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In This Issue:
Log Structures

Editorial

For regular readers of *Wood Design Focus*, you'll note that this is the first issue devoted specifically to log structures, a growing faction of the custom home market. In this issue we'll cover several topics unique and relevant to log structure design and construction.

First, Bob Leichti of Oregon State University shares some results of recent tests on log shearwalls. This is a vitally important area to the log structures industry as more designers and building officials are seeking information for design of log buildings in high seismic and wind regions.

My contribution on energy performance of log structures provides an overview of the work done over the last several decades in the area of thermal mass research. The approach presented provides designers with a code accepted methodology for calculating the energy performance of log structures.

Next, Dalibor Houdek of Forintek Canada, outlines his results of fire tests on a log wall assembly. This is another important area for code acceptance of these types of structures.

Finally, Ed Burke of the University of Montana gives a snapshot of the log grading procedures and establishment of design values for logs used in structural applications. Design values provide the starting point for any design of a log structure.

You might be interested to know that much of the material discussed in this issue of *Wood Design Focus* is making its way into a standard being developed by the International Codes Council (ICC) called *Standard for Design and Construction of Log Structures*. I have the privilege of chairing the committee tasked with that effort, and while it's a difficult and sometimes tedious process, the draft is shaping into something that will provide great value to the industry.

I hope you find the information in this issue helpful. As always, we appreciate your comments and suggestions.

Rob Pickett
Contributing Editor
Rob Pickett & Associates

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Lateral Resistance of Log Walls and Foundation Anchorage

Robert Leichti, Randy Scott, and Thomas Miller

Abstract

Lateral force resisting systems are reviewed in the context of log structures. Lateral force pathway is discussed from the wall through the foundation anchorage. It is shown that construction and design details have an effect on lateral force resistance and stiffness. The role of inter-log connection hardware is essential to lateral force resistance in log buildings with many or large wall perforations. Common anchorage details appear to be adequate.

Introduction

Log structures are part of American history and the contemporary building inventory. Early structures were low, squat buildings with few wall perforations for windows and doors. However, newer log structures more often than not are large, have many and/or large wall perforations for windows and doors, and include high aspect ratio wall segments. Just as in older log structures, new log buildings incorporate interlocked corner connections, and in certain types of log structures, the wall height changes dimension during the life of the structure as the logs lose and absorb moisture. Although interlocked corners develop considerable integrity in the building system, joints at window and door openings must permit slip to accommodate moisture response dimensional change if logs are installed with a high moisture content.

Log shearwalls are also bearing walls and resist lateral loading through a different mechanism than light-frame walls. A typical log wall is illustrated in **Figure 1**. In light-frame walls, lateral loads are transferred from the top plate to the foundation through the nailed sheathing. However, according to Haney (2000), lateral loads in log shearwalls are transferred from top plate to foundation through log-to-log friction, inter-log hardware, and inter-wall corner connections. Light-frame and log shearwalls also dissipate energy differently. Nail fatigue, nail withdrawal, and nail pull-through are important energy dissipation mechanisms in light-frame shearwalls. However, log-log slip is a critical energy dissipater in log shearwalls.

In a recent research project, Scott (2003) examined foundation anchorage and base shear capacity for log buildings and the effect of construction details on lateral force resistance in log walls. The objective of this paper is to describe some basic features of log construction and relate those to performance expectations. For more details, the reader is directed to Scott (2003), Scott et al. (in press), and Scott et al. (in review).

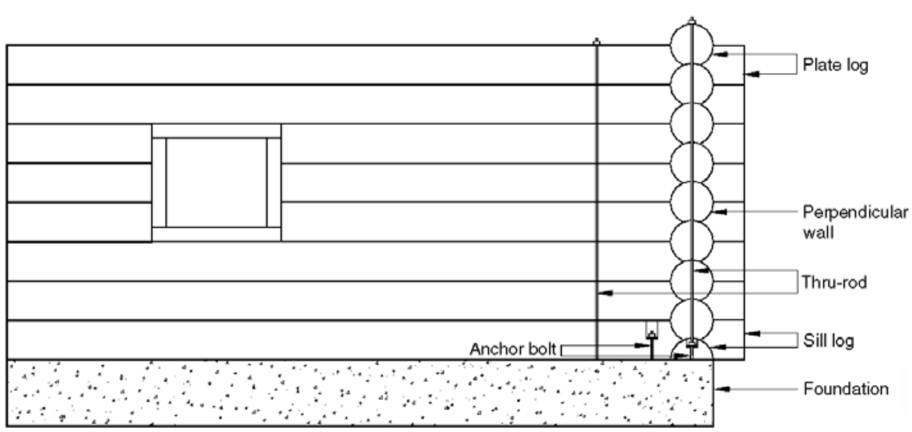

Figure 1.—Log wall including a window opening and an inter-wall connection on a rigid foundation (after Scott et al. in press).

Foundation and Base Shear Capacity

Foundation anchorage is an important component of seismic performance in log buildings. Mahaney and Kehoe (2001) provided literature review on the subject of foundation anchorage for light-frame buildings. Log structures are placed on foundations that are similar in design to those used for light-frame wood and masonry construction. Shear forces that develop at the base of the wall are transferred from the sill log (bottom log in the wall) to the foundation by anchor bolts. A standard anchor bolt spacing is 1,830 mm (72 in.), and anchor bolt holes are oversized to facilitate construction. Anchor bolts lose tightness if the log shrinks due to drying (Scott et al. 2002), and anchor bolt nuts may be inaccessible so they cannot be tightened later in the life of the structure. In addition, the building mass is somewhat greater than a light-frame building and connection geometry is different because the log diameter is greater than the thickness of a typical 2x sill plate.

Two foundation/anchorage details are common to log structures (**Fig. 2**). The first has the log wall sitting on the floor diaphragm. In this case, the anchor bolt must be long enough to extend from the top of the foundation wall through the floor cavity and finally through the sill log. In the second design, the sill log is in contact with the foundation wall. In this instance, the anchor bolts pass from the foundation directly into the sill log.

