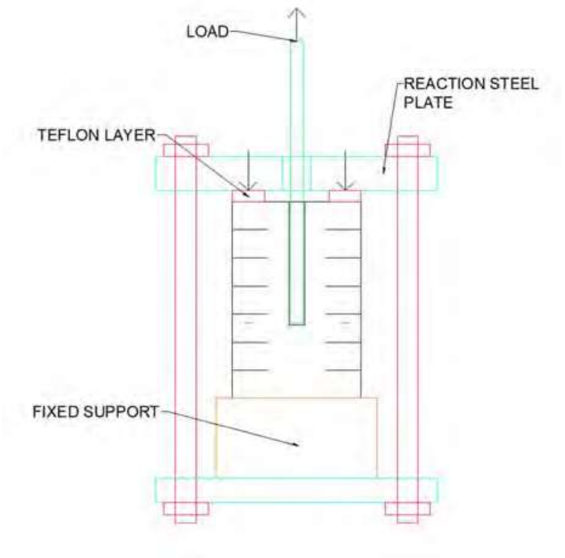

***Figure 6:*** *Setup details*

The static monotonic tension loading was applied at a rate of 2.54 mm/min, in accordance with ASTM D1761 [7].

## 2.4 EXPERIMENTAL RESULTS

Figures 7 to 12 present load versus displacement relationship measured for each specimen and each series.

