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TIMBER BEAMS SUBJECTED TO LONG – TERM LOADING

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ABSTRACT

Wood is a significant structural material, which is often used for timber bearing structures. Elements of timber structures must especially satisfy safety requirements, which are expressed by the ultimate limit states in the established standards. The structure must also satisfy the serviceability limit states. Local and global deformations make it impossible for the structure to serve the purpose it was designed for. It is important to take the deflections and their possible increase into account in the design to provide a structure which can be used during the whole period of service. Based on earlier examinations, it is known that a timber element over the course of long-term loading shows creep behavior. The structure of wood is able to adapt to the conditions of the surrounding environment. The properties of wood are especially affected by the relative humidity of the air and then by the type, intensity and duration of the loading. The most important factors affecting the serviceability of timber structures are volume changes caused by humidity and additional deflections caused by the effects of long-term loading. These phenomena emphasize the importance of serviceability limit states for timber structures. The paper deals with a long-term experimental investigation of timber girders that are currently often used. The aim was to obtain the deflection curves and mark the time dependence and the final deflections. The paper will also define the approximations for simulating the time-dependent deflections and obtain the creep coefficients for calculating the final deflections of the girders investigated.

KEY WORDS

- *Rheology,*
- *timber structures,*
- *long-term loading,*
- *creep,*
- *experimental investigation*

1 INTRODUCTION

The scientific research on wood as a structural material began in the 19th century. The first examinations served to confirm the theory of elasticity. Later, investigations began to deal with an examination of the strength properties of wood in accordance with the direction of force and further with changes in elastic parameters depending on a fiber's direction and density and the moisture in the wood. For the first time F. Savart established several elastic properties of wood in three basic directions in 1830 (Szalai 1994). He defined the relations between Poisson's constants.

M. Reiner and E. C. Bingham established rheology as a scientific discipline in 1926. Since then, attention has been paid to the long-term action of bearing elements (Sobotka 1981).

A long-term examination of timber elements was carried out in the Forest Products Laboratory in Madison, Wisconsin, in the 1940s. The dependence of the time of failure on the strength of timber elements subjected to bending was detected. It was discovered that after 10 years of loading, a 40% decrease in strength can be assumed. Based on these examinations the modification coefficient $k_{mod}=0,6$ is currently used for a permanent load.

But these results were obtained for small specimens without any defects. Further long-term investigations were conducted in Canada in the 1970s, when the results for small and actual size specimens were compared. Worse properties of structural timber were discovered. Smaller coefficients of long-term loads were obtained in comparison with small specimens. This knowledge led to a further investigation of structural wood in North

Tab. 1 *Observed girders*

Type of Girder	Cross section dimensions		Total length	Theoretical length	Nodal force	Number of specimens
	Width	Height				
I-OSB	90 mm	356 mm	4000 mm	3900 mm	4,24 kN	3
Spacejoist	90 mm	243 mm	4000 mm	3900 mm	3,26 kN	3
Sawn spruce beam	120 mm	200 mm	4000 mm	3900mm	1,80 kN	4

America and Europe. But a large examination did not confirm the markedly smaller value of a long-term load coefficient. Hoffmeyer and Fridley dealt with the effect of changes in moisture on creep and the time of failure in 1987 and 1992 (Koželouh 1998).

Of famous investigations in Slovakia, the works of Pavel Dutko, Pavel Bulko, Ján Siegel, Alexander Požgaj, and Vladimír Mackuliak can be mentioned (Dutko 1990). The course of deflection over time has been observed for different girder types. Timber beams with homogenous cross sections and non-homogenous cross sections combined with steel and other materials based on wood have been observed. The beams had real dimensions; their spans were from 2,3 to 3,0 m. The approximation functions for the time variable modulus of elasticity in bending was deduced. These experimentations lasted 166 days (Dutko 1990).

