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CONSTRUCTION AND PERFORMANCE OF A 1:2 SCALE TIMBER STRUCTURE UNDER STANDARDIZED LOAD TESTS♣

Patricia Vallelado-Cordobés[1,♠]

https://orcid.org/0009-0002-9536-9486

Roberto D. Martínez[1]

https://orcid.org/0000-0002-0567-1781

Gamaliel López[2]

https://orcid.org/0000-0003-3418-0583

Álvaro Iglesias-Pordomingo[3]

https://orcid.org/0000-0002-7093-4568

Luis-Alfonso Basterra[1]

https://orcid.org/0000-0002-5273-9726

ABSTRACT

Timber's growing prominence in both new construction and heritage rehabilitation demands reliable methods to evaluate structural safety. However, most current load-testing protocols target concrete and overlook key timber-specific characteristics such as creep, delayed deflection, and service classes. This study addresses these gaps by investigating a 1:2 scale two-story timber prototype subjected to monotonic (UNE-EN 380) and cyclic (DAfStb) load tests. A comprehensive array of sensors captured time-dependent deflections and post-unloading recovery, revealing pronounced creep effects and highlighting the limits of existing standards to account for timber's long-term deformation. Although cyclic tests can be completed more quickly, they do not adequately track delayed deflection behaviour crucial to timber structures; by contrast, the sustained-load protocols demanded by monotonic tests provide meaningful insights into creep and sostenibility considerations (such as water usage). These findings underscore the need to develop updated, consensus-based load-testing guidelines that better reflect timber's unique mechanical response. Such standards would enable more accurate assessments of timber floors, roofs, and frames in both historic and contemporary contexts.

Keywords: Cyclic load testing, timber structure, load testing standards, static load testing, structural performance.

[1]Universidad de Valladolid. ETS de Arquitectura de Valladolid. GIR Estructuras y Tecnología de la madera. Valladolid, Spain.
[2]Departamento de Construcciones Arquitectónicas. Ingeniería del Terreno y Mecánica de los Medios Continuos y Teoría de Estructuras. Valladolid, Spain.
[3]Universidad de Valladolid. Escuela de Ingenierías Industriales. Grupo de Dinámica Estructural. Valladolid, Spain.
♠Corresponding author: pvallelado@uva.es

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INTRODUCTION

In recent years, there has been a significant resurgence in the use of timber as a structural material, driven primarily by increased building rehabilitation activities, socioeconomic factors, and sustainability considerations. Standardising timber's mechanical properties and load-bearing behavior internationally has become a critical aspect of its application in preserving historical buildings. Our research on the evaluation of timber structures using static load tests significantly contributes to this standardisation and emphasizes the importance of this topic in structural engineering and conservation, particularly in the current context of timber's resurgence. Despite this renewed focus, a persistent global issue is the absence of unified and specific standards governing load testing for timber structures, particularly in historical contexts (Luechinger *et al.* 2015; Loebjinski *et al.* 2019). Timber structures, especially heritage buildings, frequently exhibit complex assembly conditions, material anisotropy, deferred deflections, environmental impacts, and varying states of degradation. These unique challenges underscore the critical need for specialised standards that precisely address timber's mechanical properties and structural behaviour under diverse conditions (Reschel and Vielhaber 2003; Marx *et al.* 2011).

Throughout history, load testing has played a pivotal role in confirming structural integrity, dating back to ancient times (Marx *et al.* 2011). Its initial importance for bridges, due to the limited accuracy of early analytical methods (Fred-Moses *et al.* 1994; Veneziano *et al.* 1984; Lantsoght *et al.* 2017), has evolved significantly. The advent of reinforced concrete in the late 19th century, a period marked by limited confidence and undeveloped calculation methodologies (Bolle *et al.* 2010), further underscored the significance of load testing. At this stage, load tests served both to verify safety and to validate emerging calculation theories (Brent-Hall and Tsai 1989). The introduction of reinforced concrete significantly elevated the relevance of load testing, prompting the American Concrete Institute (ACI) to publish the first standardised load-testing protocol in 1920 (De Luca *et al.* 2013; ACI 318S-05 2019; ACI 437.2 2014). Criteria based on deflection-span relationships soon followed, offering standardised measures of structural performance (Galati *et al.* 2008; Galati and Alkhrdaji 2009). The 20th-century advancements in computational methods reduced the prominence of physical load testing, shifting structural design towards analytical calculations due to greater efficiency and precision (Schacht *et al*. 2016; Brent-Hall and Tsai 1989).

Despite the advancements in load testing, contemporary interest in structural renovation and conservation has revitalised its relevance. This is particularly true when evaluating the safety of historical and existing structures. Analytical methods alone often fall short due to incomplete documentation, previous structural damage, or outdated construction methods (Jones and Oliver 1978; Marx *et al.* 2011; Schacht *et al.* 2016; The Institution of Structural Engineers 2010). Load tests remain crucial when structural integrity is compromised by accidents, fires, poor workmanship, or changing usage conditions (Jones and Oliver 1978; Tumialan *et al.* 2014; Reschel and Vielhaber 2003). Although beneficial, these tests are sometimes expensive, time-consuming, and might necessitate temporary closure of structures (Reschel and Vielhaber 2003). Besides, a crucial challenge in load testing is that accurate implementation requires careful installation of measurement systems, independently supported to avoid structural interaction during testing, and the correct selection of reference points for reliable deflection measurement (De Luca *et al.* 2007; Menzies 1978). Consequently, rigorous and unified evaluation procedures remain indispensable.