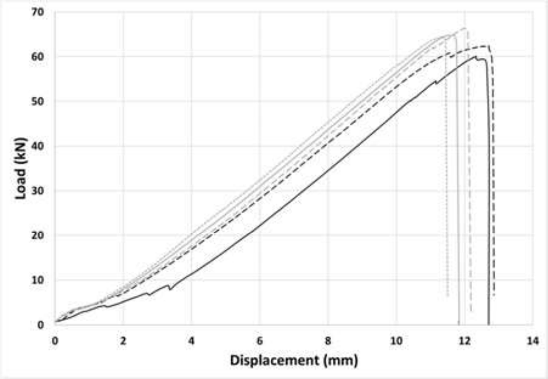

***Figure 7:*** *Load-displacement curve for series 150A*

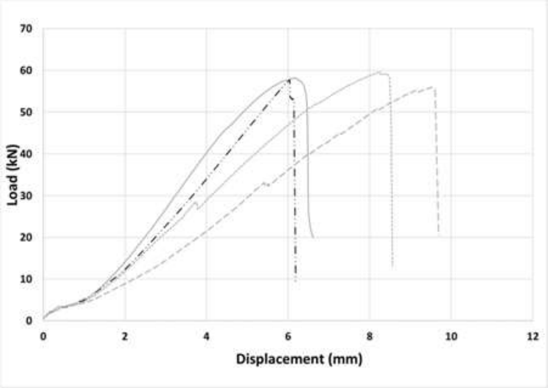

***Figure 8:*** *Load-displacement curve for series 150B*

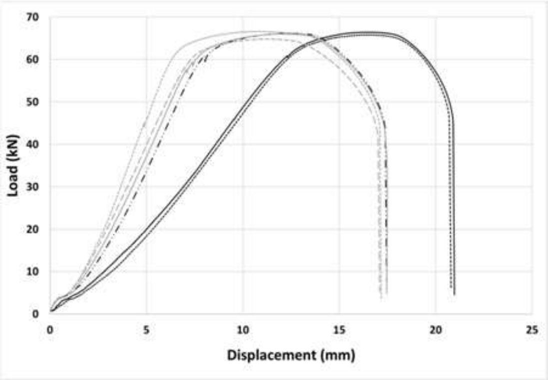

***Figure 9:*** *Load-displacement curve for series 220A*

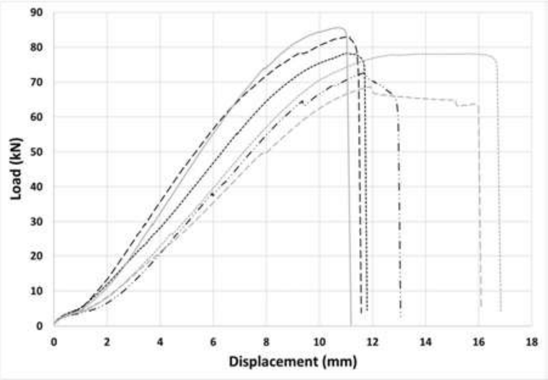

***Figure 10:*** *Load-displacement curve for series 220B*

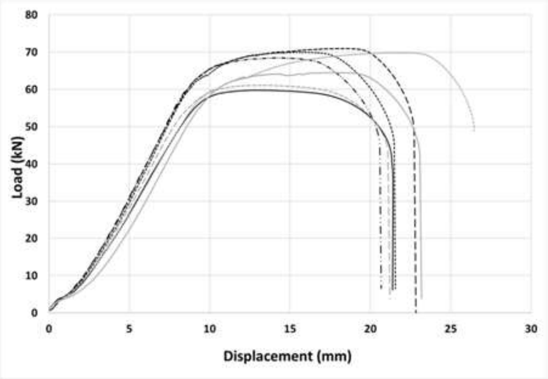

***Figure 11:*** *Load-displacement curve for series 300A*

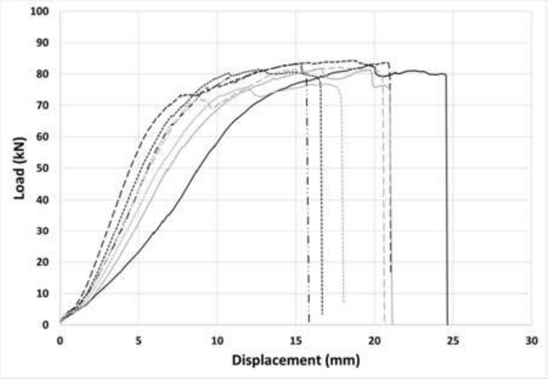

***Figure 12:*** *Load-displacement curve for series 300B*

The difference of stiffness between some specimens of the same series is mainly due to some changes made on the reaction steel plate in order to strengthen it.

The average failure load and the range of all considered values for each series are presented in Figure 13. Two types of failure modes presented in Figures 14 and 15 were observed. As presented in Figure 14, a brittle pull-out failure was observed for specimens of the series 150A, 150B, 220B and 300B. These specimens exhibited wood shearing around the rod and steel did not reach yielding. For the specimens of the series 220A and 300A, steel rod yielded and ruptured before pull-out (see Figure 15).

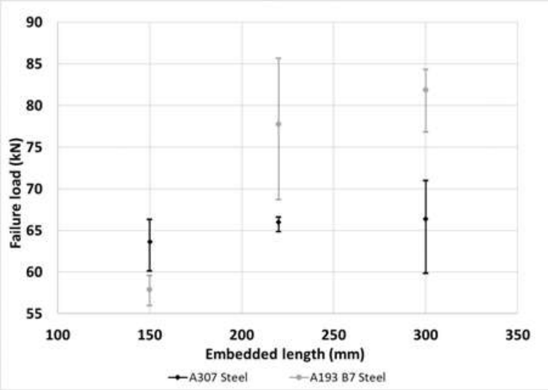

***Figure 13:*** *Range and average failure loads for each series*

Finally, the table below indicates the average maximum load and the failure types.

***Table 3:*** *Tests results at failure*

| Series | Average failure load (kN) | Failure type | Behaviour |
|---|---|---|---|
| 150A | 63.6 | A | Brittle |
| 150B | 57.9 | A | Brittle |
| 220A | 66.0 | B | Ductile |
| 220B | 77.7 | A | Brittle |
| 300A | 66.4 | B | Ductile |
| 300B | 81.8 | A | Brittle |

With failure type A corresponding to wood shearing around the rod and type B is yielding of the steel rod (see figures 14 and 15).

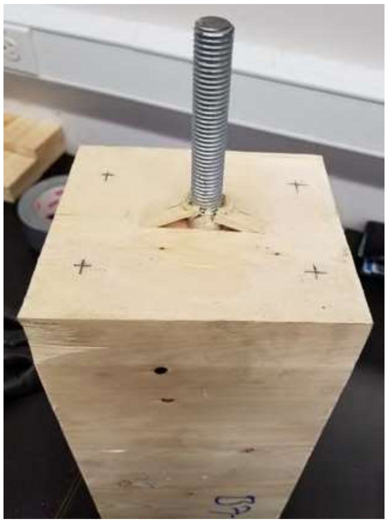

***Figure 14:*** *Wood shearing around the rod (failure type A)*

***Figure 15:*** *Yielding of the steel rod (failure type B)*

## 3 THEORETICAL MODELS

Theoretical models to predict the pull-out capacity of glued-in rods have been proposed in the literature.