Inter-log connectivity is provided by either a set of thru-rods or lag screws. Thru-rods are continuous threaded rods from the plate log (top log in the wall) to the bottom of the floor diaphragm or to coupler nuts threaded on anchor bolts. Lag screws or spikes are also used to enhance force transfer between logs. Thru-rods can be tightened by automatic take-up springs or by manually tightening the nuts at the top plate if the building system shrinks, but lag screws and spikes are not accessible and are not tightened later.

A series of tests was conducted to evaluate the effectiveness of the two foundation/anchorage designs. The test systems were assemblies that included all components of each foundation, sill log, and anchorage hardware. Static tests of each were performed and these were followed by a set of quasi-static tests based on the CUREE test protocol (Krawinkler et al. 2000). The test configuration included a vertical load to mimic dead and live loads in the designed wall system as well as the lateral loading mechanism. Details of the testing apparatus and protocol are given by Scott (2003).

Test results, as shown in **Figure 3**, for each of the foundation/anchorage details showed that friction between the sill log and the sill plate is an important part of system behavior. The open boxy shapes of the hysteresis diagrams are typical of friction damping behaviors. These tests were terminated when the lateral force reached 44 kN, which was before the system was destroyed. For the sill log on the floor diaphragm, the system was still accepting load at 44 kN (9,892 lb.), but it appeared that the ultimate yield mode included the rim board to sill plate toenail connection. In the system with the sill log on the foundation wall, the sill plate sustained damage, but the system capacity was limited by anchor bolt bending.

For seismic design, the *Uniform Building Code (UBC)* (ICBO 1997) requires that structures be designed for an earthquake load (E), where:

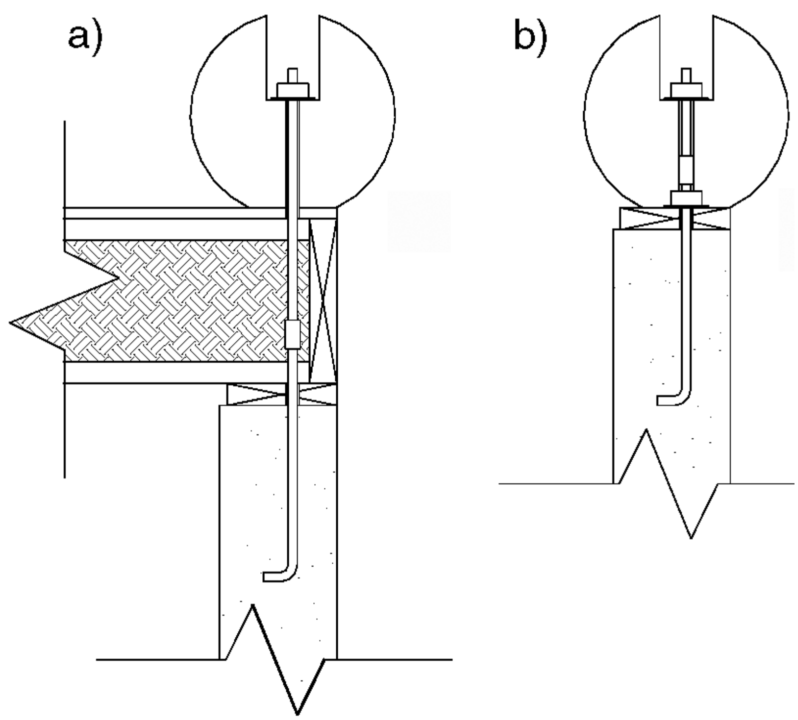

Figure 2.—Typical foundation details for log buildings. (a) sill log on floor diaphragm; (b) sill log on concrete foundation wall (after Scott et al. in press).

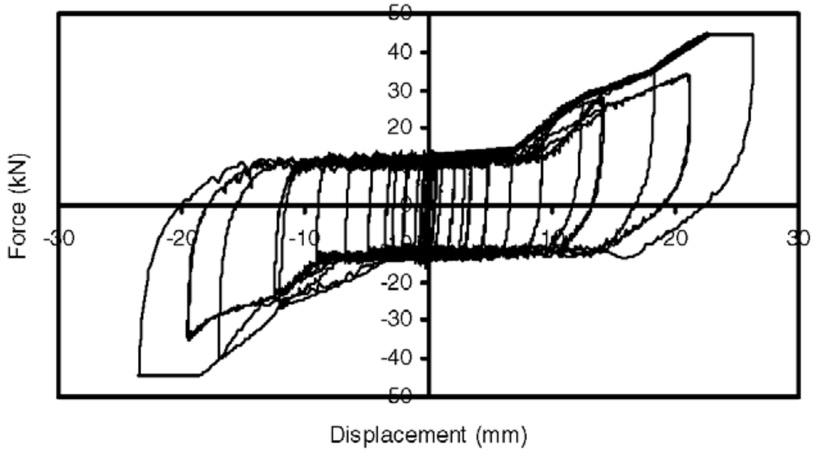

Figure 3.—Hysteresis diagram from a fully reversed quasi-static test of a sill log on a floor diaphragm (after Scott et al. in press).

$$E = \rho E_h + E_v \qquad [1]$$

The redundancy factor ρ has an upper bound of 1.5. E_h is the load due to horizontal ground motion (base shear), while E_v is the load effect attributed to vertical ground motion and is zero for allowable stress design.

The *UBC* base shear formula is

$$V = \frac{C_v I}{RT} W \qquad [2]$$

The *UBC* also defines the upper bound for base shear as,

$$V = \frac{2.5 C_a I}{R} W \qquad [3]$$

where:

C_v = 0.64 and C_a = 0.44 are seismic (response spectrum) coefficients (*UBC* Tables 16-R and 16-Q), respectively,

I = 1 is the importance factor (*UBC* Table 16-K),

T = 0.111 sec. is the fundamental period that is calculated following *UBC* equation 30-8 for height = 3 m (9 ft.).