2 EXPERIMENTAL VERIFICATION

Experimental work investigating creep was undertaken in the laboratory of the Department of Metal and Timber Structures in Bratislava. The investigation was aimed at determining a beam's final deflection. The aim was to determine the creep coefficients and find a suitable function to approximate the deflection course over time. The beams have been loaded with a constant load since September 2006.

Three sorts of beams were observed: (1) beams with an I-cross section (Fig. 1), timber flanges and a wall made of OSB-3 plate, (2) beams known as Spacejoist with steel diagonal members (Fig. 2), which were compressed into timber flanges, and (3) the last girder type was made of sawn spruce wood. At least three specimens of each type were observed. The beam properties are shown in table 1. The girder materials, according to STN 731701 and STN 741401, were made of SI strength class wood, and the steel grade is S235. The moisture content of the wood materials was under 12%. The joists were subjected to single loads acting on a third of the beam's length. The specimens were arranged in pairs as seen in Fig. 3. Sacks, which were filled with gravel, were placed on a platform on top of the beam flanges.

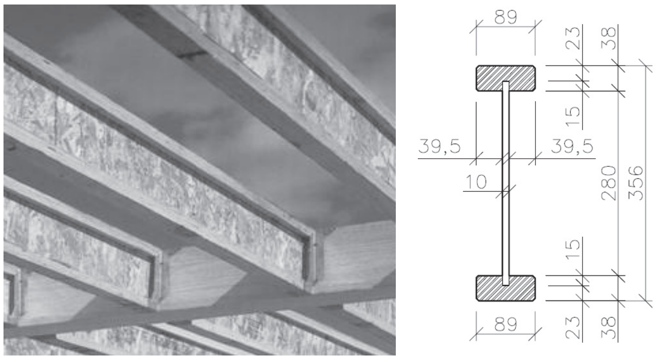

Fig. 1 *View and cross section of I-OSB beams*

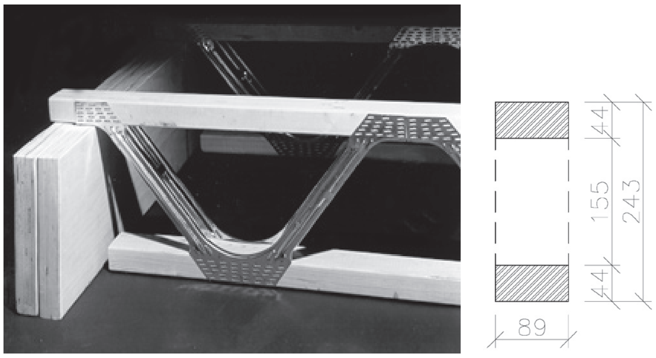

Fig. 2 *View and cross section of Spacejoist beam*

The large experiments demonstrated that creep is independent of the level of stress up to 35% of the wood's short-term strength (Koželouh, 1998). The bending strength of the coniferous wood is in a range from 50 to 130 MPa (Požgaj, 1993), and the design strength fluctuates around 12 MPa according to STN 731701. This means that if a specimen is under an ultimate stress according to the mentioned standard, the assumption of linear creep would be appropriate. The linear creep means that with any level of loading in the mentioned range, the same creep coefficients would be achieved. The level of loading was designed to be 60% of the beam's short-term resistance according to STN 731701. The listed intensity represents a common long-term loading of roof structures.

