Fundamental Period of Timber Structures

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ABSTRACT

In seismic design, the fundamental period of a building is a key parameter for assessing earthquake actions. Due to modeling uncertainties and simplifications, especially in timber structures, verifying the plausibility of calculated periods is crucial. Accurate determination is essential: overestimated periods can underestimate seismic forces in force-based design, while underestimated periods may lead to overly conservative and costly bracing systems. Thus, it's a matter of balancing safety and cost-effectiveness. Since 2023, the research project "Guideline for Determining the Fundamental Period of Timber Buildings" has been conducting Ambient Vibration Tests (AVT) on approximately 50 timber or timber-hybrid buildings. For about half of these, a comparison is made between spatial structural models and correctly interpreted AVT results. The aim is to establish a reliable basis for both determining and validating the fundamental period of timber buildings. Preliminary results indicate that calculated periods from structural models are often too high. This discrepancy is largely due to unaccounted stiffness contributions from secondary seismic and non-structural elements, as well as other influences like dynamic effects, spatial interaction, and minor damage in the elastic range. These factors are actively studied within the project. Ultimately, the project will deliver a practical guideline for engineers, combining interpreted measurement data and model results. This will support more accurate assessments of fundamental periods, reducing uncertainty and helping achieve more balanced seismic designs for timber buildings.

Keywords: Fundamental Period, Ambient Vibration Tests, Timber Buildings, Dynamic Response

1. INTRODUCTION

In Switzerland, earthquake hazard is considered moderate according to the Federal Office for the Environment, yet seismic effects are often governing when designing bracing systems for buildings. Elastic response spectra serve as a key tool in assessing these effects. In the case of seismic loading, the dynamic response of a structure is considered, with the fundamental period playing a decisive role. There are various approaches to determine the fundamental period, but their results can vary greatly.

In timber structures in particular, simplified assumptions during modeling often lead to significant discrepancies between the calculated and actual fundamental period. The results must therefore be verified for plausibility. An overly long assumed fundamental period results in lower seismic forces and may lead to insufficient earthquake resistance. This raises the fundamental question of the extent to which spatial structural models, often based on simplified assumptions, are suitable for determining periods.

Of particular concern is the influence of secondary seismic elements on the dynamic behavior of buildings. Secondary seismic elements are load-bearing elements that are not part of the bracing system and thus are not intended to absorb seismic effects. Additionally, non-load-bearing components can significantly increase the stiffness of timber structures. This is particularly true because bracing systems in timber construction tend to be softer, making the stiffness contribution from non-bracing components proportionally large.

According to Eurocode 8 [1], the contribution of all secondary seismic elements to horizontal stiffness should not exceed 15 % of the contribution from primary seismic elements – i.e., those forming the bracing system. The draft of the new Eurocode 8 – Part 2 [2] contains the same provision. A similar regulation exists in the National Building Code of Canada (NBCC) [3], where the fundamental period can be reduced by less than 15 % due to the stiffness contribution of components not part of the bracing system, equating to a stiffness contribution of around 30 %. Additionally, the NBCC [3] stipulates that the seismic force-resisting system (SFRS) must be designed to withstand all seismic forces and that components not part of the SFRS cannot be used to resist seismic displacements.

In timber construction or buildings with timber bracing systems, the stiffness contribution of non-bracing components often significantly exceeds the limits set by the aforementioned standards (see Thommen [4] or Kunz [5]). This relatively low stiffness of timber bracing systems may be one reason why the draft of Eurocode 8 – Part 2 [2] introduces an empirically based limit for the fundamental period in Chapter 13 (specific rules for timber structures). The same limit is found in the NBCC [3], not only for timber construction, and refers to an empirical formula for estimating the fundamental period as a function of building height h.

$$T_{1,est} = 0.05 \cdot h^{0.75} \tag{1}$$

According to the draft Eurocode 8 – Part 2 [2] and NBCC [3], the fundamental period of timber buildings calculated via numerical or analytical models should not exceed $2 \cdot T_{1,est}$.