For all the models, the average shear strength of Spruce-Pine glulam timber was taken as approximately 5.5 MPa in accordance with ASTM D2555 and ASTM D245 standards to establish clear wood strength values [8, 9]

### 3.1 RIBERHOLT MODEL (1988)

Initially, Riberholt [10] proposed Equations (1) and (2) to determine the anchor capacity (N). This model considers the wood density (g/cm³), ρ, and the average withdrawal parameters, $f_{ws}$ and $f_{wl}$ (MPa). It can be used for rods installed both parallel and perpendicular to the grain.

For $l_a \geq 200$ mm, use Equation (1). For $l_a < 200$ mm, consider Equation (2):

$$R_{ax} = f_{ws} \cdot \rho \cdot d_h \cdot \sqrt{l_a} \qquad (1)$$

$$R_{ax} = f_{wl} \cdot \rho \cdot d_h \cdot l_a \qquad (2)$$

### 3.2 WIDMANN MODEL (2007)

Widmann [11] proposed Equation (3) based on experimental test carried out on a 435 kg/m$^3$ density wood to determine pull-out capacity (kN).

$$R_{ax} = k_1 \cdot A_g^{k_2} \qquad (3)$$

In this equation, the coefficients $k_1 = 0.044$ and $k_2 = 0.8$. The effective anchor zone (mm²), $A_g$, is function of the hole diameter and the anchorage length.

## 3.3 RUSSIAN STANDARD APPROACH (2017)

The Russian standard 64.13330.2017 [12] proposed Equation (4) for glued-in rods installed at an angle to the grain.

$$R_{ax} = f_w \cdot \pi \cdot d_h \cdot l_p \cdot k_c \cdot k_\sigma \cdot m_d \tag{4}$$

Where $f_w$ is the design withdrawal resistance of the timber (MPa), $l_p$ design length (mm), $k_c$ is a coefficient considering the shear stress distribution along the anchorage zone, $k_\sigma$ is a coefficient of normal stresses along the grain, and $m_d$ is a coefficient depending on the rod diameter.

## 3.4 STEPINAC SUMMARIZED MODEL (2018)

Stepinac [13] review existing models developed during the last decades and proposed the following equation to predict the pull-out capacity. Like most of the existing models, this equation considers the wood adhesive shear interface and the average shear strength of the timber to determine the average pull-out capacity.

$$R_{ax} = \pi \cdot d_h \cdot l_a \cdot f_v \tag{5}$$

With $f_v$ = average shear strength of the timber (MPa).

## 3.5 COMPARISON WITH EXPERIMENTAL RESULTS

Tables 4 to 7 indicate the percentage of deviation between the experimental results and the previously discussed theoretical models.

***Table 4:*** *Comparison with Riberholt approach*

| Series | Failure load (kN) | | % deviation |
|---|---|---|---|
| | Exp. | Theo. | (Theo.-Exp.)/Theo |
| 150B | 57.9 | 65.1 | 11.1% |
| 220B | 77.7 | 90.9 | 14.5% |
| 300B | 81.8 | 106.2 | 23.0% |

***Table 5:*** *Comparison with Widmann approach*

| Series | Failure load (kN) | | % deviation |
|---|---|---|---|
| | Exp. | Theo. | (Theo.-Exp.)/Theo |
| 150B | 57.9 | 65.4 | 11.5% |
| 220B | 77.7 | 88.9 | 12.6% |
| 300B | 81.8 | 113.9 | 28.2% |

***Table 6:*** *Comparision with the Russsian Standard Approach*

| Series | Failure load (kN) | | % deviation |
|---|---|---|---|
| | Exp. | Theo. | (Theo.-Exp.)/Theo |
| 150B | 57.9 | 49.9 | -16.0% |
| 220B | 77.7 | 62.3 | -24.7% |
| 300B | 81.8 | 76.5 | -6.9% |

***Table 7:*** *Comparison with Stepinac approach*

| Series | Failure load (kN) | | % deviation |
|---|---|---|---|
| | Exp. | Theo. | (Theo.-Exp.)/Theo |
| 150B | 57.9 | 49.2 | -17.7% |
| 220B | 77.7 | 72.2 | -7.6% |
| 300B | 81.8 | 98.5 | 23.0% |

It can be observed that the Riberholt and Widmann models overestimate the average pull-out capacity for all series. However, their models were developed for other type of wood and the coefficients used in these models might be inadequate for Spruce-Pine glulam timber. The Stepinac model underestimate the average pull-out capacity for the series 150B and overestimates the average capacity for the series 300B.