Addressing the complex evaluation challenges posed by timber structures, innovative Non-destructive Evaluation (NDE) technologies have emerged as indispensable tools for inspecting structural health and quantifying residual load-bearing capacity without causing damage (Olaszek *et al.* 2010; Marx *et al.* 2011; Lantsoght *et al.* 2017). However, these methods can be labor-intensive and costly if applied to many components (Reschel and Vielhaber 2003). Analysing and predicting the overall behavior of a system with complex joints can be challenging.

The results of load tests are typically assessed by comparing the observed deflections under the total test load, a moderate load, and after recovery following load removal with the deflections predicted in structural analysis models. Calculation models and load tests have become complementary tools in structural design. Analytical models are often used to plan the load test, helping to anticipate load distribution and the impact of its magnitude and location on the structure. After the test, these models are adjusted to reflect the actual conditions experienced, thereby improving the accuracy of the analysis and providing a deeper understanding of the internal forces induced by the applied loads (Galati and Alkhrdaji 2009).

Finally, recognising the necessity for consensus among European load testing standards, (BS 8110-2 1985; Código Estructural 2021; ISO 13822 2010; DAfStb Belastungsversuche 2020; UNE-EN 380 1998; UNE-EN

595 1996), this study primarily aims to compare two distinct load-testing methodologies for timber structures-monotonic (UNE-EN 380) and cyclic (DAfStb)-to address the lack of unified, material-specific guidelines in current practice. By examining a 1:2 scale reproduction of a two-story timber structure, we seek to capture how each method handles critical phenomena like creep, delayed deflection, and environmental constraints that are often overlooked in standards geared toward other materials. The half-scale approach balances the need for realistic replication of actual in-service conditions with practical constraints on full-scale testing. Beyond collecting static results-such as mid-span deflections-our core focus is a methodological evaluation, including the feasibility, time demands, and accuracy of each protocol. By systematically contrasting these testing procedures, this work lays the groundwork for timber-focused load-testing guidelines that better align with the material's unique behavior, ultimately fostering safer and more sustainable practices in structural assessment and rehabilitation.

MATERIALS AND METHODS

Scale model

1:2 scale model of a two-story timber structure was meticulously crafted. The model measures 5,42 meters x 3,28 meters in plan and stands 3,20 meters high (Figure 1). It included six columns, ten laminated timber beams (GLT), and four cross-laminated timber (CLT) panels forming the two floors.

The columns and beams, made of Norway spruce (*Picea abies* (L.) H.Karst.) from Austria, had a 440 kg/m³ - 460 kg/m³ density and were classified as GL24h according to UNE-EN 14080 (2022). The beams had cross-sectional dimensions of 140 mm x 200 mm and are made up of five glued layers. The columns (140 mm x 140 mm) were anchored using tulip-shaped metal brackets secured to a reinforced concrete slab. Perimeter beams were connected with mortise and tenon joints reinforced with lag screws (Figure 1). The central beams on both floors used metal stirrup-type brackets, which are different from the other connections due to assembly requirements.

The CLT panels were made from radiata pine (*Pinus radiata* D.Don) or cluster pine (*Pinus pinaster* Aiton), sourced from northern Spain. These panels had a minimum average density of 500 kg/m³ and were classified as C16 according to UNE-EN 338 (2016). Each panel was 80 mm thick, comprising three layers (30 mm + 20 mm + 30 mm). The longitudinal joint between panels was a carpentry joint with a rebate, not reinforced with screws. The CLT was supported by the beams and connected to them at specific points using lag screws. The structure was reinforced with four steel cross-braces composed of 12 mm diameter cables anchored to the columns. These cross-braces were installed following standard construction practices to ensure a realistic structure. Placing them at the outermost bay enhanced lateral stability, and adding more braces was avoided to prevent excessive stiffness, which would be uncharacteristic of practical scenarios.

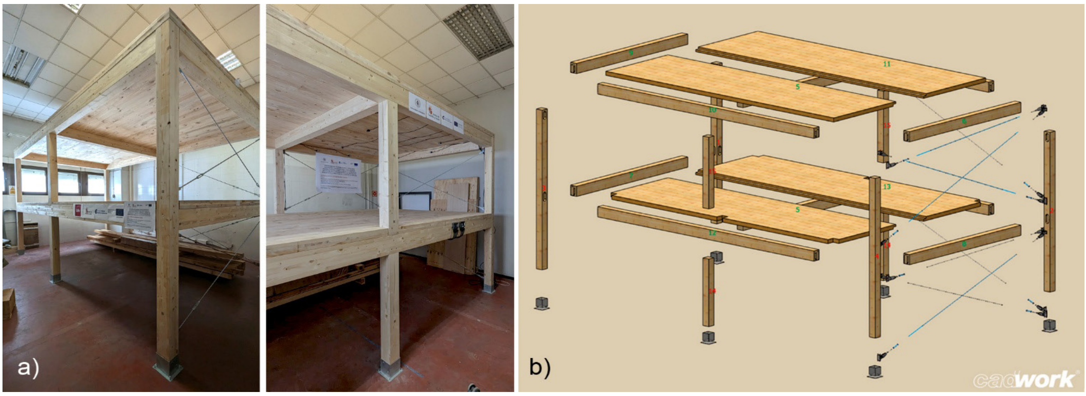

Figure 1: 1:2 Scale Model. a) photographs of the structure b) exploded view of the model's structure for fabricating components, with detailed joints.