Using empirical formulas to limit or even determine the fundamental period of buildings can be considered a meaningful approach, as the underlying, correctly interpreted measurements capture the actual stiffness of a structure. For example, Hafeez et al. [6] conducted measurements on nearly 50 light-frame timber buildings using Low Amplitude Ambient Vibration Tests (LAAVT). These tests measure the vibrations of a building under very small displacements caused by natural and environmental excitations. The fundamental period can be derived from these measurements, although it does not directly correspond to the period during an earthquake, which involves significantly larger displacements. Due to the nonlinear structural behavior of timber buildings, the fundamental period increases considerably with increasing load or displacement. Furthermore, it should be noted that the mass present at the time of measurement may differ from the design-relevant mass.

Hafeez et al. [6] developed an empirical formula for the studied timber frame buildings that accounts not only for building height but also for the geometry of the bracing system and—indirectly through the floor area—the building's mass. The general equation is:

$$T = \alpha \cdot \left(\frac{h}{l} \cdot A\right)^{\beta} \tag{2}$$

Where h is the building height, l is the length of bracing elements in the considered main direction and A is the floor area. The ratio h/l indicates the slenderness of the bracing system, and A indirectly reflects the mass. The empirical regression parameters α and β are obtained from curve fitting and represent constants that best align the proposed period formula with the measured data. For the examined timber frame buildings, regression analysis yielded the formula:

$$T = 0.045 \cdot \left(\frac{h}{l} \cdot A\right)^{0.36} \tag{3}$$

As part of the *Guideline for Determining the Fundamental Period of Timber Buildings* project at the Institute for Timber Construction at Bern University of Applied Sciences, around 50 buildings made of timber or timber-hybrid systems are being tested using LAAVT. For approximately 20 of these, a comparison and correlation between LAAVT results and those from spatial structural models are also being carried out. This supports the accurate interpretation of LAAVT results as a basis for determining the fundamental period. Whether empirical formulas can be developed for different timber construction types remains to be seen. As the comparison between measurement and model results is still ongoing, this paper primarily presents findings from the LAAVT.

2. LAAVT ON TIMBER BUILDINGS

2.1. Methodology

The project includes a total of nearly 50 buildings with bracing systems made of timber and/or reinforced concrete. However, all buildings feature a portion of load-bearing components constructed in timber. Half of these buildings are federal properties, made available for measurement either by the Federal Office for Buildings and Logistics (BBL) or by armasuisse Real Estate. The second half consists of projects from engineering firms affiliated with the Swiss Timber Engineers (STE) association. For around 20 of these buildings, in addition to LAAVT, a comparison and reconciliation between the results from spatial structural models and the measurement data is being carried out. These investigations are currently ongoing and briefly outlined in Section 3, with detailed results still pending.

For the LAAVTs conducted as part of the project, velocity is measured at six positions within each building using MR3000 sensors (Syscom). Data acquisition is synchronized, ensuring that measurements are taken simultaneously at all locations. The recorded signals are divided into time windows, transformed into the frequency domain using Fourier transformation, and then cross-correlated in pairs. This makes frequency-dependent relationships visible, from which the natural frequencies or fundamental periods of the buildings can be determined.

In addition to the project's own measurements, results from literature are compiled that also involve LAAVT on timber buildings. The following sections provide a summary of these results.

2.2. Results from LAAVT on Timber Buildings

Figure 1 shows the fundamental periods determined from LAAVT as a function of building height for various types of bracing systems used in timber and hybrid construction. For some buildings, vertical lines connect the fundamental periods measured in the two main directions of the same building. The dashed lines represent the empirical estimation of the fundamental period as a function of building height according to Equation (1), as well as the previously mentioned upper limit of $2 \cdot T_{1,est}$.

For buildings with bracing systems made of cross-laminated timber (CLT), a distinction is made between CLT buildings (CLT A), in which all walls are constructed of CLT, and buildings braced with CLT components (CLT B) (see Lignum [7]).

