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Analysis of timber log-house construction system via experimental testing and analytical modelling

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HIGHLIGHTS

- Performance of log-house construction systems under lateral loading.
- In-plane behaviour of *Standard half-lapped joint* and *Tirolerschloss joint* systems.
- Monotonic and cyclic testing of single corner joints and full-scale wall specimens.
- Proposal of a simplified rheological model.

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ABSTRACT

The paper presents the outcome of a research on the in-plane behaviour of two different log house construction systems when subjected to lateral loading. Such systems, identified by the way the logs are joined together are: the *Standard half lapped joint* (ST) system and *Tirolerschloss joint* (TR) system. Two stages of experimental testing were carried out at the laboratory of the University of Trento. In the first stage the focus was on the corner joints and on a possible wall reinforcement system (22 monotonic and 5 cyclic tests were performed). In the second stage full-scale wall specimens were tested (5 monotonic and 5 cyclic tests). Several layouts were investigated: 4.2 m long walls with thin (TR and ST) or thick logs (ST); "short" walls (2.75 m long); walls with openings.

The test results highlighted some critical aspects in the in-plane behaviour of the walls. The lateral load carrying capacity of the wall appeared to be influenced by two main phenomena: friction and corner-joint interlocking. Due to mounting tolerance a large displacement was required to fully engage the corner joint resistance. A large horizontal plateau characterized the post friction part of the load displacement curve (wide plateau) both for ultimate limit state (ULS) and serviceability limit state (SLS). The cyclic tests showed a high level of energy dissipation that was attributed to the "inter-log friction". In order to have a better insight into such aspects, a simplified rheological/analytical model was developed by using the experimental data as input parameters. A good agreement between the model output and the experimental behaviour was obtained.

1. Introduction

Log-house (LH) is a traditional construction system that is widely used in the northern regions, where large amounts of straight and tall trees were easily available. The constructive principle of the walls is the superposition of linear elements connected to the orthogonal walls by corner joints.

Records show that this construction type has its roots in the late Bronze Age (1100–1800 BC), most likely in Northern Europe. Originally, the structures were fairly simple and less architecturally sophisticated constructed with round overlapping logs with moss covering the gaps between the logs. Due to the good insulation properties of solid wood, the robust design and the fact that a log structure can be erected relatively quickly in all weather conditions, the log-house system found wide application in many countries such as Scandinavia, Northern Russia and the Alpine region.

In modern constructions, logs are squared solid wood or laminated beams. The logs are locked together with single or multiple tongue-and-groove connections that facilitate the assembly and improve the wall stability. This milling ensures also an improved building airtightness.

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Although the system may appear extremely simple at a first glance, the construction details require very careful design. The load inclination to the grain (90°) and the effects of moisture content variations, are two of the most critical factors that can limit the use of the log-house system. Log shrinkage/swelling in the direction perpendicular to the grain can in fact range from 1 cm to 3 cm per meter in the worst environmental conditions [1]. This fact implies a series of both structural (special joints) and non-structural (e.g. door/window fixing, insulation etc.) issues.

Special devices that allow for such dimensional variation of the structural elements need therefore to be adopted.

1.1. Mechanical behaviour

Log houses are typically classified as "load-bearing wall" structures. Each wall has usually both space-defining and structural functions. Both vertical and horizontal loads are transferred to the foundation through external and internal walls.

Vertical loads are transferred from the floors to the foundation through compressive stress perpendicular to the grain. Wall vertical instability is prevented by the intersection with orthogonal walls. The horizontal load bearing capacity is provided by the friction force and the interlock between the logs.

Despite several corner-joint typologies have been developed over the centuries, the most common solutions are based on two basic configurations namely *saddle notch* and *dovetail*. These interlocks at the end of the logs ensure the connection between the overlapped elements.

The interaction between the two resisting mechanisms is quite complex because, unlike friction, the contribution of the corner joints is activated only after an initial gap. A typical lateral-load versus horizontal-displacement curve for a log-wall is given in Fig. 1. A large horizontal plateau (governed by dynamic friction) is visible between the "initial friction regime" and the phase where the interlocking effect is engaged. Therefore, when no fasteners are used, mounting tolerance is the critical parameter in determining the response of the system.