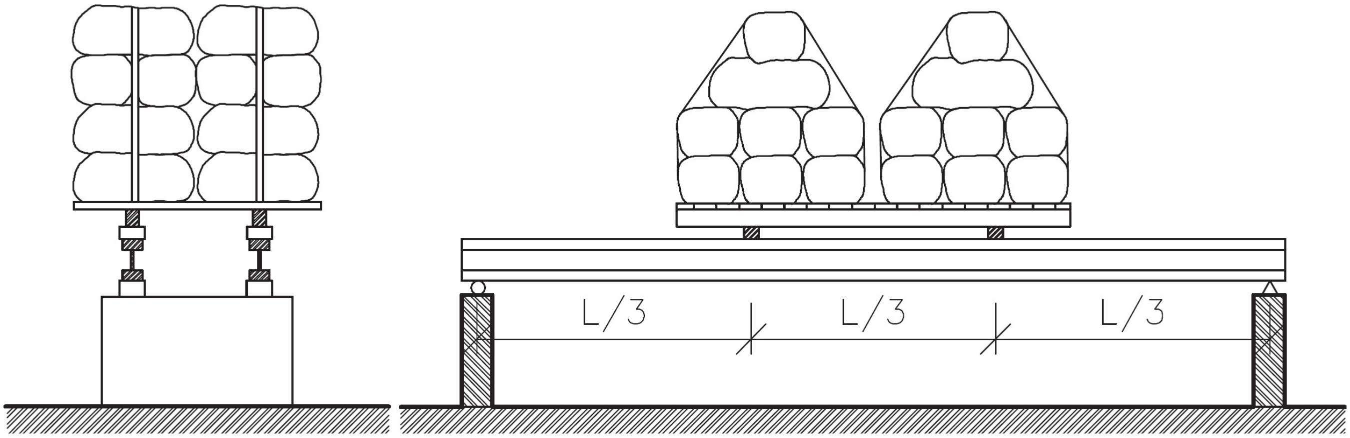

Fig. 3 *The arrangement of beams into pairs and drawing of loading*

The deflections were measured by mechanical deflectometers with an accuracy of 1/10 and 1/100 mm. The transducers were arranged in the middle of the beam, in thirds and 150 mm from the theoretical support. All the deformations were registered manually.

The observation took place in a closed room. The windows were darkened to minimize the fluctuations of the surrounding conditions. An electronic hydro-thermograph continually recorded the temperature and relative humidity of the air in the laboratory.

The last specimen was loaded on 16 September 2006. The deflections were examined several times a day. The period between the readings gradually extended. The deflections were evaluated in a time frame till March 2008.

3 DEFLECTIONS OBSERVED AND THEIR APPROXIMATION

The deflections recorded during the observation period are illustrated in the following figures. There are a large number of readings in the graphs, which indicate the trends. It is possible to express this tendency with an approximation function, which best describes the course of the deflections over time. The least squares method was used, which is based on the minimal distinction between the measured and approximate deflections. The constants of the functions were changed, until the correlation approached the number 1. There was a strong relation between the registered deflections and their approximations. The constants of the approximation function are called rheological constants.

Three functions were applied in the process of the approximations for all the beam types. The aim was to achieve the most accurate description of the deflection course over time with a suitable function. The following functions were used:

1. The function derived from Poynting-Thomson's rheological model (Požgaj 1997) (adapted for deflections).

The original form of the function defined for strains is:

$$\varepsilon = \frac{\sigma}{E_0} + \frac{\sigma}{E_1}\left(1 - e^{-\frac{E_1}{\lambda}t}\right) \tag{1}$$

Where: E_0, E_1, λ are rheological constants.

The form for the beam deflection:

$$w = w_0 + w_1\left(1 - e^{-\frac{E_1}{\lambda}t}\right) \tag{2}$$

Where:

w_0 is the instantaneous deflection,
w_1 – the delayed deflection,
t – time.

2. An exponential function used for approximating the long-term deflections of the Lafranconi Bridge in Bratislava (Bolha 2006).

$$w = w_0 + A\left(1 - e^{-B\sqrt{t}}\right) \tag{3}$$

Where:

w_0 is the instantaneous deflection,
A, B – rheological constants,
t – time in days.

3. Hyperbolic function (Ross – modified)

$$w = w_0 + \frac{A.t^B}{C + t^B} \qquad (4)$$

Where:

w_0 is the instantaneous deflection
t – time in days
A, B, C – rheological constants

It was determined, that the modified hyperbolic Ross function (3) fits the best. The constants obtained are listed in Tab. 2.