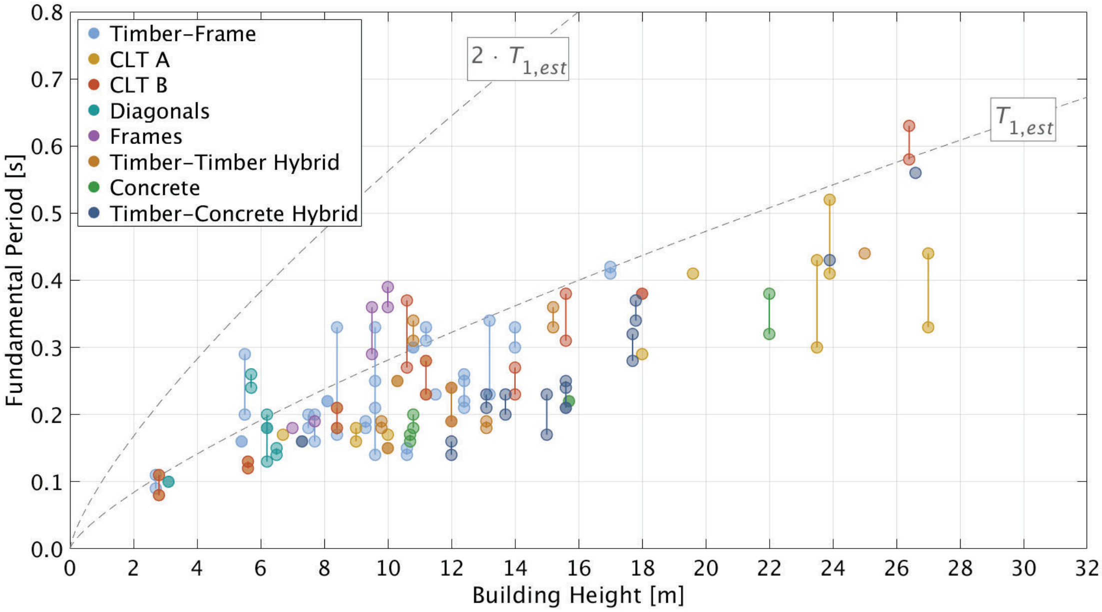

Figure 1. Fundamental periods from LAAVT for different types of bracing systems as a function of building height, compared with code-based estimations.

Figure 2 presents the same results but displayed separately for each bracing system. Additionally, the number of buildings and the number of stories is shown for each case. In the histograms, buildings for which measurements have not yet been conducted are shown in a lighter shade. In total, the graphic includes 75 buildings, with measurements still pending for five of them.

It can be observed that the fundamental periods estimated using equ. (1) for $T_{1,est}$ agree quite well with the LAAVT results for certain bracing systems—especially in buildings braced with timber frame walls and cross-laminated timber (CLT), where this trend becomes evident. The higher stiffness of CLT seems to be reflected in the results.

Furthermore, buildings with bracing systems that include reinforced concrete elements appear significantly stiffer, resulting in shorter fundamental periods. However, it is important to note that these are purely measurement-based results from LAAVT and must be correctly interpreted for application in seismic design.

2.3. Interpreted Measurement Results

As mentioned in the introduction, two aspects must be considered when interpreting the results from LAAVT. First, the measurements are conducted at very low amplitudes, which do not correspond to those expected under seismic loading. Due to the nonlinear behavior of timber structures - particularly timber joints - the fundamental period increases with increasing amplitude, a phenomenon referred to as frequency drop. Depending on the construction type, the increase in fundamental period ranges from 1.2 to 2.0. For most cases considered here, a frequency drop factor of approximately 1.4 to 1.5 can be assumed, though these findings are not yet conclusive (see Furrer [8]).

Second, it must be considered that the mass present in the building at the time of LAAVT does not correspond to the design-relevant mass. Various studies have shown that the difference between normative mass and the actual mass at the time of measurement can lead to an increase in the fundamental period by a factor of 1.1 to 1.5 (see Thommen [4] and Kunz [5]). A significant influencing factor in this context is the reference elevation h_0. In most cases, there is no snow on the building's roof during LAAVT, whereas according to SIA 261 [9], snow must be considered a concurrent load in seismic design for buildings above 1000 meters elevation. This is particularly important, as the snow load acts at the very top of the building, where it has the greatest influence on the fundamental period.

