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Róbert Németh, Christian Hansmann, Holger Militz, Miklós Bak, Mátyás Báder

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Investigation of old hardwood structure element

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ABSTRACT

This paper reports on the structural testing of the dismantled Kecske hill lookout tower. The wooden structure stood in the Szárhalom forest, near Sopron, Hungary. It was erected in 1973, closed off in 2018 due to the failure of its structural elements, and finally demolished in 2021. Structural elements were tested and evaluated after 45 to 48 years of service, using, among others, electron microscopy, dynamic modulus of elasticity measurements, compression and bending tests. A literature review was conducted on the structural details of lookout towers, on the characteristics and production technology of glued-laminated wood, as well as the examined materials, including Norway spruce (*Picea abies*) and sessile oak (*Quercus petraea*). Literature values of compression and bending strength were also determined to compare them to our results. The analysis extended to describing the details of the new lookout tower, including the footing and stair installations, which were the main failure locations in the old structure. Based on the results, samples cut from the undamaged parts of the old structure had high residual strength even after 45 years of service, but the structure as a whole was no longer safe, due to the failure of certain elements.

INTRODUCTION

The old structure under investigation was made of Norway spruce (*Picea abies*) and Sessile oak (*Quercus petraea*), while the new, current edifice has a larger variety of materials. Columns are made of GL24h glulam and beams are C24 softwood. A mixture of larch and oak were used for the stairs and decking.

The structural utility of one of the examined species, Norway spruce (*Picea abies*) largely depends on knots. It is prone to warping, but its strength and elastic properties are excellent. Based on literature data, its compression strength and bending strength ranges between 35-50-79 MPa and 49-78-136 MPa (at 12% MC, Molnár 2016).

The compression strength and bending strength of Sessile oak (*Quercus petraea*) at 12% MC is 55.7 MPa and 112.4 MPa, respectively, while its density is 750 kg/m^3 (Molnár – Farkas 2016).

During an inspection in the summer of 2018, the owner TAEG Forest Enterprise realised that the ends of the structural beams and other elements have deteriorated, rendering the lookout tower unsafe to use. The tower was cordoned off, and the lower steps removed to restrict access. The old lookout tower was finally dismantled in September 24, 2021. Specimens were accrued from the owner after landfilling the debris in October. Samples were collected from various places within the structure, described in detail in the testing section.

Selected samples were transported to the Timber Structures Testing Laboratory of the Institute of Applied Mechanics and Structures of the Sopron University for testing. To protect the cutting and testing machines, nails, bolts and other pieces of hardware were removed from the material. Testing took place after this, starting with non-destructive measurements and then strength testing.

Several measurements were made on the structure. Methods, results and conclusions are discussed separately for the various tests. Second level headings will introduce these tests for electron microscopy, non-destructive testing, compression and bending, respectively.

EXPERIMENTAL METHODS

Dynamic Modulus of Elasticty Measurements

Dynamic Modulus of Elacticity (MOE) testing was done using the non-destructive PLG testing equipment, developed in Hungary, based on sound velocity measurement. This instrument measures the density, MOE and estimates the bending strength. The instrument determines the stress grade according to MSZ EN 338 for softwoods. In case of oak, we determined the grade ourselves, based on the standard.

Compression tests

Compression strength is the resistance capacity of wood against loading along or across the fibres. Investigations included both cylindrical and rectangular specimens of materials that had been loaded in compression in the original structure as well. Measurements included 5 cylindrical and 2 rectangular oak, as well as 2 sound but checked spruce specimens. Specimens were placed in a Matest Servo-Plus Evolution (3000 kN capacity) material testing machine that subjected them to a gradually increasing pressure at a rate of 0.6 MPa/s. The determination of the strength values followed values in the table "Eurocode5 stress grades of wood". Since literature values pertain to air-dry moisture content, these values were converted to 12% MC, as indicated in the tables.

Bending tests

Four-point bending tests were used to compare the bending strength of oak with literature values. The advantage of the four-point bending scheme, compared to 3-point bending is that failure occurs in clear bending. Shear failure may occur due to the shortness of the specimen. The machine loaded the specimen at a rate of 0.500 kN/s, and stopped the test after failure when the load fell back to 50% of the ultimate level. The moisture content at the time of testing was 15%, and the values were converted to 12% before assigning the stress grades.