Tab. 2 *Rheological constants for the Ross function used for determining the deflection in the middle of the span and the average instantaneous deflections of the beams*

Rheological constants	Sawn girder (D, E, F, J)	I-OSB (A, B, C)	Spacejoist (G, H, I)
A	197931	197 931	352 845
B	0.6026	0.5038	0.467
C	3.682.106	3.682.106	3.650.106
Instantaneous deflection			
w_0 [mm]	7.270	4.301	6.456

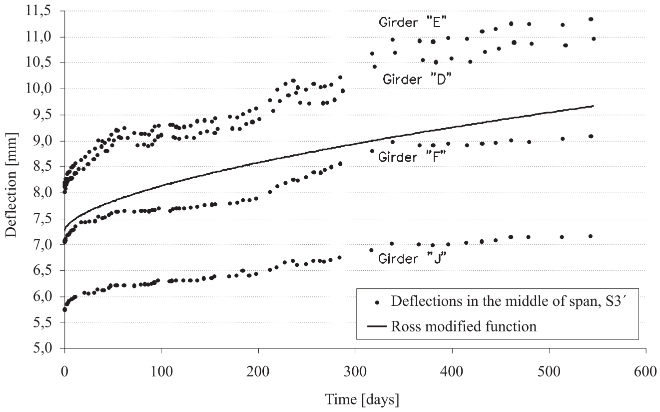

Fig. 4 *Registered deflections of sawn beams over time and their approximation*

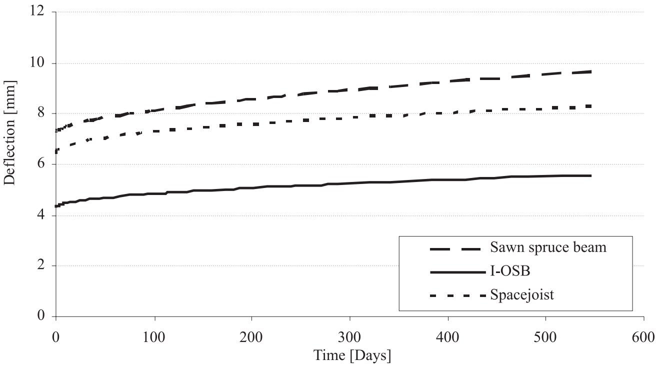

Fig. 5 *The approximation functions, which represents the beam's deflection in the middle of a span*

4 CREEP COEFFICIENTS

The additional deflections caused by the duration of the loading are mostly expressed by a creep coefficient. A creep coefficient is defined as the final and instantaneous deflection ratio reduced to the number 1. The creep coefficients were obtained from the most suitable approximation functions. The course of this coefficient over time is illustrated in Fig. 6.

$$k_{def} = \frac{w_t}{w_0} - 1 \qquad (5)$$

Where:

w_0 is the instantaneous elastic deflection over time $t=0$
w_t – deflection in given time t
k_{def} – the creep coefficient

The curves for the I-OSB and Spacejoist beams are almost identical. The OSB wall and steel diagonals have a noticeable effect on the creep behavior. On the other hand, the number of test samples was small, and the variability of the wood properties is high. This means that any consideration about the positive effect of diagonals and the OSB wall can only be confirmed by extensive experimentation.

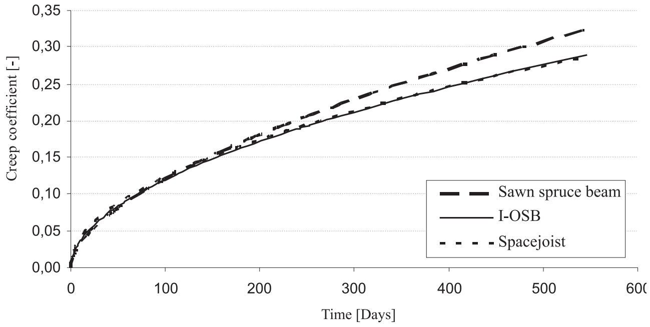

Fig. 6 *The course of creep coefficients for the beams investigated*

5 PREDICTION OF CREEP TREND

According to the approximation functions obtained, it is possible to develop a time variable course of the creep during the whole period of a building's lifetime. STN EN 1990 specifies the design working life of building structures for 50 years. By extrapolation of the approximation functions for beam deflections through the period of a building's working life, it is possible to predict the final deflection (Fig. 7).

