WOOD RESEARCH
65 (4): 2020
645-652

doi.org/10.37763/wr.1336-4561/65.4.645652

PRESTRESS LOSSES IN SPRUCE TIMBER

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(Received October 2019)

ABSTRACT

Prestressing force and its change is one of the key factors that affect wooden constructions, especially those using methods of transverse prestressing. To achieve a description of a prestress force (P) in transversally prestressed wooden constructions a simulated experiment was done. Prestressing force, external temperature, and moisture were measured during 669 days. The main goal of this article was to model the primary losses of the prestress force at the spruce element of the 138 x 138 mm cross-section with the sensor installed. For this purpose, all measurements were statistically analyzed and the period of primary loss was found. During this period the prestress force was decreasing with time mainly and the influence of temperature and moisture could be omitted. Based on this analysis a mathematical model of losses of the prestress force was found as P = 8.538-0.014.day.

KEYWORDS: Wood, diagnostics, bridges, prestressing, spruce, timber.

INTRODUCTION

Using timber as a building material has increased in past decades. Thanks to modern technologies this material is more and more frequently used even for bridge constructions with higher demands on mechanical durability and lifetime. Glued laminated timber, especially those reinforced (Issa and Kmeid 2005), ranks among these technologies enabling to span even large distances. Also, timber-concrete composites have high potential. Coupling of wooden elements and concrete roads ensures the resistance of roadway section to abrasion and it protects the timber supporting structure (Duwadi and Ritter 1997, Fragiacomo et al. 2018, Honda 2017, Liu et al. 2012, Lyu et al. 2017, Veie et al. 2017, Yeoh et al. 2011, Zhou et al. 2013). Analysis of the long-term behavior of timber-concrete composites was investigated by Kanócz and Bajzecerová (2014). It was found that some of the investigated parameters have significant and some of them have a less significant influence on the timber-concrete composite elements resistance under long term loading. Significant influence has the concrete shrinkage and mechano-sorptive creep of wood which is depending on environmental humidity. Less significant influence has the strength classes of applied concrete and wood. The transverse prestressing method was first used in Canada for the reconstruction of existing structures. Structures using this technology can be also found in Scandinavia and the USA. The first Czech bridge, built with the help of the transverse prestressing method in the timber-concrete bridge, was erected in the municipality of Bohunice, Prachatice district, in 2019 (Fig. 1).

Fig. 1: First transversely prestressed bridge in the Czech Republic.

This technology brings an increase in transverse stiffness, which can reduce material consumption as well. Required prestressing, due to which the frictional force among individual profiles of timber laminated bridge board increases, is carried out using prestressing elements. The prestress rate is usually checked with a torque spanner or any other device a so-called monitor torsional moment. Prestress force and its change are key factors that affect wooden transverse prestressing constructions.

Ritter (2005) based on his research carried out in Ontario (Canada) defines the necessity of secondary prestress due to the influence of wood mass creep. Monitoring of transverse prestressing over time / with time and from the point of mechanical properties is also described by Fragiacomo and Davies (2011a,b), Quenneville and Van Dalen 1994, and Granello et al. (2017). Some authors defined an integral expression of the change of prestressing force with time (Ritter 2005a,b, Dahl et al. 2006, Ekholm et al. 2012, Vašková et al. 2016, Vavrušová et al. 2016, Fojtík et al. 2017, Tazarv et al. 2019).

The rate of primary prestressing mostly corresponds to the timber resistance perpendicular to the fibre. The rate of primary prestressing is not permanent, so follow-up tightening to stabilize these forces is recommended. Experiments to define the development of change of prestressing force in wood mass was conducted by Sarisley and Accorsi (1990), Widmann et al. (2010), Fortino et al. (2013), Björngrim et al. (2016), and Fortino et al. (2019). The experiments monitored the changes of prestressing force with time, change of temperature, and humidity.

MATERIAL AND METHODS

The dried compact spruce wood profile sized 138 mm x 138 mm in the cross-section and 273 mm long without significant cracks or any damage, strength class C24 was used for the experiment. This element was prestressed transversely using a steel bolt, strength class 8.8. The quality of monitored material from the point of compression strength perpendicular to the fibre can be proved based on the maximum prestress force that the element distributed before the imprint happened. When the prestressing force was applied with a torque spanner, the material parameters had the following values: temperature of the sample 20°C and moisture content 8%. Prestress force 8 kN was applied (Fojtík 2019, Fojtík and Dědková 2016). The experimental sample was built-up and prestressed in laboratory VSB TU Ostrava Faculty of Civil Engineering and then located in the exterior of VSB TU Ostrava, Faculty of Civil Engineering.