Load arrangement

Water pools with dimensions of 3,70 m x 1,60 m applied the required load to the structure. These pools were centrally positioned on the floors. There was one pool on each floor; even though the load test was only conducted on one floor, this setup enabled water reuse. Figure 2 illustrates a schematic of the structure's loading and unloading.

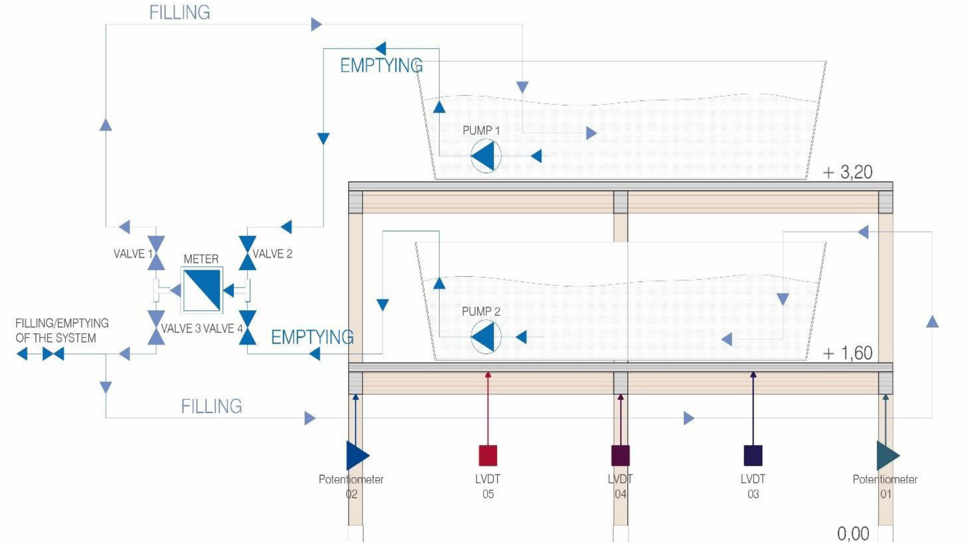

Figure 2: Schematic of the hydraulic system for loading and unloading the floors.

The testing process was characterized by meticulous attention to detail, particularly in the precise arrangement of loads and measurement of water volume. This careful approach instillsed confidence in the reliability of the testing methods. The process was initiated by activating pump 1 to load the lower floor, followed by opening valves 2 and 3 to transfer water from the upper pool to the lower one. After loading, pump two was activated, and valves 4 and 1 opened to unload the lower floor.

The system was designed to prevent any potential impact on the columns from crushing or settling during loading and unloading. The columns were consistently exposed to the same load, ensuring accurate measurement of floor deflections (CLT panels + beams) during the load test and freedom from external influences. This design feature created a secure and precise measurement environment, inspiring confidence in the reliability of the testing methods.

Instrumentation of the structure

The following types of sensors were used:

- 2 units of 250 mm string potentiometers
- 3 units of LVDT WA/100MM-T HBM instruments
- 2 units of LVDT WI/10MM-T HBM instruments

The strategically positioned sensors were pivotal in the testing process, ensuring accurate deflection measurement. Placed at points of expected maximum deflection (Figure 3), these sensors were also symmetrically placed on the structure to ensure data comparability. This setup, along with tripods and specific adapters for each sensor type, guaranteed the precision of our measurements. All sensors were connected to a computer through the Quantum data acquisition system, further enhancing the thoroughness of the testing.

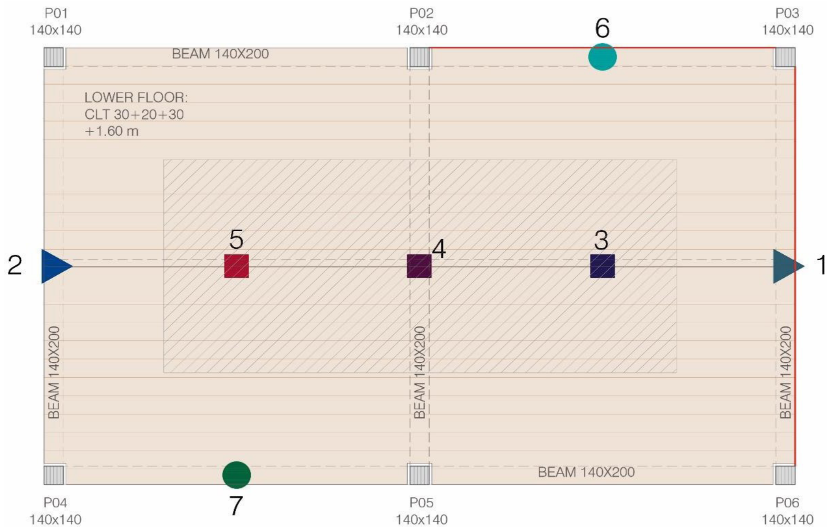

Figure 3: Sensor arrangement on the lower floor. Braced areas are marked in red. D 250 mm string potentiometers, □ LVDT WA/100MM sensors, and O LVDT WI/10MM sensors.

Experimental campaign

The tests were conducted according to two different standards: the UNE-EN 380 (1998) and the German DAfStb Belastungsversuche (DAfStb 2020). Each test type was performed at least twice to validate results, with the load applied only to the lower floor. A minimum resting period of three days was allowed between tests to ensure that the structure returned to its original state. Throughout this period, the entire water volume remained on the upper floor.