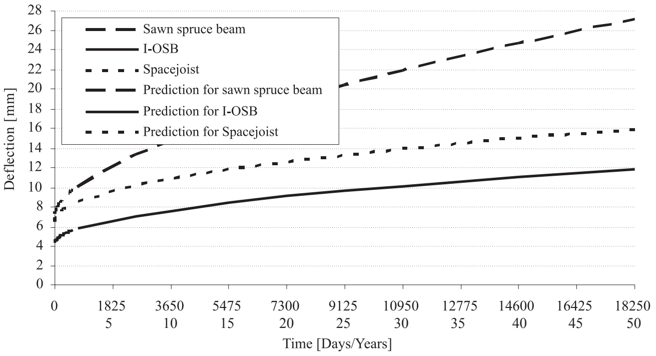

Fig. 7 *The predicted deflection in the middle of the span for the final approximate functions*

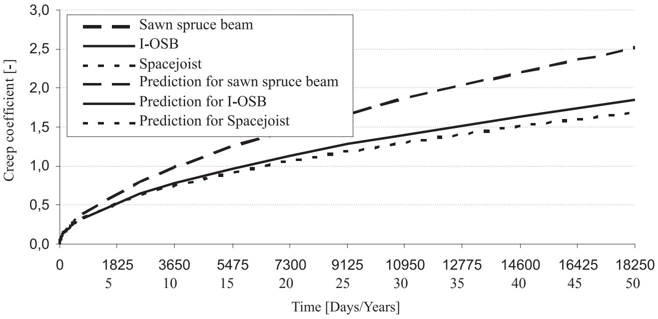

Fig. 8 *The prediction of the creep coefficients over time*

Through the approximated functions, the courses of the creep coefficients over time were obtained till the end of the structure's working life (Fig. 8). The creep coefficients, which were obtained for the end of the observation time (t = 545 days) and the final values at the end of the working life (t = 50 years), were compared with the values listed in STN 731701, STN EN 1995-1-1 and DIN 1052:2004-08 (Tab. 3).

The creep coefficients at the end of the observation were smaller than the values in the valid standards. But the values at the end of the work-life of a building, which were reached through an extrapolation, are markedly higher. It must be mentioned that these results are only preliminary, and will depend on the subsequent development of the deflections of the beams investigated.

Tab. 3 *Comparison of the experimentally obtained creep coefficients with the values in the standards*

Standard	Sawn timber beam (spruce)	I-OSB*	Spacejoist*
STN 731701	0.5	0.5	0.5
STN EN 1995-1-1	0.6	0.69	0.6
DIN 1052:2004-08	0.6	0.69	0.6
Experimental result (t = 545 days)	0.324	0.289	0.287
Prediction (t = 50 years)	2.51	1.84	1.69

*the value considers the various materials in a cross section

6 CONCLUSION

The thesis is aimed at the experimental verification of creep behavior. Various beams, which were loaded since September 2006, were investigated. The deflections were continuously registered. According to an evaluation of the data, the following conclusions can be drawn:

From the functions investigated, an optimal one was determined for the observed time range. It was demonstrated that the hyperbolic modified Ross function represents the best course of the deflections over time.

The creep coefficients were obtained according to the approximate deflections for each type of beam. Their values are markedly smaller than the coefficients listed in the valid standards for the corresponding conditions. The differences are perhaps caused by the short observation range (545 days).

It is possible to predict the final deflection values and final creep coefficients through the use of the approximation functions. The final creep coefficients are markedly higher than the values listed in the standards.

But the prediction can be less accurate because it results from a short experimental observation, even though the high values of creep coefficients show the necessity for more long-term experimentation specialized to the observation of deflection increase in time.