RESULTS

Dynamic Modulus of Elasticty Measurements

8 specimens were measured as described above. The results of the dynamic MOE measurements show the mean of the spruce 11668 MPa, the oak specimen MOE 11270 MPa. The samples were also classified into the appropriate stress grade based on the results, which showed C22, C27 and D18, D30, D35, D50 categories, but in case of the Nr. 3 specimen it was out of grade. The Moisture Content of the material was 18%. The instrument converted the measured data to 12% MC as the standard MC value. (Table 1, Figure 1)

Table 1: The results of the dynamic MOE measurements

Nr.	Species	l [m]	w [mm]	h [mm]	m [kg]	ρ [kg/m^3]	MOE [MPa]	Stress grade
1	Spruce	1.36	160	160	13.62	379	11009	C22
2	Spruce	1.47	140	140	12.52	420	12326	C27
3	Oak	1.11	135	55	5.46	652	8571	out of grade
4	Oak	1.52	140	140	21.60	705	11393	D30
5	Oak	1.13	260	50	11.24	742	11762	D30
6	Oak	1.16	220	45	8.30	702	14011	D50
7	Oak	1.17	250	50	9.34	619	9682	D18
8	Oak	1.16	245	45	10.80	822	12205	D35

The Moisture Content of the material was 18%. The instrument converted the measured data to 12% MC as the standard MC value, and the values in Table 1 are these converted values.

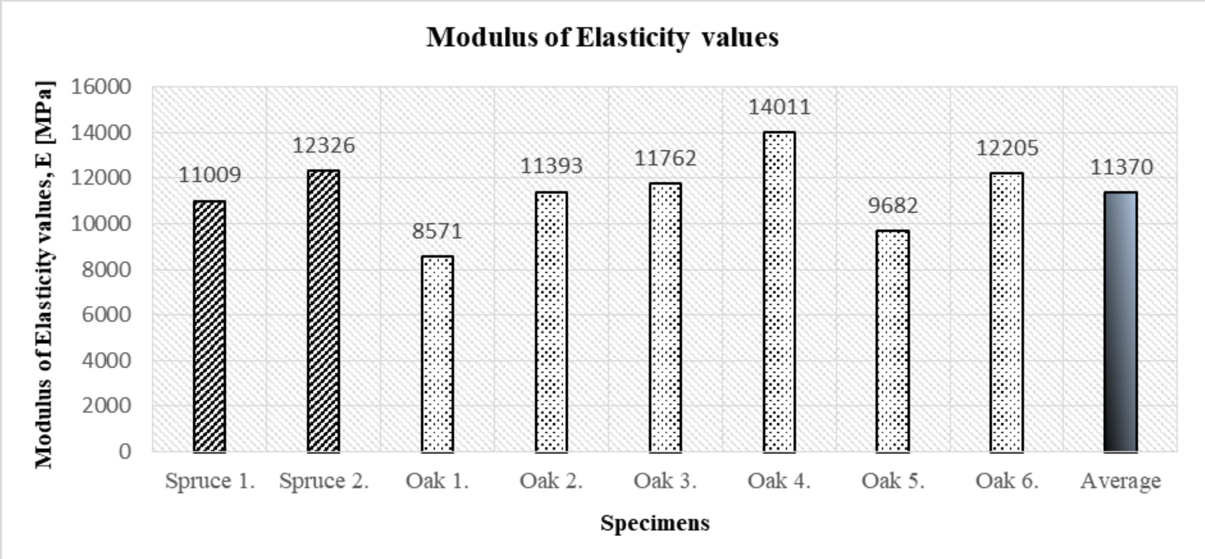

Figure 1: The measured Dynamic MOE values

Compression tests

Results of the air dry (12%) values show that the compression strength of spruce (mean: 57,5 MPa) reach and even exceed those of oak (mean: 45,8 MPa). One explanation may be that fluctuating climatic conditions induced higher stresses in oak, and thus created a larger number of drying fissures throughout the years. These fissures acted as fracture initiation locations during the failure process and manifested as a kind of cross sectional area reduction. (Figure 2)