For a bearing wall system, the base shear is most conservatively estimated (the objective here) by using R = 2.8, which would be used for a light steel frame, whereas R = 4.5 for masonry would be more appropriate for design practice. Calculations show that the upper bound for V controls for this log structure. Seismic dead load is W and includes the weight of the wall and the roof. When the upper bound is divided by 1.4 to convert from strength level to allowable stress design E = 9.16 kN (2,059 lb.) for a representative wall that is 2.44 m (8 ft.) long.

The foundation/anchorage assemblies reached lateral forces of at least 44 kN (9,892 lb.). Thus, the ratio of capacity to design is at least 4.8, which is consistent with the factor of safety for mechanical connections.

Modeling the Effect of Construction Details

To model the effect of construction details, the lateral force resisting mechanisms of shearwalls can be incorporated into finite-element models. In light-frame shearwalls, nail behavior is critical to global model effectiveness. Each nail is modeled with one or more nonlinear spring elements or multiple stiffnesses. This results in a large number of elements and complex path-dependent functions. In contrast, a model for a log wall needs fewer elements because there are fewer mechanical connections.

Common construction practice places thru-rods 200 to 300 mm (8 to 12 in.) from the end of each wall, the same end distance around each window and door opening, and 1,830 mm (72 in.) on-center along the wall. Thru-rods pass through oversized holes and are continuous from the plate log to the sill log or foundation. A common approach is to post-tension thru-rods to 4,450 N (1,000 lb.) using continuous take-up springs at the top of the wall.

Gorman and Shrestha (2002) tested two log walls using the sequential phase displacement test method. The walls were made with manufactured logs and were 3.44 m (11.29 ft.) long and 2.44 m (8 ft.) tall. Thru-rod hardware was included. Their tests showed that log shearwalls with thru-rods exhibit initial linear behavior followed by slip and additional capacity, which is observed as an ascending load-displacement response before failure. This is the same behavior that was seen by Scott (2003) while testing log building foundation/anchorage assemblies.

Finite-Element Models

Wall dimensions, rod placement, and boundary conditions closely matched the log walls tested by Gorman and Shrestha (2002). The finite-element model was 2.44 m (8 ft.) wide by 2.44 m (8 ft.) high and 153 mm (6 in.) thick. Two thru-rods extend from the top to the bottom of the wall and are located 203 mm from each end. The model consists of solid, beam, nonlinear spring, and elastic spring elements. The logs are modeled as rectangular bodies using structural 4-node, plane-stress elements and are assigned elastic properties typical of Douglas-fir. The thru-rods, represented by beam elements and assigned properties of low-carbon steel, were pretensioned at various levels as part of the parametric investigation. The two separate effects of thru-rods being in oversized holes and bearing at the edge of the holes were combined into a single nonlinear spring where the initial force-displacement response is due to the oversize hole, and the second part of the response is the thru-rod bearing on the edge of the hole. The models included log-log friction as represented by nonlinear spring elements and log weight. Details of the modeling process, force-displacement behaviors, boundary conditions, and loading are given in Scott (2003). A parallel basic model was developed for the two basic foundation/anchorage systems.

Finite-Element Results

The log shearwall model has three main behaviors in the load-displacement diagram as shown in **Figure 4**, where displacement is the horizontal motion of the top plate log. The wall begins to slip at the top plate and then slips at consecutive interfaces between the logs following a top down displacement process because the models have both weight and inter-log friction. The first section, ***0a***, represents system stiffness before friction is overcome (initial stiffness). At point ***a*** (slip force), friction is overcome so that path ***ab*** represents slip displacement, which is limited by thru-rod and anchor bolt oversized-hole slack. The third section (post-slip stiffness), ***bc***, represents system stiffness after the slack is taken up and the thru-rods and anchor bolts are engaged.

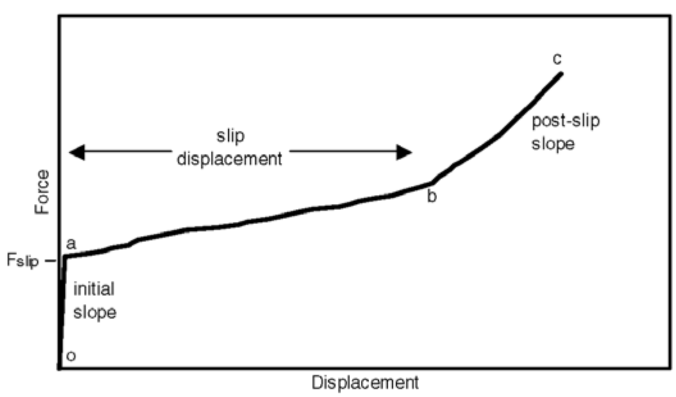

Figure 4.—Basic force-displacement curve for a log shearwall with thru-rods (after Scott et al. in review).

The wall model is compared to the backbone curve from fully reversed cyclic tests by Gorman and Shrestha (2002) in **Figure 5a**. **Figure 5b** shows the foundation model compared to data generated in the Scott (2003) foundation/anchorage tests.

A series of parametric studies were undertaken to assess the effects of friction as generated by thru-rod hardware, window and door openings, and wall aspect ratio. In all, 14 models were developed to evaluate the effect of construction variables on lateral force resistance and stiffness of log shearwalls. It was shown that:

- Wall performance is strongly influenced by the coefficient of friction and the normal forces developed by thru-rods. Thus, maintaining the thru-rod tension will enhance building system performance under seismic loads.
- Changing the wall aspect from 1:1 to 2:1 decreased the post-slip stiffness and increased overall wall displacement more than any other attribute. High aspect ratio walls may require additional stiffening.
- Additional thru-rods are often included in construction details for doors and windows and are important to minimizing the effect of wall perforations.
- Thru-rod hole size affects overall wall displacement. Minimizing the hole diameter minimizes slip displacement potential.