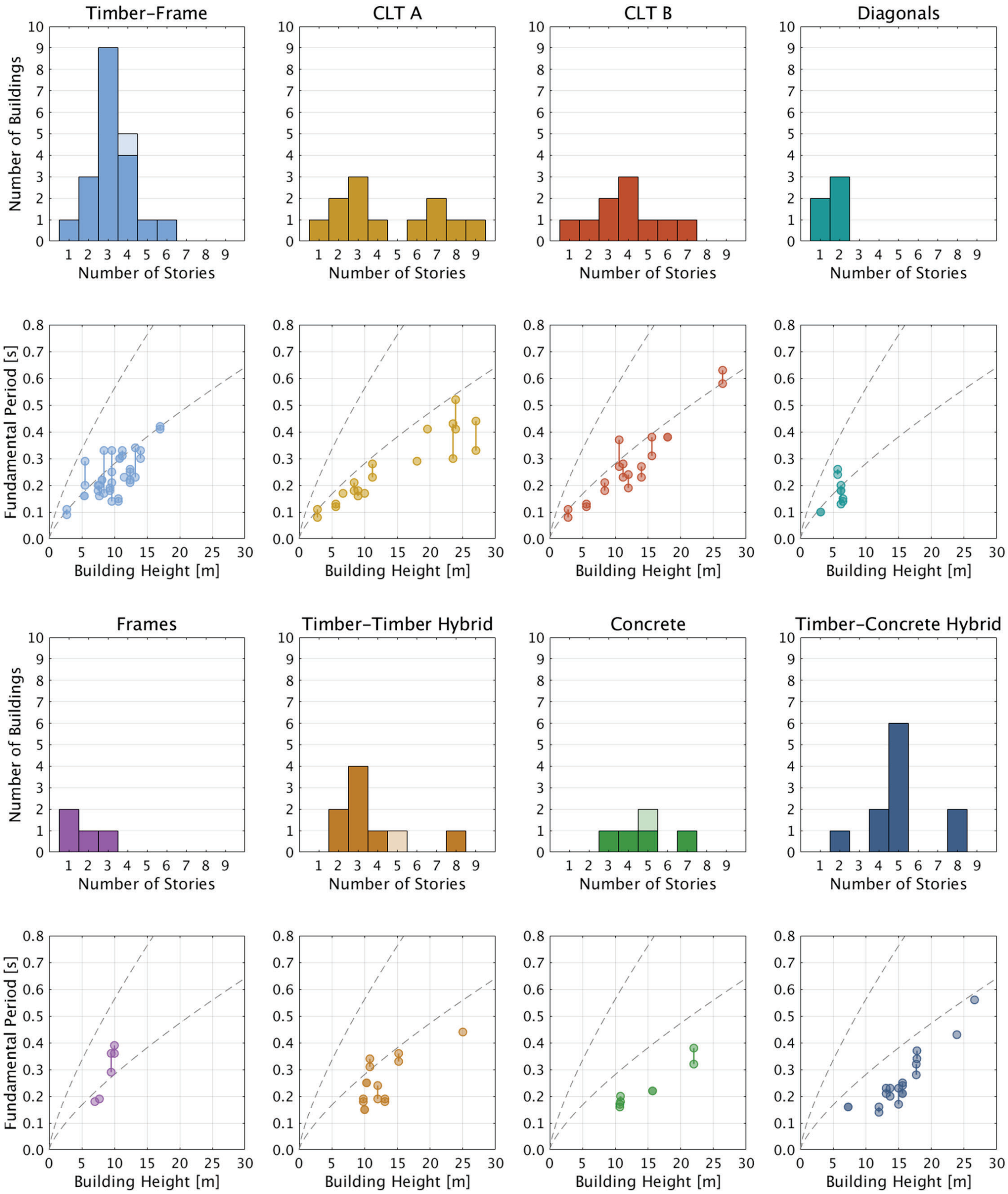

Figure 2. Number of buildings and number of stories, along with fundamental periods from LAAVT, shown individually for different types of bracing systems.

Since the presented research project is still ongoing, only generalized assumptions can currently be made regarding the described effects. These assumptions will be refined or addressed separately in the final project phase. Figure 3 shows the measurement results multiplied by a general factor of 1.7. This simplified assumption is based on an increase in the fundamental period due to frequency drop (factor 1.4) and the consideration of design-relevant mass (factor 1.2).

The figure also includes elastic response spectra according to SIA 261 [9] for five different soil classes, with the range above the corner period T_C shaded in gray. It becomes apparent that for a corner period of 0.25 seconds (soil classes A and E), the fundamental periods already lie on the descending branch of the response spectrum at building heights as low as 6 meters. This highlights the fact that accurately determining the fundamental period is often crucial for the cost-efficiency of buildings, even for low-rise structures. Another notable observation is that the corrected measurement results exceed the empirical upper limit of $2 \cdot T_{1,est}$ in only a few cases, suggesting that this upper limit is reasonable.