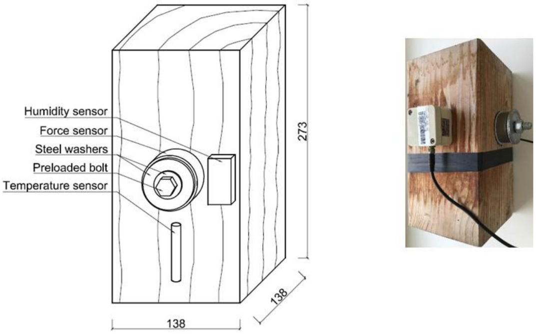

Fig. 2: Scheme and view on the experimental investigation of transverse prestressed timber.

ALMEMO K-13B sensor was used to monitor transverse prestress, ALMEMO FHA 696 MFS1 sensor for monitoring of timber surface moisture content, and ALMEMO FPA686 sensor to monitor temperature (Fig. 2). All data were recorded using of ALMEMO 710 data logger. Obtained data were cleansed using a descriptive statistic method. A time interval, during which primary prestress decreased, was estimated with the help of correlation coefficient analysis. A linear regression describes the dependence of transverse prestresses on creep.

The experiment was carried out during the period from November 15, 2016, to September 14, 2018, i.e. 669 days and during which values of prestress P (kN), moisture M (%), and external temperature T (°C) were measured and recorded in minute intervals. Altogether 959663 data records were obtained, these were analyzed, sorted, and cleansed from error or measurement failure loading records.

RESULTS AND DISCUSSION

Timber, as an organic, inhomogeneous, and hygroscopic material, is always influenced by the external environment. And so is the transverse prestressing. The key factor for prestressing technology is the primary loss of prestressing force which is caused by wood mass creep. That is why the determination of the period when the primary loss of prestress occurs, and its mathematical description is an important part of the assessment of data obtained from the experiment. A set of 669 average daily values was made from the minute measurement Tab. 1 summarizes important values.

Tab. 1: Summary of basic statistics.

	Prestress P (kN)	**Moisture M (%)**	**Temperature T (°C)**
Minimum value	0.797	14.2	-12.7
Average	4.057	17.0	12.3
Maximum value	9.055	21.0	29.3

There are measured values of prestressing plotted on the graph in the Fig. 3, so it is possible to monitor their development during the whole experiment. The graph shows that at first, this is after placing the monitored sample into the exterior, the prestress subsequently increases. This increase might be caused by the response of the sample to the change of environment. Following the decrease of prestressing force corresponds to the expected creep which is influenced by the changes of the external environment continuously, the temperature and moisture in particular.

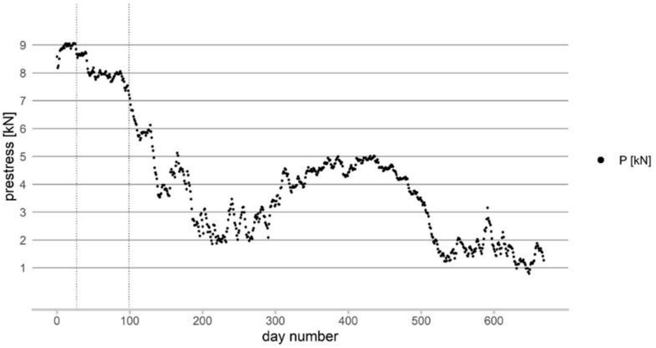

Fig. 3: Development of prestress during the experiment.

To determine the period in which the primary prestress loss occurs an analysis of correlation coefficient among time, temperature, moisture, and prestress, i.e. cor(P, day), cor(P, T) and cor(P, M) was used.

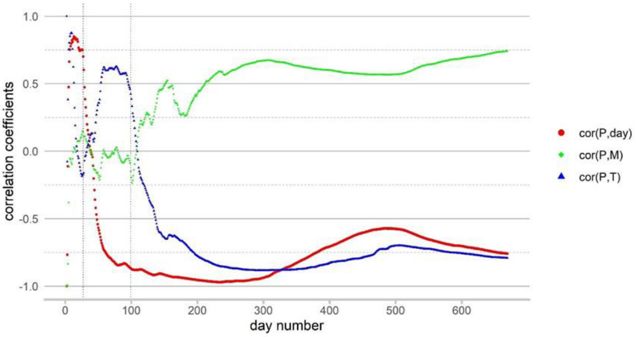

Fig. 4: Development of the correlation coefficient values.