It was expected that the OSB wall by girders with an I-cross section and joints by the Spacejoist beam were going to have a marked unfavorable effect on the creep behavior. This marked effect was not observed. A moderate positive effect was registered by the given level of loading. It must be demonstrated that the results are subjected to a large degree of uncertainty because of the small number of specimens and the large variability of wood properties. More exact conclusions can be made after a larger long-term experiment.

In conclusion, recommendations for further investigation can be introduced. The valid standards STN EN 1995-1-1 and DIN 1052:2004-08 do not define creep coefficients according to the loading mode. It would be advisable to determine the creep behavior for specimens subjected to shear loading. The standards also do not consider the effect of a strength grade on the values of the creep coefficients.

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REFERENCES

- Bolha, Ľ. (2006) Dlhodobé deformácie mosta Lafranconi (Long-term deformations of the Lafranconi Bridge). Zborník prednášok, Konferencia fib pri príležitosti 2.fib kongresu – Neapol, Betón na Slovensku 2002-2006, Žilina, p. 375-380.
- Dutko, P. (1990) Záverečná správa štátnej výskumnej čiastkovej úlohy č. III.-3-1/8. Zvýšenie efektívnosti využitia konštrukčných kovových a drevených materiálov (Final report of the partial state research project). Téma č. III.-3-1/8.9. Podtéma č. III.-3-1/8.9-1. Pôsobenie nosných prvkov a sústav na báze dreva – experimentálne overenie (Operation of bearing elements and bearing systems on the base of wood – experimental verification). Slovenská vysoká škola technická v Bratislave, Stavebná fakulta, Katedra kovových a drevených konštrukcií, 1990.
- Koželouh, B. (1998) Dřevené konstrukce podle eurokódu 5. Step 1. Navrhování a konstrukční materialy (Timber structures according to EC 5. Step 1. Design and structural materials). Ing. Bohumil Koželouh, CSc., KODR, Zlín
- Požgaj, A., Chovanec, D., Kurjatko, S., Babiak, M.(1993) Štruktúra a vlastnosti dreva (Structure and properties of wood). Príroda, Bratislava
- Riečanová, Z.(1983) Numerické metódy a matematická štatistika (Numerical methods and mathematical statistics), Alfa, Bratislava
- Eurokód 5 (2006), STN EN 1995-1-1, Navrhovanie drevených konštrukcií, časť 1-1: Všeobecne – Všeobecné pravidlá a pravidlá pre budovy (Design of timber structures, part 1-1: General rules and rules for buildings). SÚTN
- DIN 1052:2004-08 (2004) Entwurf, Berechnung und Bemessung von Holzbauwerken – Allgemeine Bemessungsregeln und Bemessungsregeln für den Hochbau
- EN 380 (STN 732811) – Drevené konštrukcie. Skúšobné metódy. Všeobecné zásady skúšania statickým zaťažením (Timber structures. Experimental methods. General principles of examination with static loading). SÚTN
- Šmerda, Z., Křístek V. (1988) Creep and Shrinkage of Concrete Elements and Structures, SNTL – Publishers of Technical Literature, Prague
- Sobotka, Z. (1981) Rheology of materials and engineering structures, Academia, Prague, 1981
- STN 730035 (1986) Zaťaženie stavebných konštrukcií (Loading of building structures). Vydavateľstvo Úradu pre normalizáciu a merania, Prague
- STN 731701 (1983) Navrhovanie drevených konštrukcií (Design of timber structures). Vydavateľstvo Úradu pre normalizáciu a merania, Prague
- STN 731701 zmena a (1990) Navrhovanie drevených stavebných konštrukcií (Design of timber building structures). Vydavatelství norem, Prague
- Szalai, J. (1994) A Faanyag és faalapú anyagok anizotróp rugalmasság- és szilárdságtana (The knowledge in the elasticity and strenght of the wood and materials based on wood). I. rész. A mechanikai tulajdonságok anizotrópiája (The anisotrophy of the mechanical features). Hillebrand nyomda, Sopron, 1994