Conclusions

The foundation/anchorage systems used for contemporary log structures appear to be adequate for lateral force resistance, and the anchor bolts can be designed using the yield mode provisions of the *National Design Specification® for Wood Construction* (AF&PA 2001). Safety levels appear to parallel those for dowel-type connections used in wood construction.

Finite-element models have reproduced basic behavior of log wall systems and were extended to assess several

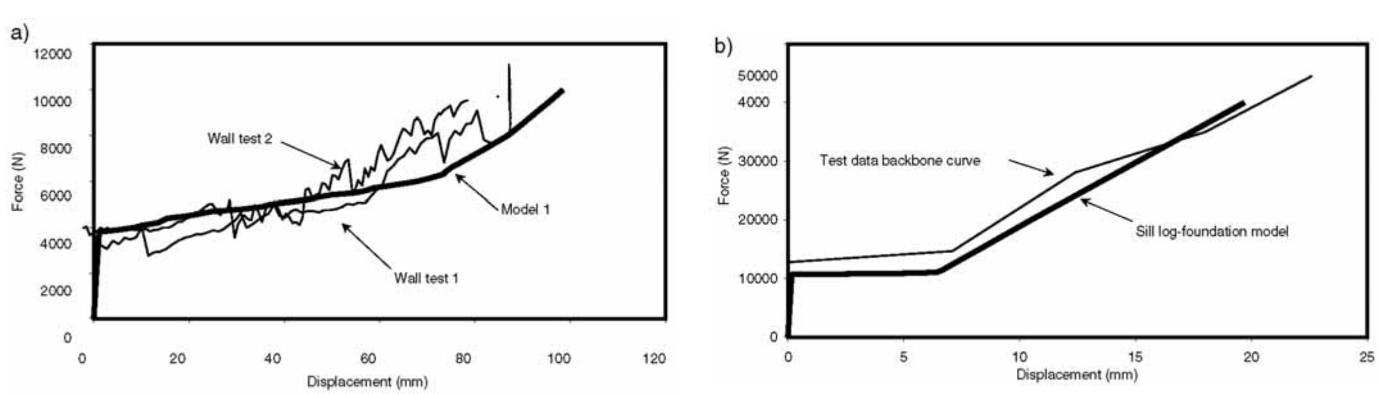

Figure 5.—Test data and finite element model results for (a) the log wall model and test backbone curves from Gorman and Shrestha (2002), and (b) the foundation anchorage model and text backbone curve from Scott (2003).

common construction details including thru-rod tension, wall perforations, and thru-rod hole sizes. Further studies are planned to examine the three-dimensional behavior of log structures as affected by wall interconnection and the roof diaphragm.

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Robert Leichti, Associate Professor of Wood and Fiber Mechanics; Randy Scott, formerly Graduate Research Assistant, Department of Wood Science and Engineering; and Thomas Miller, Associate Professor, Department of Civil, Construction, and Environmental Engineering, Oregon State University, Corvallis, OR. This paper is based on the MS thesis written by the second author.

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Energy Performance of Log Homes

Prepared by the Technical Committee of the Log Homes Council, Building Systems Councils, National Association of Home Builders

Background

With the accelerating growth of log home construction across the United States, the National Association of Home Builders (NAHB) Log Homes Council conducted a comprehensive review of the available studies that document log homes' energy efficiency and thermal mass benefits to help improve understanding in the construction codes and HVAC engineering community.

A log home constructed of 7-inch solid wood walls might have an indicated steady-state R-value of R-9, but in most U.S. climates – especially those where log homes are most popular – a stick-framed home would have to be insulated to about R-13 (or even R-15 in some areas) to perform as well for heating and air-conditioning energy use on an annual basis. This comparison assumes similar attic insulation, window performance, foundation design, and the use of identically efficient mechanical systems for heating and cooling. In practical terms, log homes may be expected to perform from 2.5 percent to over 15 percent more energy efficiently compared to an identical wood-frame home, considering annual purchased heating and cooling energy needs.

Steady-State Calculations: R-value and U-factors

Engineers use design conditions where steady-state values must be estimated to predict maximum loads for sizing

HVAC equipment. The term "steady-state" means the indoor comfort temperature is compared to outdoor design temperatures and then used with estimated heat-loss factors over the surface areas of the building. These data are used to calculate "worst-case" heating and cooling loads that may be placed on a buildings' mechanical equipment during its useful life. For a specific location, long-term weather data is used with simplified calculations to estimate how large a mechanical system may be needed. These calculations are done for a specific building depending on its surface areas, insulation levels, windows and doors, foundation type, and assumptions about how much air leaks into and out of the exterior "shell."

A building materials' "R-value" is a measure of its resistance to heat flow over the thickness of the material, or over a fixed thickness (R- per inch for example). In reality, building assemblies – such as walls, the roof, or other sections – are put together from a variety of materials, each layer or section having its own R-value. The engineer calculates the overall system thermal effectiveness (U overall or "U_o") using equations that represent the assembly thermal transmittance, which is then reported as a U-factor. The U-factor is the reciprocal of the calculated assembly's R-values over their effective heat flow pathways. These R-value data are reported in design manuals and manufacturer's data sheets, and conform to regulations put forth by the U.S. Federal Trade Commission (FTC) in the mid-1970s.

ASHRAE Based Standards — Situation Analysis

Prior to 1989, the CABO *Model Energy Code (MEC)* [now the *International Energy Conservation Code* (*IECC*)] did not contain adjustments for considering heat capacity influences on annual heating and cooling in buildings. All wall assemblies were treated as if they had similar performance, and the compliance calculations in the model code were entirely based on steady-state assumptions about material physical properties.

This changed with the 1989 edition of the *MEC*, when new thermal mass correction factor tables based largely on work done in the DOE Thermal Mass Program (1979–1985) were approved. **Table 1** illustrates the correction factors that are now accepted in the *IECC*, and connected codes such as the *International Residential Code* (*IRC*) which is now becoming more widely referenced by state and local jurisdictions.