Before the experimental campaign, a calculation model was created using general structures theory. All the elements possessed the structural parameters specified by the UNE-EN 338 standard. This model was employed to validate that the maximum deflection results fell within the anticipated range and to ensure the safety of the load test.

Load test according to UNE-EN 380 (UNE 1998)

Given the objectives of this study, a long-term deformation load test was selected. Following the standards, the deflection was measured at the expected maximum deformation points (span centres), and force and displacement values were continuously recorded. Data was logged at 15-second intervals during the loading and unloading phases and at 120-second intervals during the constant load phases. The target load value was 3,5 kN/m² with a preload value of 0,5 kN/m².

Adhering to the time guidelines specified in UNE 7457 (1986) standard, the observation phase under maximum load (phases 7-8) must be maintained for at least 16 hours. The unloading phase (8-9) should be performed in steps similar to the loading phase. Subsequently, the post-unloading observation phase (9-10) should also mirror the maximum load phase, lasting 16 hours. Figure 4 graphically details the procedure. The load test was conducted over four consecutive days.

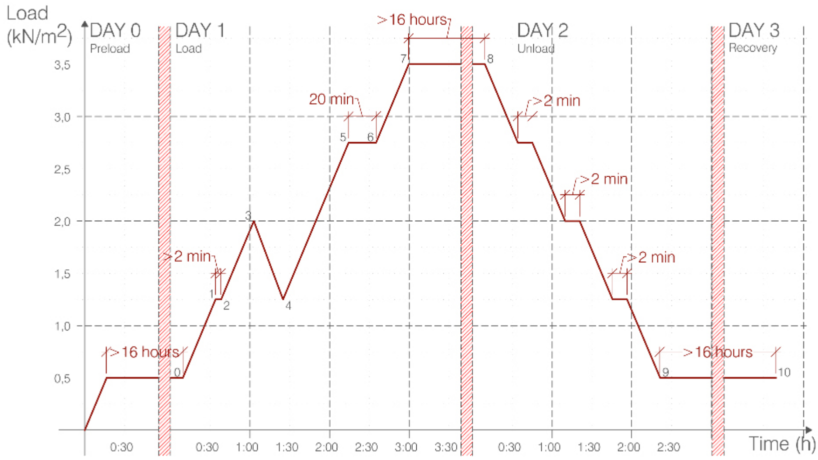

Figure 4: Load-time graph for the load test according to the UNE-EN 380 standard (1998).

Load test according to DAfStb belastungsversuche (DAfStb 2020)

The German load test distinguishes between the target calculation load (Fobj,k) and the target design load (Fobj,d), which excludes safety factors. Therefore, the following values were established:

- Fobj,k = 3,5 kN/m²
- Fobj,d = 4,5 kN/m²
- Fpreload = 0,35 kN/m²

This load test is cyclic, with closely timed loading and unloading stages. The constant load time is minimal, approximately 6 minutes, as shown in Figure 5. The load test takes 17,5 hours and is completed in a single day.

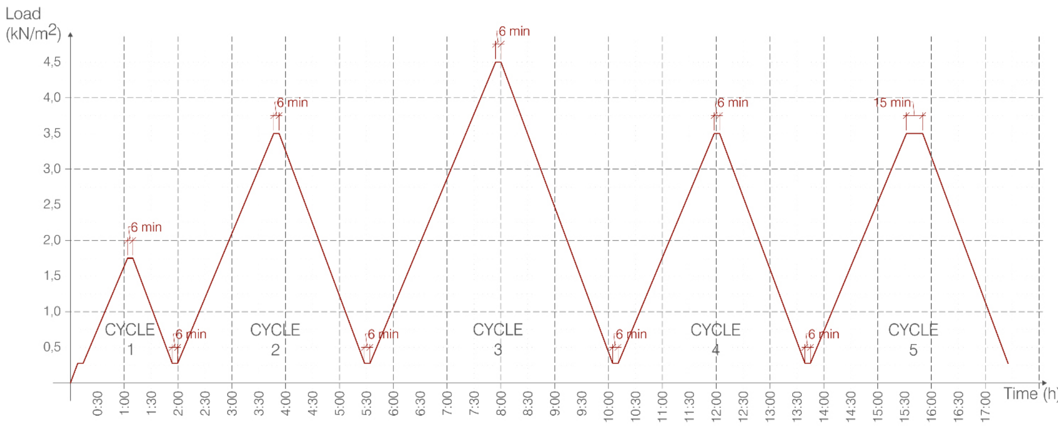

Figure 5: Load-time graph for the load test according to the DAfStb Belastungsversuche standard (DAfStb 2020).

A modified loading model was proposed based on the test objectives and conditions. This model follows the test cycles but extends the constant load times (Figure 6) for two reasons. First, it facilitates test execution by extending load times and spreading the test over five consecutive workdays, with the longest day being eight and a half hours. Second, the methodology needs were adapted to the specific material of the structure. Since timber is significantly affected by the creep phenomenon, it is appropriate to study its delayed deflection during loading and recovery periods after unloading.