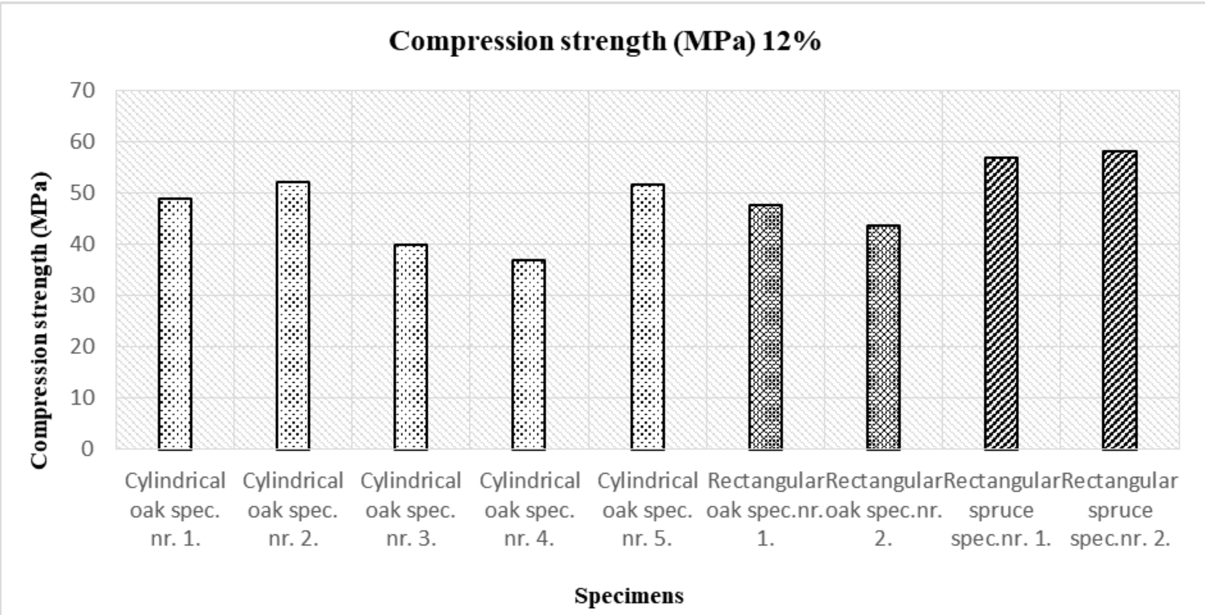

Figure 2: A comparison of compression strength values at air dried MC (u=12%)

Bending tests

The specimens show the mean of bending strength (u = 12%) 64.25 MPa. The samples were also classified into the appropriate stress grade based on the results, which showed D50, D60, D70 categories. All of them belong to one of the three highest stress grades. Specimens cut from the sound sections of the elements had high bending strength. (Table 2)

Table 2: The results of the bending tests

	a [mm]	b [mm]	u [%]	F [kN]	σ [MPa] (u=15%)	σ [MPa] (u=12%)	τ [MPa]	Stress grade
spec. nr. 1	45	90	15	21.023	51.908	58.137	7.786	D50
spec. nr. 2	45	90	15	21.210	52.370	58.654	7.856	D50
spec. nr. 3	45	90	15	29.170	75.025	84.028	10.804	D70
spec. nr. 4	45	90	15	22.074	54.504	61.045	8.176	D60
spec. nr. 5	45	90	15	19.500	48.148	53.926	7.222	D50
spec. nr. 6	45	90	15	25.202	62.227	69.694	9.334	D60
Mean	-	-	-	23.030	57.364	64.247	8.530	-
Minimum	-	-	-	19.500	48.148	53.926	7.222	-
Maximum	-	-	-	29.170	75.025	84.028	10.804	-
Std.	-	-	-	3.553	9.832	11.012	1.316	-
Var%	-	-	-	15.430	17.141	17.141	15.431	-

Table 2 shows the measurement data, where *a* is width, *b* is height, *u* is moisture content, *F* is the ultimate load in kN, which is half of the maximum force measured, due to the two-point loading, σ is bending strength, τ is the shear stress generated during bending.

DISCUSSION

Dynamic Modulus of Elasticty Measurements

MOE values are nearly identical for all specimens. Spruce and oak specimens yielded densities typical of these species. The MOE values of spruce calculated based on stress-wave velocity indicate medium quality. The measured MOE values of around 11,000 N/mm^2 correspond to medium stress grades in coniferous beams. Failure primarily occurred near the bolted connections; in farther positions, wood integrity was unaffected. The density and MOE of oak planks, in contrast, show significant variation. One of the specimens did not even reach an MOE value necessary to be classified as the lowest grade of D18. Four of the six specimens received low grades, i.e. the oak specimens showed a lowered strength after four decades.

Compression tests

Cylindrical specimens clearly show almost identical values and diagram shapes, due to the similar characteristics arising from the same species. In the diagrams of the rectangular samples, on the other hand, the differences between the two species in terms of Modulus of Elasticity, proportional to the slope of the linear portion, are clearly visible. Compared to spruce, oak specimens exhibit much steeper curves, due to the higher MOE of oak. Oak's more intensive initial checking may have caused the lower strength of these specimens. When compared to the characteristic values of 34 N/mm^2 set forth in the table for the stress grade D70 for hardwoods, these specimens exceed this value significantly, by approx. 34%. The compression strength of the columns was generally high. The failure, again, occurred at the connections, as demonstrated before.