Similarly, considerations of both a building's thermal protection system and the relative economics of delivering the needed thermal protection levels, were used in developing mass wall curves for the ASHRAE Standard 90.2-1993 *Energy Efficient Design of New Low-rise Residential Buildings*. In this standard – adopted in late 1993 but never widely implemented in model codes due to complexity and opposition by builder groups – a combined approach was used to generate compliance information. The effort was based both on building economics (relative life cycle cost scales for different unique construction systems) and for the first time simultaneous use of heating and cooling weather data as opposed to only heating criteria.

Properly Calculating Thermal Mass Correction for Log Walls

This section will help clarify the correct approach to calculating and reporting heat capacity (thermal mass) corrections. Mass wall correction data are shown in *IECC* Chapter 5: Section 502.2.1.1.2 *Mass Walls*.

However, prior to discussing mass wall corrections, it is important to understand how they are used in model-code overall compliance calculations of residential walls. The 502.2 *IECC* section covers compliance by analyzing individual components of the building's thermal shell – walls, roof, ceilings, foundation, etc.

Analysis begins with consideration of the combined thermal transmittance of the exterior walls of the building, over the total gross surface area including both the opaque wall sections, and the windows and doors. Where there is more than one type of structural wall, window, or door used, their relative areas and thermal transmittance factors must be expanded to include the specific information needed for accurate calculations. For example, if a house has both log walls and a masonry wall in its exterior shell, then proportional areas and thermal transmittance factors for both types of walls need to be included, not simply lumped to-

Table 1.—Required U_w (U-factor of opaque walls) for walls having sufficient heat capacity.

Heating degree days	Uw required for walls with a heat capacity less than 6 Btu/ft.^{2}°F as determined by using Equation 5-1 and Figure 502.2*										
	0.24	**0.22**	**0.20**	**0.18**	**0.16**	**0.14**	**0.12**	**0.10**	**0.08**	**0.06**	**0.04**
0 to 2,000	0.33	0.31	0.28	0.25	0.23	0.20	0.17	0.15	0.12	0.09	0.07
2,001 to 4,000	0.32	0.30	0.27	0.24	0.22	0.19	0.17	0.14	0.11	0.09	0.06
4,001 to 5, 500	0.30	0.28	0.26	0.23	0.21	0.18	0.16	0.13	0.11	0.08	0.06
5,501 to 6,500	0.28	0.26	0.24	0.21	0.19	0.17	0.14	0.12	0.10	0.08	0.05
6,501 to 8,000	0.26	0.24	0.22	0.20	0.18	0.15	0.13	0.11	0.09	0.07	0.05
>8,001	0.24	0.22	0.20	0.18	0.16	0.14	0.12	0.10	0.08	0.06	0.04

* See IECC Equation 5-1 and Figure 502.2.
For SI: °C = [(°F)–32]/1.8; 1 Btu/ft.^{2} · °F = 0.176 kJ/(m^2 · K).

gether. To obtain the initial value for the required overall thermal transmittance value for walls, **Figure 1** is consulted, along with the relevant heating degree day (HDD) value for the climate location where the building is being erected. The curves and line-segment equations are shown in **Figure 1**, where the horizontal axis is the climate description in HDD and the vertical axis is the overall wall U-factor – U_o. The U_o is then utilized in more detailed calculations of acceptable component thermal performance factors using simple arithmetic equations.

Calculating Wall Thermal Values

The equation shown in this section is used to calculate the overall thermal transmittance factor for the wall, from its component parts. Note that this equation includes all typical component parts of a building wall; however, it pertains to above grade walls. A separate approach for below grade foundation walls is included elsewhere in the model code, and not discussed here.

To use this equation for determining the appropriate U_w factor for an "equivalent" mass wall compared to the basic lightweight frame wall of typical U.S. home construction, the next step is to calculate and verify the log walls to be used have sufficient heat capacity.

In the model code, when a wall has sufficient heat capacity – at least 6 Btu/ft.^{2} - °F [1.06 kJ/(m^2 – K)] – then it provides sufficient thermal protection to be "deemed to comply" with the model code in lieu of the more highly insulated frame wall (having a corresponding lower numerical U-factor). The calculation starts with a compliance frame wall requirement, then backs into the allowable U-factor for a mass wall. This is because the heat capacity correction is based on comparisons of the effective thermal protection of the wall with higher heat capacity versus a lightweight wall. The overall average thermal transmittance value is calculated as follows:

$$U_o = \frac{(U_w \times A_w) + (U_g \times A_g) + (U_d \times A_d)}{A_o}$$

where:

U_o = average thermal transmittance of the gross area of exterior walls
A_o = gross area of exterior walls
U_w = combined thermal transmittance of various paths of heat transfer through the opaque exterior wall area
A_w = area of exterior walls that are opaque
U_g = combined thermal transmittance of all glazing within the gross area of exterior walls
A_g = area of all glazing within the gross area of exterior walls
U_d = combined thermal transmittance of all opaque doors within the gross area of exterior walls
A_d = area of all opaque doors within the gross area of exterior walls

Notes:

1) When more than one type of wall, window or door is used, the *U* and *A* terms for those items shall be expanded into sub-elements as:

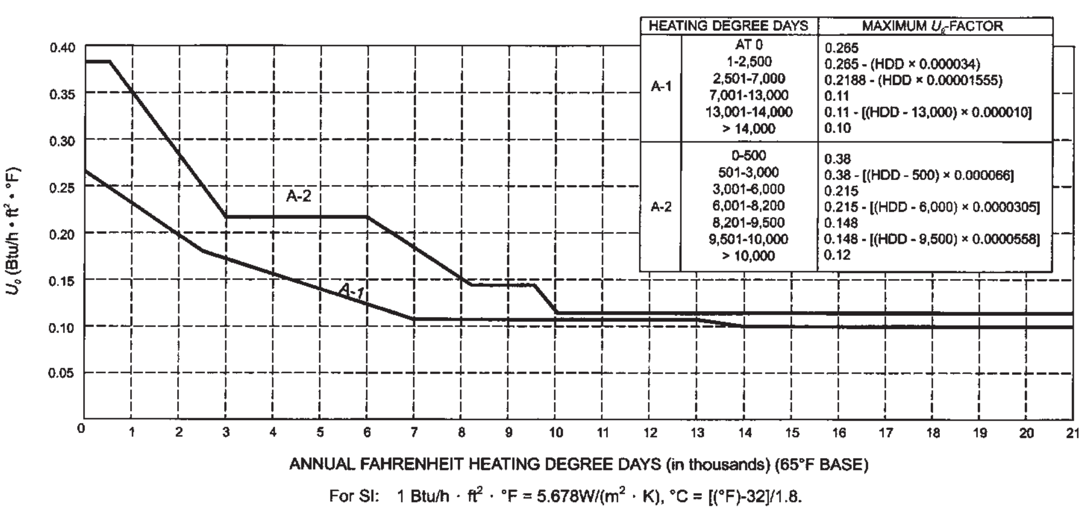
$$(U_{w1}A_{w1}) + (U_{w2}A_{w2}) + (U_{w3}A_{w3}) + \dots \text{(etc.)}$$

2) Access doors or hatches in a wall assembly shall be included as a sub-element of the wall assembly.

In the model code, a compliance note within the thermal envelope calculation section says:

> *"…solid wood walls having a mass greater than or equal to 20 pounds per square foot have heat capacities equal to or exceeding 6 Btu/ft.^{2} - °F [1.06 kJ/(m^2 – K)] of exterior wall area."*

Despite this note, most code approval submittals will still require direct calculation of the log wall's heat capacity. It is better to make the calculations in advance rather than risk



HEATING DEGREE DAYS		MAXIMUM U_o-FACTOR
A-1	AT 0	0.265
	1-2,500	0.265 - (HDD × 0.000034)
	2,501-7,000	0.2188 - (HDD × 0.00001555)
	7,001-13,000	0.11
	13,001-14,000	0.11 - [(HDD - 13,000) × 0.000010]
	> 14,000	0.10
A-2	0-500	0.38
	501-3,000	0.38 - [(HDD - 500) × 0.000066]
	3,001-6,000	0.215
	6,001-8,200	0.215 - [(HDD - 6,000) × 0.0000305]
	8,201-9,500	0.148
	9,501-10,000	0.148 - [(HDD - 9,500) × 0.0000558]
	> 10,000	0.12

Figure 1.—Overall U-factor compliance lines by heating degree days (A-1 = one- and two-family dwellings, A-2 = other low-rise residential buildings).

getting held up on energy approvals due to submitting insufficiently detailed documentation.

Calculating Wall Assembly Heat Capacity

The construction materials' heat capacity (HC) of an exterior wall is calculated as follows:

$$HC = (\text{Wall thickness} \times \text{Density}) \times \text{Specific Heat}$$

where:

HC = the heat capacity of the exterior wall, Btu/ft.^{2} - °F [1.06 kJ/(m^2 - K)];
Note: Wall thickness is entered in feet for this equation;

Density = Material Density, lb./ft.^{3} [kg/m^3];

Specific Heat of wood = 0.39 Btu/lb. - °F [kJ/(kj – K)][1]

According to ASHRAE, wood species have the following physical and thermal properties, relevant to these calculations (**Table 2**). Hence, referring to the table, an SPF log wall of 8-inch diameter would provide an average value of R = 9.84 at an HC of at least 9.5. So, in the example climate a log wall could easily comply with model code requirements without having to step up to higher performance doors or windows. Additional calculations could be made to optimize windows and doors for least cost while still meeting or exceeding the requirements.

The user of the HC formula must know the net log wall thickness, and appropriately correct it for any physical attributes that influence its actual overall thickness from a thermal standpoint. For example if a whole log is used, where the diameter is larger than the meeting points between courses, a net thickness must be calculated. This caution is not dissimilar from knowing the amount of framing and its conductance in lightweight "stick" wall construction at corners, plates, headers, etc. The framing elements have about three times higher heat transmittance than the insulation materials in the stud cavities. These effects are accentuated for steel-frame walls, due to the extremely high thermal conductance of steel. Included in the model code are correction factors that account for the "thermal bridging" of steel studs.

Air-tightness is very important in helping control heating and cooling loads in log wall homes. Where large quantities of chinking materials are used in finishing exterior walls, appropriate corrections should be made for their physical properties. Chinking materials are likely to have different thermal transmittance and heat capacities than those of the solid wood wall sections. If insulating layers are laminated or installed in a composite log wall system, these properties must be accounted for as well. Likewise proper accounting must be done when other materials are extensively mixed in a log home's exterior structural system.

Here is an example of why careful assessment of all materials and layers is important. Let's say a natural log wall (round but debarked and de-tapered) has a 10-inch nominal diameter. However, if the meeting points between courses are only 4 or 5 inches across – such as where planing is done to make joints between courses more uniform – the net thickness of the overall wall is not really 10 inches; it may be substantially less, perhaps only 8 inches depending on actual system geometry. Since both the R-value of the wall and the heat capacity are sensitive to thickness, then the net overall thickness needs to be accurately estimated and, if needed, appropriate adjustments made prior to making U-factor calculations and thermal mass corrections.

The overall impacts of actual surface contours of a natural log wall include:

- potential reduction in R-value (thinner wall provides less material to resist heat flow); and
- potential reduction in wall thermal mass, since thinner walls have lower heat capacity.

[1] ASHRAE Fundamentals Handbook, 2001 (See Table B.)

Table 2.—Thermal physical properties of wood species at 12% moisture content (Source: ASHRAE Fundamentals Handbook, 2001).