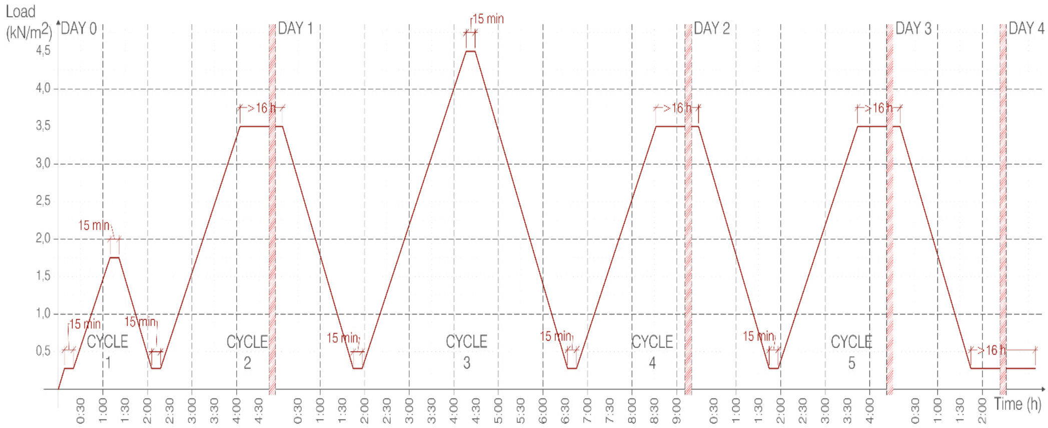

Figure 6: Load-time graph for the load test according to the DAfStb Belastungsversuche standard (DAfStb 2020).

RESULTS AND DISCUSSION

Load test according to UNE-EN 380 (UNE 1998)

Figure 7 shows the time-deflection graphs from the two load tests conducted following the standard UNE-EN 380 (1998).

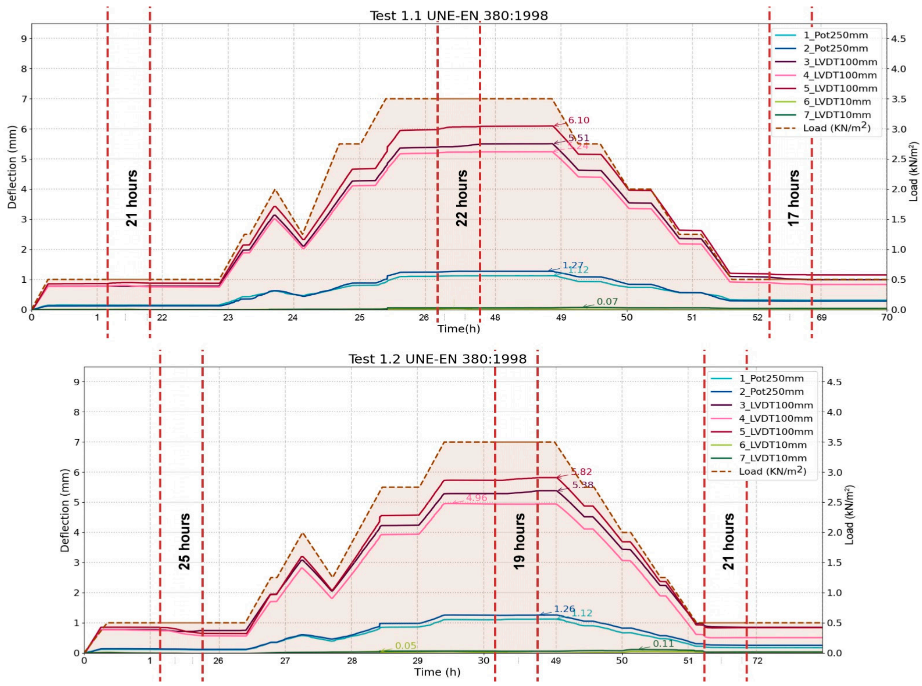

Figure 7: Load-deflection graph during UNE-EN 380 (1998) load tests. Above test 1.1, below test 1.2.

The analysis of the UNE-EN 380 (1998) load tests uncovered significant findings of great interest to our research. The most significant deformations were recorded at points 3, 4, and 5. In the first test, the deflection remained almost constant during the preload stage throughout the sustained load period. However, in the second test, the deflection decreased over time despite the constant load (Table 1). This variation in deflection highlights the importance of the preload phase. At the onset of loading, the structural system undergoes minor adjustments, which may introduce uncertainties and complicate the interpretation of results. To mitigate these effects and preserve the integrity of the experimental data, a preloading phase is implemented in every test to address and account for potential inconsistencies.

Table 1: Variation of deflections (mm) during the constant load stage in the preload.

Test	mm	1_HILO25 0	2_HILO25 0	3_LVDT10 0	4_LVDT10 0	5_LVDT10 0	6_LVDT1 0	7_LVDT1 0
1.1	Initial def.	0,15	0,12	0,78	0,77	0,86	0,01	0,01
	Final def.	0,15	0,12	0,78	0,75	0,87	0,02	0,01
	%	0 %	0 %	0 %	2,6 %	101,2 %	200 %	0 %
1.2	Initial def.	0,11	0,13	0,75	0,73	0,84	0,02	0,02
	Final def.	0,10	0,12	0,74	0,56	0,64	0,04	0,02
	%	9,1 %	7,7 %	1,3 %	23,3 %	23,8 %	200 %	0 %

The peak load during stages 2-4 impacted the deflections, as indicated in Table 2. Despite being subjected to the same load, the deflection at the centre of the span increased by up to 134 % in the first load test and 108,8 % in the second load test.

Table 2: Deflection variation for the same applied load before and after the peak load of stages 2-4.