The influence of the mounting gaps is even more evident when looking at the wall-response under cyclic loading. As shown in Fig. 1b, when the tolerances are larger than the displacement imposed by the actuator, the system behaves almost like a "friction damper" with the typical square hysteresis loops. When the total gap between the logs is overcome both friction and interlocking are active and the slope of the backbone curve increases.

The system behaviour can be improved by introducing timber (dovetail shaped) reinforcing elements or steel fasteners (self-tapping screws or dowels). Such inter-log connection strategies, are often used when the architectural layout has a limited number of corner joints or when wide openings interrupt the log-element continuity. These solutions could be used systematically in order to achieve a more efficient behaviour. As for the traditional LH systems, a careful evaluation of the compatibility issues due to dimensional variations induced by humidity changes and loading perpendicular to the grain must be done.

As concerns the structural design, the LH system is completely different from the other timber "load bearing wall" systems such as the light timber frame system (LTF) and the cross-laminated timber platform system (CLT). In LH structures, the force distribution and the resistance are influenced by the number of intersections (and therefore independent from the length of the wall) and by the magnitude of the vertical load (friction mechanism). Conversely in LTF and CLT systems, strength and stiffness are correlated with the number and the position of the connections (and therefore dependent on the wall length).

The behaviour of these systems, as shown in Fig. 2, is completely different in term of stiffness, maximum load and energy dissipation.

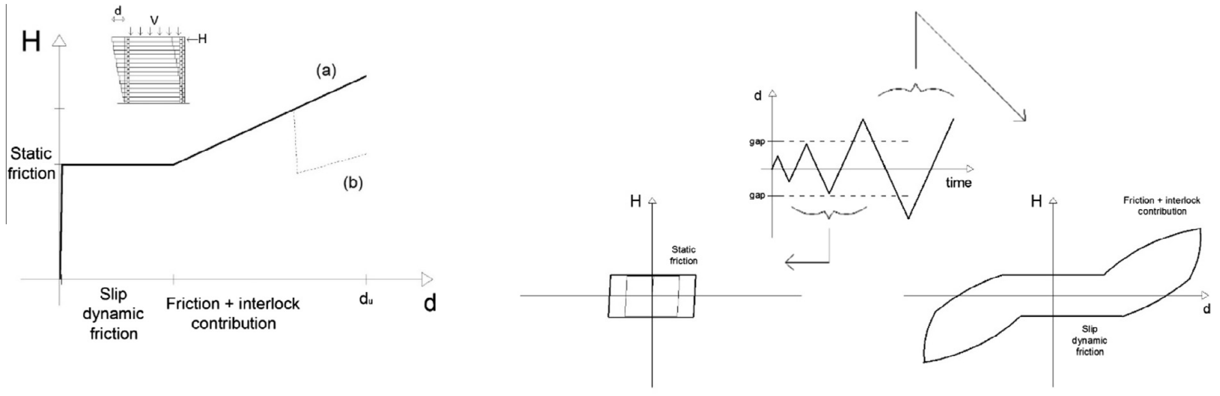
The horizontal load carrying capacity of LTF constructions has been deeply investigated by several authors from different countries over the last fifty years [4,12]. Analytical models and calculation approaches have been validated on data from extensive testing performed at different scale levels. The current design codes, deriving from the outcome of such research efforts, provide effective rules and prescriptions for the design of LTF buildings.

On the contrary, the common design approach for log-houses is based on verifying the resistance of the single carpentry joints (compression perpendicular to the grain, tension, shear/rolling-shear), with no focus on the global response of the structural system. For instance, nor specific rules or general guidelines are provided for the seismic design of this king of structures and the LH system is not explicitly treated in the current standards that deal with constructions in earthquake prone areas (e.g. Eurocode 8; Italian building code). This paucity of provisions and recommendations can be partially attributed to the great variability in construction techniques and materials.

Log house buildings can be built by using different timber cross sections, different materials (solid-wood; glued-laminated timber) and by adopting a wide range of corner joints (double-saddle notch, dovetail notch, half-cut notch, half-dovetail notch, V-notch etc.).

1.2. State of the art

Considering that LH system has been generally treated as a "non-engineered" construction technology, few research studies



(a) (b)

Fig. 1. Log house shear wall behaviour: monotonic test (a) and cyclic test (b).