	Density (lb./cf)	Conductivity (*k*)	R per inch (1/*k*)	Specific heat (lb./°F)
Hardwoods				
Oak	41.2 to 46.8	1.12 to 1.25	0.89 to 0.80	0.39
Birch	42.6 to 45.4	1.16 to 1.22	0.87 to 0.82	
Maple	39.8 to 44.0	1.09 to 1.19	0.92 to 0.84	
Ash	38.4 to 41.9	1.06 to 1.14	0.94 to 0.88	
Softwoods				
Southern pine	35.6 to 41.2	1.00 to 1.12	1.00 to 0.89	0.39
Southern cypress	31.4 to 32.1	0.90 to 0.92	1.11 to 1.09	
Douglas-fir–Larch	33.5 to 36.3	0.95 to 1.01	1.06 to 0.99	
Hem-Fir, Spruce-Pine-Fir	24.5 to 31.4	0.74 to 0.90	1.35 to 1.11	
West coast woods, Cedars	21.7 to 31.4	0.68 to 0.90	1.48 to 1.11	
California redwood	24.5 to 28.0	0.74 to 0.82	1.35 to 1.22	

Both of these issues can result in changes to expected energy performance characteristics that need to be accounted for in the required calculations. For a totally fair set of calculations that accurately reflect the performance of any building wall, appropriate corrections for physical properties and actual component geometry are essential.

Example: Log Wall Calculation Correcting for Thermal Mass

In a 2,000 ft.^{2} log wall home, located in the Midwest, the builder determined the climate has 5,200 heating degree days. Using the overall U-factor graph (**Fig. 1**), the required overall U-factor is found to be 0.138 Btu - hr./ft.^{2} - °F. Recalling that the U_o value includes all wall, window, and door surfaces, the builder makes a basic listing of the home's components and its surface areas.

Example Building Take-off Listing

	Area	U-factor
Gross wall area (A_o)	1,200	0.138 (U overall, allowable)
Window area (A_g)	180	0.42 (U_g typ. Low-E window)
Door area, 2 doors (A_d)	44	0.25 (U_d insulated door)
Opaque wall areas (A_w)	976	? (U_w compliant frame wall)

First the frame wall U-factor is determined, from which the corrected log wall U-factor will be derived using values in **Table 1**. Using the simple U_o calculation, solve for the compliant frame wall U-factor prototype needed to meet the model code, as follows:

$$U_o = \frac{(U_w \times A_w) + (U_g \times A_g) + (U_d \times A_d)}{A_o}$$

using the known quantities:

$$0.138 = \frac{(U_w \times 976) + (0.42 \times 180) + (0.25 \times 44)}{1{,}200}$$

then solving for U_W:

$$U_w = \frac{(0.138 \times 1{,}200) - [(0.42 \times 180) + (0.25 \times 44)]}{976}$$

the initial frame wall required opaque area U-factor to meet the model code is calculated:

$$U_W = 0.081 \text{ Btu - hr./ft.}^2 \text{ - °F}$$

In this example house, an R-13 cavity insulation level (including 1 in. exterior sheathing and typical dry-wall inside finishes) would satisfy the frame wall U_w requirement in the model code. The user then needs to correct for the use of a high heat capacity log wall used over the same surface area of the home.

Looking back at the heat capacity correction factors for log walls (**Table 1**), the nominal U_w factor is used to select the appropriate base U_w column (shown in bold); then the user reads across the appropriate climate category row (in this case selecting the 4,100 to 5,500 HDD category) to obtain the compliant log wall "equivalent" U_w value.

In this example the log wall would be required to have a U_w value of U-0.11 Btu - hr./ft.^{2} - °F. This means a log wall assembly with a net value of "R-9" qualifies for the model code criteria that otherwise would require a stick-framed house to use R-13 cavity insulation. The table permits selection of the log wall U_w value that will provide equivalent annual heating and cooling performance, similar to a home built with a code-compliant light-frame wall.

Conclusion

There is extensive technical literature supporting the validity of granting performance adjustments or "credits," as they are sometimes called, for thermal mass in structural walls of buildings. When the annual heating and cooling benefits of mass are analyzed for single-family homes, it is important to realize that the overall assessment of net benefits should be the focus of study. In some cases increased energy use may occur during one part of the year (days, months) versus another period, while net-net the building may be shown to use less overall space conditioning energy on an annual basis.

For homes, these whole-building performance benefits fall into a range of 2.5 percent to over 15 percent for most U.S. climates. This means, a log home having 30 to 40 percent lower numerical R-value's will provide equivalent performance for heating and cooling when using numerically lower steady-state R-values in its walls than will a stick-framed home of otherwise identical design.

Exceptions are areas with especially cold or especially hot weather, where the benefits of wall heat capacity are reduced according to engineering studies. There are extreme climates where thermal mass has little or no benefit, such as those with greater than about 8,500 heating degree days (HDD) and those with very high cooling degree hours (CDH).

References

A complete list of references is available in the full research report from the Log Homes Council available at www.loghomes.org.

Prepared by the Technical Committee of the Log Homes Council, Building Systems Councils, National Association of Home Builders. Based on research conducted for the Log Homes Council by Bion D. Howard, President, Building Environmental Science & Technology, Edgewater, MD. Edited for the Technical Committee by Rob Pickett, Rob Pickett & Associates, Hartland, VT.

Fire Resistance of Log Walls

Dalibor Houdek, Ph.D.

Log construction is growing in popularity, but little is known about the fire performance of log walls. Sometimes when a high fire resistance rating of a log wall is needed, a layer of gypsum wallboard is applied over the logs to increase the fire resistance, even though this covers up the logwork.

Experimental research of a scribe-fit log wall proved that it can achieve a very high fire resistance rating by itself, and additional steps to increase its fire resistance are not necessary.

Introduction

There is a trend toward performance-based building codes, and this has increased the need for information on performance of various building systems. Research on the structural fire resistance of wood construction has focused on light wood frame. Heavy timber construction, especially log construction, has been mostly ignored.