The Russian Standard approach underestimates the capacity for all series. Figure 16 illustrates these comparisons.

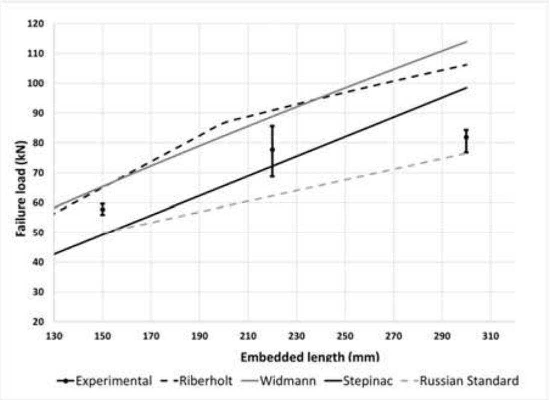

***Figure 16:*** *Comparison of experimental and theoretical values*

# 4 COMPARISON WITH PULL-OUT STRENGTH PARALLEL TO THE GRAIN

The effect of the orientation of the rod relatively to the orientation of the grain is still not clearly understood in the literature.

Most studies consider that the pull-out strength of rods installed parallel to the grain is the strongest. For example, Gustaffson and Serrano [14] consider that the pull-out strength of rods installed parallel increased by 10% compared to rods installed perpendicularly to the grain. On the other hand, Widmann [11] supposed that the pull-out resistance of rods installed perpendicularly to the grain should be the strongest.

As it is unclear and different experimentations have not given similar conclusions, parallel to the grain pull-out strength experimental results using identical properties material are compared to this study results in the next table. Indeed, Dussart and Ouellet studies [15, 16] were performed with spruce-pine glulam timber and ASTM A193 B7 steel rods installed parallel to the grain.

However, these results were only available for a 300 mm embedded length. Thereby, they will be compared to series 300B. Equation (parallel-perpendicular)/parallel is considered to determine the percentage of deviation.

***Table 8:*** *Comparison between perpendicular and parallel to the grain capacities*

| | Perpendicular to the grain | Parallel to the grain | % deviation |
|---|---|---|---|
| Average pull-out strength (kN) | 81.8 | 109.4 | 25.2 |

Thus, using Spruce-Pine glulam timber 20f-EX and ASTM A193 B7 steel rods with 15.9 mm diameter, the pull-out resistance is 25.2% higher when the rod is glued-in parallel to the grain, supporting Gustaffson and Serrano assumption.

However, it must be precise that the test configurations were not the same. Pull-Pull configuration was used for testing parallel to the grain while Pull-Push tests were performed perpendicular to the grain.

## 5 CONCLUSIONS

The main objective of this was to investigate the influence of the anchorage length and the steel grade on the behaviour and failure mode of glued-in rods installed perpendicularly to the grain of Spruce-Pine glulam timber. The main findings are presented here after:

- A new pull-push loading for glued-in steel rod in glulam timber setup was used in this experimental investigation

- The test results showed that the rod embedded length influences the pull-out capacity and the failure mode of glued-in steel rod anchorages. Based on experimental results, a minimum of 220 mm embedded length is required to observe a ductile failure for A307 A steel rods used in this study, while all the tested specimens with A193 B7 steel rods exhibited a brittle failure.

- Experimental pull-out test results were compared with four theoretical models. The model proposed by the Russion code gave the best predictions of the experimental pull-out capacity compared to the other models.

- The effect of the orientation of a rod on Pull-out srength was briefly investigate. For the same materials and geometry properties, a glued-in rod parallel to the grain allows a 25% stronger pull-out capacity.

This investigation will lead to experimental testing of true-scale moment resisting glued-in rods connections as recommendations will be provided to design glued-in steel rod ductile beam to column connections.

## ACKNOWLEDGEMENT

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