Test	mm	1_HILO250	2_HILO250	3_LVDT100	4_LVDT100	5_LVDT100	6_LVDT10	7_LVDT10
1.1	Previous def.	0,43	0,35	1,98	1,89	2,15	0,01	0,01
	Subsequent def.	0,52	0,55	2,62	2,52	2,88	0,01	0,01
	%	120,9 %	157,1 %	132,3 %	133,3 %	134 %	0 %	0 %
1.2	Previous def.	0,35	0,35	1,95	1,71	1,94	0,01	0,01
	Subsequent def.	0,39	0,46	2,08	1,85	2,11	0,01	0,03
	%	111,4 %	131,4 %	106,7 %	108,2 %	108,8 %	0 %	300 %

Observing creep during the sustained maximum load stage has significant implications for understanding the structure's behavior (Table 3). In both tests, deflection increased under a constant applied load. This effect was also evident during recovery, with negative delayed deflection. These observations highlight the importance of considering the structure's behavior under sustained load conditions, as it can significantly impact its performance and safety.

Table 3: Variation of deflections during constant maximum load and recovery stages.

Test	mm	1_HILO250	2_HILO250	3_LVDT100	4_LVDT100	5_LVDT100	6_LVDT10	7_LVDT10
1.1	Initial def.	0,93	1,01	4,80	4,63	5,24	0,03	0,02
Loaded	Final def.	1,12	1,27	5,51	5,24	6,10	0,01	0,06
	%	120,4 %	125,7 %	114,8 %	113,2 %	116,4 %	66,7 %	300 %
	Initial def.	0,33	0,29	1,10	0,91	1,20	0,01	0,04
	Final def.	0,31	0,28	0,99	0,83	1,15	0,01	0,04
Recover	%	6,1 %	3,5 %	10 %	8,8 %	4,2 %	0 %	0 %
1.2	Initial def.	1,10	1,25	5,29	4,94	5,73	0,01	0,06
Loaded	Final def.	1,12	1,26	5,38	4,95	5,82	0,01	0,06
	%	101,8 %	100,8 %	101,7 %	100,2 %	101,6 %	0 %	0 %
	Initial def.	0,22	0,31	0,98	0,61	0,93	0,03	0,07
Recover	Final def.	0,17	0,24	0,83	0,51	0,85	0,01	0,04
	%	22,7 %	22,6 %	15,3 %	16,4 %	8,6 %	66,7 %	42,9 %

During both tests, the highest deflections occurred at the centre of the CLT span (sensor 5_LVDT100mm) at the end of the constant load stage. The asymmetry observed with sensor 3 may be due to its central placement, which is impacted by the joint between the CLT panels. These panels are stacked without being fastened together, and the longitudinal joint causes displacement variations around it. In the first load test, the maximum displacement variation between these two sensors was 9,7 %, and in the second load test, it was 8,6 %. The results of maximum deflections obtained are consistently below those calculated theoretically.

Load test according to DAfStb belastungsversuche (DAfStb 2020)

Figure 8 shows the time-deflection graph from the load tests conducted according to the DafStb Belastungsversuche (DAfStb 2020). Unlike the European standard, the German code is specific to concrete structures rather than timber ones. Given the lack of specific standards for load testing in timber structures apart from UNE-EN 380, this reinforced concrete code is utilised, and its cyclic methodology is examined to determine if it is also applicable to timber structures. Another significant difference is that this standard involves cyclic load testing, where the structure is subjected to the design load in consecutive cycles with a single loading and unloading step. The standard does not specify the periods for constant load or recovery after unloading, which is essential for timber structures. An initial test was conducted following the standard's guidelines.

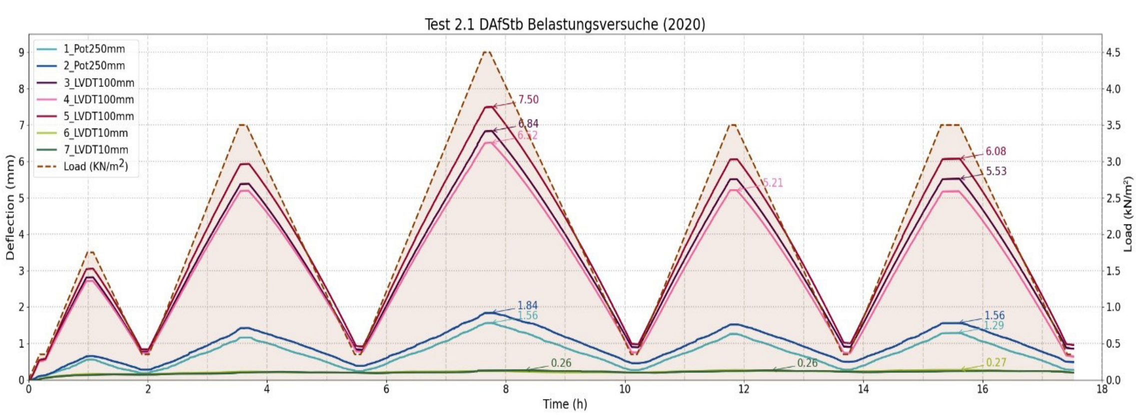

Figure 8: Test 2.1. Load-deflection graph during DAfStb Belastungsversuche (DAfStb 2020) load test.

The test lasted 17,5 continuous hours and was completed in a single day. Typical construction conditions do not usually include automatic systems for loading and unloading, making this methodology impractical due to its duration. As a result, a more feasible methodology was proposed due to the lack of defined times in the standard. This new methodology, which allows the load test to be spread over four workdays, is more practical and feasible for real-world applications. Additionally, it enables the study of the delayed deformation and recovery of the structure on a fifth day. The second test, conducted following this adapted methodology, duplicated the German code. The resulting time/deflection graph, shown in Figure 9, clearly demonstrates the practicality of the proposed method.