Fig. 4 shows the development of correlation coefficient with time. There is a significant fickleness of coefficients evident at the beginning. This can be put down to the response of the experimental sample to the change of environment again. There are also positive correlation coefficients cor(P, day) and cor(P, T) depicted that indicates that the value of prestressing will increase as well as the time and temperature rises. The coefficient cor(P,day) declines quite quickly in the following period as low as the values close to -0.9 which means significant dependence of both values. Negative values even indicate the decrease of prestress (kN) with increasing time. Correlation coefficients cor(P,T) and cor(P,M) are negligible over this period and so only a small influence of temperature and moisture decline on the prestress value can be expected. A significant increase of all investigated correlation coefficients can be seen in the final phase and also their stabilizing at presumed values, i.e. cor(P, M) = 0.742, cor(P, T) = - 0.791 and cor(P,day) = - 0.758. These values indicate a strong influence of prestress on the monitored quantities. It is also obvious that the value of prestress rises with increasing value of moisture. On the contrary, opposite dependence can be seen between the temperature, or time, and prestress (Fragiacomo and Davies 2011, Fragiacomo and Davies 2011, Quenneville and Van Dalen 1994, Quenneville and Van Dalen 1994).

The above-mentioned analysis shows that the primary decline of prestressing with a strong influence of creep of timber occurred in the period between the 27th and 99th day of the course of the experiment. During this period the correlation coefficient cor(P,day) increased to the value cor(P,day) = -0.826, while the values of the correlation coefficients cor(P,M) and cor(P,T) were close to zero. Hence strong time dependence could be assumed here.

An overview of correlation coefficient values in individual periods can be found in the Tab. 2.

Tab. 2: Overview of important correlation coefficients.

Period	cor(P,day)	cor(P,M)	cor(P,T)
1-27	0.571	-0.182	-0.180
27-99	-0.826	0.044	0.046
1-669	-0.758	0.742	-0.791

As the creep is manifested as the decline of prestress with time with minimum influence of the environment, it can be described with the help of the regression model of this dependence. That is why we search for a linear function P=k*day+q that will describe the prestress decrease. The final model will be obtained in the form:

$$P = 8.538 - 0.014\, day \tag{1}$$

where: *day* represents a serial number of the day from the beginning of a period of permanent decrease of prestress.

The resultant regression line is plotted in the graph (Fig. 5) as well as the measured values of prestress. As the graph shows the measured values are in concordance with an approximated regression line. This concordance can be described by determination coefficient R^2 with values between 0 and 1 where the value 1 corresponds to maximum prediction. In the case of the resultant model has the coefficient of determination R^2 = 0.678.

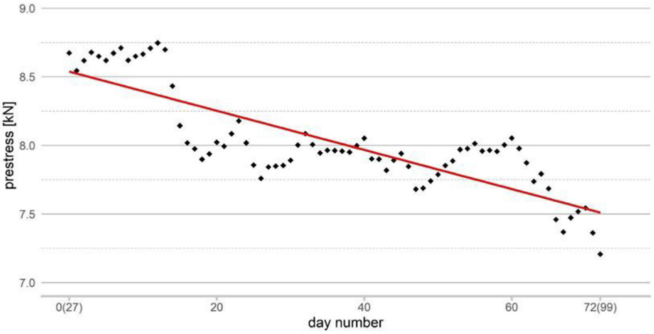

Fig. 5: Linear regression.

Indicators MAE (Mean Absolute Error) and RMSE (Root Mean Square Error) were used for the follow-up assessment of the model. The lower values of these indicators are, the more precise the model is. Values MAE = 0.173 and RMSE = 0.205, calculated for resultant linear model, indicate a good quality model.

CONCLUSIONS

In the current study, prestressed force losses of transverse timber samples in environmental conditions are introduced. The temperature, moisture, and time influence the volume changes of timber, i.e. creep of timber and also the related changes of values of prestressing force.

The experimental measurement showed that the relationship between ambient temperature and the value of prestressed force and similar to ambient moisture and prestressed force. The correlation of monitored moisture and temperature proved to be consider significant during the measurement period and have an impact on changes of prestressed force applied to the experimental beam observed in the exterior. The experimental measurement showed that increases of ambient moisture caused an increase of prestressed force value and, conversely, in case of an increase in ambient temperature caused a decrease of prestressed force value. Hygroscopic deformations and swelling occur because of the increase in moisture content in the timber which caused an increase in the size of the prestressed force which is corresponding to the expectation.

A significant increase in all investigated correlation coefficients can be seen in the final phase and also their stabilizing at presumed values. A permanent decrease of primary prestress lasting from the 27th to the 99th day is caused especially by the creep of timber, which is proved by the correlation coefficient method. The gained data can be applied in wood mass with similar physical properties. The obtained results of the experiment will be subsequently applied to the first transversely prestressed bridge in the Czech Republic.

ACKNOWLEDGEMENT

This research was realized under financial support of Conceptual Development of Science, Research and Innovations IP2309911/2104.

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