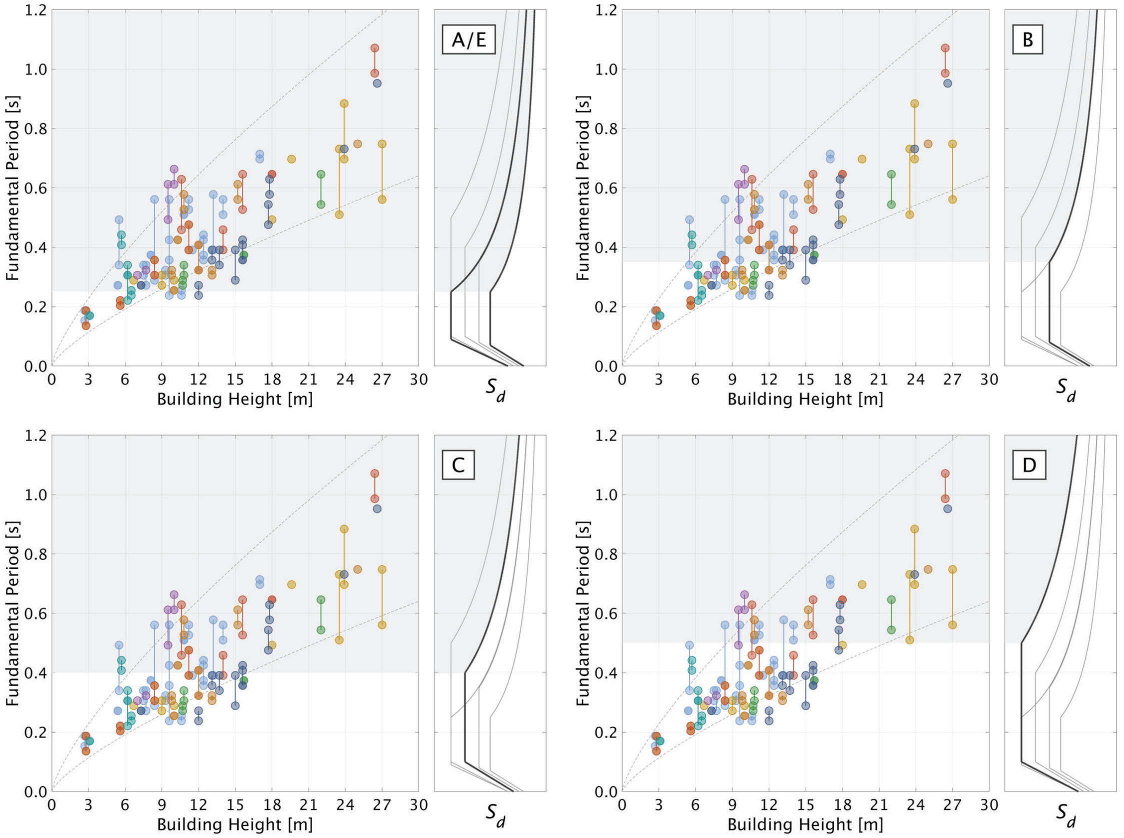

Figure 3. Generally interpreted measurement results (factor 1.7) and classification with respect to response spectra according to SIA 261 [9].

3. CONCLUSIONS

As mentioned, the project is now in its final phase, in which LAAVT results from around 20 buildings are being used to compare and calibrate with spatial structural models. The underlying methodology cannot be described in full detail here. In summary, two spatial structural models are created: one that includes only the primary seismic elements (P-model) and another that also includes the secondary seismic elements (PS-model). This allows the contribution of the secondary seismic elements to the overall stiffness to be quantified. By comparing the resulting fundamental periods from the PS-model with the correctly interpreted LAAVT measurements, it is also possible to estimate the stiffness contribution of non-structural components to a certain extent. These investigations are essential for assessing the compliance of simplified spatial structural models with design codes.

Another important aspect is the distinction between the design-relevant mass and the actual mass present at the time of LAAVT. By applying the actual present mass in the structural model and comparing the resulting fundamental period with the one obtained from the same model using the design mass, a more accurate interpretation of the LAAVT results can be achieved.

Ultimately, the overarching goal of the research project is to significantly simplify the determination of the fundamental period of timber buildings—an aspect influenced by numerous factors and typically requiring considerable effort to calculate accurately using numerical or analytical models. Where possible, simple empirical formulas should be developed that allow the fundamental period of a building to be estimated, considering the structural and geometric properties and the type of bracing system used.

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