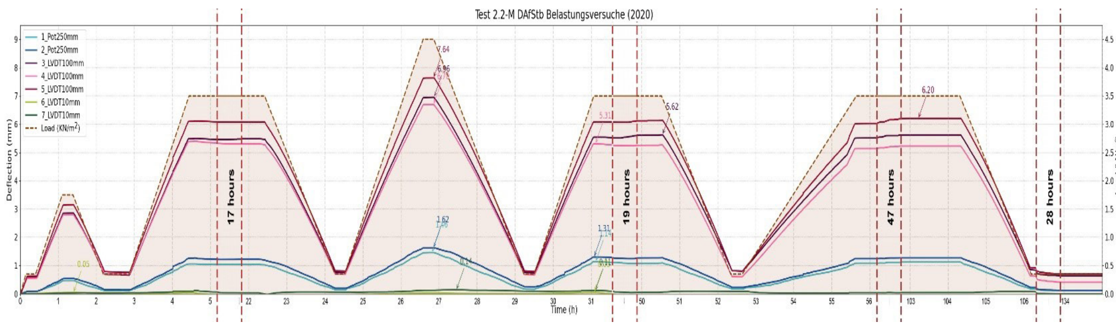

Figure 9: Test 2.2. The load-deflection graph during the DAfStb Belastungsversuche (DAfStb 2020) load test modified the procedure.

The analysis focuses explicitly on sensors 3, 4, and 5 results, indicating that the maximum deflections consistently occurred at point 5. Table 4 compares the maximum deflections obtained in each load cycle from the two tests, and it shows that the procedure modification did not significantly change the maximum results. The most notable variation was a 103,3 % increase in deflection at sensors 4 and 5 during cycle 1. Once more, the maximum deflections observed are consistently lower than those predicted by theoretical calculations.

Table 4: Deflection variation comparing the two load tests during the constant load stages of each cycle.

	Cycle 1			Cycle 2			Cycle 3			Cycle 4			Cycle 5		
Sensor nº	3	4	5	3	4	5	3	4	5	3	4	5	3	4	5
Test 2.1 (mm)	2,82	2,72	3,05	5,38	5,19	5,93	6,84	6,51	7,50	5,51	5,21	6,06	5,53	5,18	6,08
Test 2.2 (mm)	2,86	2,81	3,15	5,48	5,31	6,07	6,96	6,70	7,64	5,61	5,26	6,13	5,62	5,23	6,20
%	101, 4 %	103, 3 %	103, 3 %	101, 9 %	102, 3 %	102, 4 %	101, 8 %	102, 9 %	101, 9 %	101, 8 %	101, 0 %	101, 1 %	101, 6 %	101, 0 %	102, 0 %

The cyclic load testing method allows for observing hysteresis or fatigue phenomena. When comparing three cycles with the same load (cycles 2, 4, and 5), cycle 2 exhibited less deflection than cycle 5 in both tests. Table 5 displays the increase in deflection relative to the previous cycle.

Table 5: Deflection variation comparing the two load tests during the constant load stages of each cycle.

		Cycle 2	Cycle 4		Cycle 5	
		Max def. (mm)	Max def. (mm)	Increase %	Max def. (mm)	Increase %
Test 2.1	1_HILO250	1,16	1,26	8,6 %	1,28	1,6 %
	2_HILO250	1,42	1,52	7 %	1,56	2,6 %
	3_LVDT100	5,38	5,51	2,4 %	5,53	0,4 %
	4_LVDT100	5,19	5,21	0,4 %	5,18	-0,6 %
	5_LVDT100	5,93	6,06	2,2 %	6,08	0,3 %
	6_LVDT10	0,22	0,26	18,2 %	0,27	3,8 %
	7_LVDT10	0,20	0,24	20 %	0,24	0 %
Test 2.2 (modified)	1_HILO250	1,04	1,08	3,8 %	1,13	4,6 %
	2_HILO250	1,23	1,27	3,3 %	1,27	0 %
	3_LVDT100	5,48	5,61	2,3 %	5,62	0,1 %
	4_LVDT100	5,31	5,26	-0,9 %	5,23	-0,6 %
	5_LVDT100	6,07	6,13	1 %	6,20	1,4 %
	6_LVDT10	0,07	0,07	0 %	0,07	0 %
	7_LVDT10	0,03	0,05	66,7 %	0,04	-20 %

The discovery of non-linear deflection during unloading cycles has significant practical implications. Figure 8 and Figure 9 illustrate that deflection follows a slightly curved pattern during unloading, increasing almost linearly during loading. Comparing the strict German code approach with one adapted to a workday, reveals the importance of studying delayed deflection in timber structures. This study emphasizes the need to pay attention to deflection during constant load stages, particularly during the structure's recovery stage, where deflection reduces significantly compared to the immediate deflection after the last unloading stage (Table 6). This finding provides valuable insights for future testing procedures.