Bending tests

Compared to values in each hardwood stress grade, the bending strength of the oak specimens proved to be outstanding. All of them belong to one of the three highest stress grades. Specimens cut from the sound sections of the elements had high bending strength. The failure of the structure was caused by fungal deterioration due to wetting, primarily in the proximity of the connections.

The new lookout tower

While inspecting the new lookout tower, which was built in 2022, we detected delamination at one of the glulam elements at the anchoring site. Vanya, Kannar and Rabb (2016) showed that „ bolted connections, which hinder shrinkage and swelling through concentrated loads at the bolts, may result in the creation of cracks", but „nailplate type connectors hold the load bearing element together, and small stress peaks generated at many locations hinder the deformation, thus no significant cracking occurs. Thus, improving nailplate type connections is recommended" (Vanya – Kánnár – Rabb 2016). In another analysis, Kánnár (2011) and Vanya (2014) identified possible reasons as follows: „Delamination in glued-laminated structures may have occuered due to multiple factors, such as: restricted shrinkage and swelling, lamella runout, moisture differences among lamellas, stresses perpendicular to the axis of the beam, adhesion problems, wood's anisotropic and inhomogeneous material properties, and the visual, rather than instrumented stress grading of the lamellas" (Kánnár 2011) (Vanya 2014). The cause of failure was stresses perpendicular to the axis of the beam, caused by the bolted connection. This may lead to wood protection problems later, since a subsequent growth of the crack may lead to wetting, and later rotting. Sealing the crack using waterproof caulking may prevent this eventuality. This is especially important in case the crack becomes wider, since wind load and occupancy load continuously change the loads in the new structure. At present, continuous monitoring of the crack during periodic inspections is sufficient. The other parts of the lookout tower are in good condition, and well-executed work.

CONCLUSIONS

There are many factors to consider in structural design. The structure should provide the intended utility value with respect to the service life and financial aspects. It should reliably resist loads arising from external loads and climate-induced stresses, which may arise during erection or use. In case of accidental actions like earthquakes fire of human errors, damage should be proportional.

During our investigation, we analysed the elements of the dismantled structure to establish the causes of failure. Based on the results, specimens cut out of the sound portion of the elements had high residual strength, and the failure of the structure was caused by the rotting of the columns, primarily in the proximity of the connections, which could thus no longer safely support the otherwise still serviceable elements. It is important to limit the extent of the damages already in the design phase, but also keep it to a minimum during construction and maintenance as well, so that the edifice can fulfil its structural purpose during the intended lifespan.

REFERENCES

Bodig J., Jayne B. A. (1982): Mechanics of Wood and Wood Composites. Van Nostrand Reinhold, 1982. Michigan, Michigan State University. pp. 291.

Kánnár A. (2011): Theoretical and experimental invistigations of damage development of glulam beams The 17th International Nondestructive Testing and Evaluation of Wood Symposium 2011. szept. 14-16. Sopron Hungary. Proceedings 367-374.

Kánnár A. (2014): A faanyag mikro- és makro-tönkremeneteli folyamatai, [Microscopuc and macroscopic failure processes in wood.] Sopron, ISBN 978-963-08-8672-7, pp. 6-7., pp. 12. (in Hungarian)

Molnár S., Farkas P. (2016): Tölgy (kocsányos és kocsánytalan tölgy) – Quercus spp., In: Földünk ipari fái, Eds.Molnár S., Farkas P., Börcsök Z., Zoltán Gy., Photog. Richter, H.G. & Szeles P., ERFARET Nonprofit Kft., Sopron, ISBN 978-963-12-5239, pp. 121-126. (in Hungarian)

Molnár S. (2016): Lucfenyő – Norway Spruce, In: Földünk ipari fái, Eds.Molnár S., Farkas P., Börcsök Z., Zoltán Gy., Photog. Richter, H.G. & Szeles P., ERFARET Nonprofit Kft., Sopron, ISBN 978-963-12-5239, pp. 89-91. (in Hungarian)

Vanya Cs., Kánnár A., Rabb, P. (2016): Javaslatok rétegelt-ragasztott fatartók tervezéséhez, gyártásához és üzemeltetéséhez, felmérési és modellezési eredmények alapján – III. rész: A tönkremeneteleket igazoló vizsgálatok és eredményei. [Design, fabrication and operation proposals for gluedlaminated timber, based on measuring and modelling results. Chapter 3: Failure examinations and their results.] Faipar, 62. évf. 1. sz. (2016), https://doi.org/10.14602/WOODSCI.2016.1.45 (in Hungarian)