Table 6: Variation of deflections during the recovery phase at the end of the test 2.2

mm	1_HILO250	2_HILO250	3_LVDT100	4_LVDT100	5_LVDT100	6_LVDT10	7_LVDT10
Initial def.	0,18	0,23	0,85	0,64	0,93	0,03	0,08
Final def.	0,12	0,12	0,61	0,41	0,71	0,01	0,02
%	35,9 %	46 %	28,8 %	24,1 %	23,7 %	66,7 %	75 %

Comparison of the procedures of UNE-EN 380 (UNE 1998) and DAfStb belastungsversuche (DAfStb 2020)

The two load tests differ in their methodologies. The European standard involves a single loading and unloading stage, while the German code is cyclic. The German code (DAfStb 2020) is an updated version that suggests a more appropriate procedure. However, unlike the European standard, it is not explicitly focused on timber. Monitoring the constant load stages under maximum load and during the structure's recovery after the load test is crucial. The loading and unloading intermediate steps proposed by the European standard do not affect deformation under maximum load. These steps may make sense from a safety perspective, particularly in cases where the structure's condition is unknown or uncertain. This allows for real-time evaluation of the structure's behavior, minimizing risk and enabling the test to be stopped if necessary. It is recommended that these steps be considered advisable but not mandatory. The load peak proposed by the European standard reveals the delayed behavior of timber structures. On the other side, the repetition of the loading and unloading cycle, as proposed by the German code, seems more effective when extending the constant load stages as suggested in the modified version (test 2.2). The German procedure offers a more straightforward way to study the structure behavior.

Table 7 displays the maximum deflections recorded in each test. The results show little variation between tests. Consequently, other factors must be considered when selecting which type of load test to apply (Table 8). It is important to note that the experimentally obtained results differ by only about 20% from those derived theoretically, with the maximum deflection calulated at 7,2 mm at the middle span of the CLT slab.

Table 7: Maximum deflections (mm) obtained in the different tests conducted

Standard	Test number	3_LVDT100	4_LVDT100	5_LVDT100
UNE-EN 380	Test 1.1	5,51	5,24	6,10
	Test 1.2	5,38	4,95	5,82
DAfStb belastungsver-suche	Test 2.1	5,53	5,21	6,08
	Test 2.2 (mod)	5,62	5,31	6,20

Two aspects can be analyzed when comparing the procedures: time and water consumption. The German standard is significantly shorter than the European one, but the automation of the loading and unloading systems and large water volumes are required to complete the test in a single day. In other words, the shorter duration results in increased operational complexity. Regarding water consumption, a water reuse system was designed for the specific tests conducted. However, these standards are intended for load testing in buildings, where it may not always be possible to have a reservoir to store water for reuse. Therefore, the German code would consume 3,5 times more water than the European standard in a real-world scenario where water is used to load the structure. Considering that construction is one of the most polluting sectors, reflection on the sustainability of these procedures is essential.

Table 8: Comparison of standards UNE-EN 380 and DAfStb Belastungsversuche

	UNE-EN 380:1998	DAfStb Belastungsversuche
Material	Timber structures	Concrete structures
Methodology	Monotonic	Cyclic
Load application	Any type	Recommended hydraulic jacks
Year	1998	2020
Maximum deflection obtained	6,10 mm	6,20 mm
Time	4 days	17 hours
Water consumption	1	3,5
Phenomena studied	Creep, delayed deflection	Hystereis

CONCLUSIONS

There is a lack of consensus among European standards for load testing in building structures. They focus primarily on reinforced concrete and offer limited guidance for timber structures. Standardized testing methodologies are divided into cyclic and single-cycle (monotonic) tests. When comparing both types of tests, cyclic tests offer the advantage of quick execution but may require automated systems for loading and unloading. They can be completed in a single day, although the duration can still be excessive. On the other hand, the monotonic tests, which span over four days, better align with typical work schedules. Cyclic tests allow for the observation of structural hysteresis but do not capture delayed deformation and recovery, which are essential for timber structures and are monitored in single-cycle tests. From a practical perspective, overlooking these time-dependent effects can lead to underestimating long-term deflections or creep, potentially resulting in serviceability issues over the lifespan of a timber structure. Theoretically, this underscores the need for testing protocols that incorporate sustained loading phases, so that analytical or numerical models can accurately calibrate the creep behavior and reflect the real performance of timber components under prolonged loads.

The loading and unloading stages for timber should last at least 16 hours. Applying a stepped load does not alter the final results but enhances safety during execution. Hence, it could be recommended but not mandatory. Intermediate steps in the loading and unloading do not impact the maximum deformation under the target load. As in the cyclic test model, removing these steps could accelerate monotonic tests. The choice between monotonic or cyclic load tests depends heavily on the available resources and influences the test duration, because no significant differences have been found between maximum deflection results. To uphold environmental responsibility, it is essential to implement water reuse systems when using water as a load.

Future research should address the gaps and limitations to advance load testing standards for building structures. Here are some specific areas for future research: Expanding the study of load-testing standards to an international scope and promoting collaboration among researchers from different countries to compare methodologies comprehensively. This will facilitate the proposal of a globally accepted updated standard for timber structures. Calibrating analytical models based on static results obtained from the tests, focusing on joint behavior. Exploring dynamic tests and Structural Health Monitoring (SHM) techniques based on dynamic response and modal analysis. These techniques have successfully identified damage in buildings and civil works. However, the variability of timber's mechanical properties can conceal these modal variations, underscoring the need for careful consideration in future research. These research areas are of great urgency and significance.

Authorship contributions

P. V-C.: Conceptualization, data curation, investigation, methodology, visualization, writing-original draft. R. D. M.: Data curation, formal analysis, validation, writing-review and editing. G. L.z: Conceptualization, methodology, supervision, writing-review and editing. **Á.** I-P.: Investigation, formal análisis, visulaization, writing-review and editing. L-A. B.: Funding acquisition, project administration, supervision, writing-review and editing.

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