In 1986, Sashco Sealants Inc. sought an Underwriters Laboratories Inc. fire resistance rating for its log wall chinking. Lodgepole pine logs, 9 inches in diameter, with an average moisture content of about 5 percent were used. Wall joints were filled with foamed polyethylene backer rods and Log Jam™ chinking was applied. During the test, the surface unexposed to heat reached 95°C (200°F). The assembly was judged to afford a 1-hour fire rating by ASTM E-119.

The Technical Research Center of Finland performed a fire test according to German DIN 4102 and ISO 834 standards on log walls manufactured by Honka Log Homes. The rectangular, milled logs were 140 mm (5.5 in.) thick. The wall kept its load-bearing capability throughout the 90-minute test, but failed at 112 minutes.

Various companies have conducted burn-through field tests, and small-scale tests of non-load-bearing chinked log walls, to display the fire endurance of their products. The overall results showed good fire resistance, but no scientific measurements were done, and the details were not widely published.

All work done earlier on fire resistance of log walls was conducted on chinked or rectangular log walls. The Technical University of Zvolen, Slovakia, has commenced research to answer questions of fire resistance of a chinkless log wall used primarily in North America, and to develop a model for estimating fire resistance of log walls. The large-scale experiment according to ISO 834 was undertaken in PAVUS-Fire Research Institute, Czech Republic.

Experiment

The test sample consisted of twelve spruce logs of 257 mm (10 in.) average diameter. They were joined in the traditional chinkless, full-scribe-fit style. The cupped lateral grooves were approximately 15 mm (3/4 in.) deeper than necessary to accommodate the mineral wool insulation. The test wall was 3,250 mm (10 ft.–8 in.) long and 2,800 mm (9 ft.–2 in.) tall.

Eleven logs were kiln-dried to an average moisture content (MC) of about 19 percent, and one log was conditioned to 36 percent. The long grooves were filled with mineral wool insulation (rock-wool type). Due to the natural irregularities of each log, the width of the grooves varied between 89 mm (3.5 in.) and 130 mm (5.1 in.) with an average of 105 mm (4 in.).

The ends of the panel were splined (like a door opening) and three spruce pegs per log, 30 mm (1.2 in.) in diameter, were driven approximately 800 mm (30 in.) apart to sup-

Additional Resources for Fire Resistance Calculations

Where specific fire resistance times are required, performance of structural logs over such periods can be calculated per AF&PA's *National Design Specification® (NDS®) for Wood Construction*, Chapter 16. Additional information, including design examples and test data, are included in *Technical Report 10 (TR10)*: *Calculating the Fire Resistance of Exposed Wood Members*.

Where specific flame spread ratings are required for logs, AF&PA's *DCA No. 1*, *Flame Spread Performance of Wood Products* can be used to establish such ratings.

TR10 and DCA No. 1 are available at www.awc.org.

port the wall logs. They were driven only through two vertically adjacent logs.

The log wall was exposed to fire, and temperatures inside the logs, inside the grooves, and on the unexposed side were continuously monitored and recorded (**Fig. 1**).

The log wall was continuously vertically loaded on the centerline with 15 kN m (11.06 ft.-kips) using a hydraulic loading system built in the furnace loading frame. The load calculation is derived from a one-and-a-half story log house.

Results

According to ISO 834, structural walls can fail in three ways during a fire resistance test:

1. fail in integrity, causing ignition of a cotton pad, permitting the penetration of flames resulting in sustained flaming, or
2. fail in insulation, causing an increase of the average temperature above the initial average temperature by more than 140°C (284°F) or increase above the initial temperature at any location by more than 180°C (356°F), or
3. fail in load-bearing capacity – basically, if the wall loses 1 percent of its height, it has failed.

Inside the furnace, the log wall surface turned black in the 3rd minute of the test. In the 5th minute the surface ignited and continued to burn for the duration of the test. Large deep cracks developed around the 11th minute. From about the 30th minute, the wall surface was red and charred with large deep cracks for the rest of the test (**Fig. 2**). It was observed that when the fire-exposed edge of the lateral groove burned off, the mineral insulation inside the long groove protruded, and expanded to about its initial thickness of 50 mm (2 in.) (**Fig. 3**).

No flame penetration through the wall was observed during the test. The side unexposed to fire showed no visible changes; smoke penetration was not observed through the wall joints.

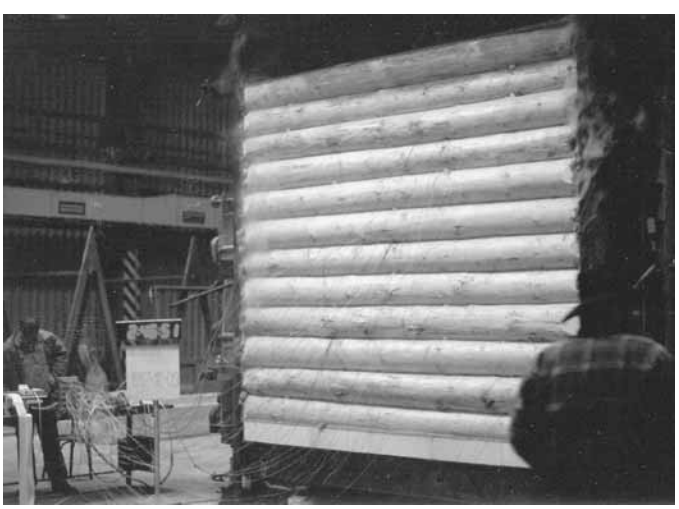


Figure 1.—Continuous monitoring.

Comparing the results of a chinkless log wall joint with the chinked wall joint tested by Sashco Sealants Inc., the scribe-fit log wall has much higher insulation value. At 60 minutes of the test duration, the chinkless log wall showed absolutely no increase in surface temperature compared to an average 71°C (160°F) temperature of the chinked log wall tested by Sashco Sealants Inc.

The temperature on the hot side of the scribe-fit log wall exceeded 1,100°C (2,000°F), but the cool side never got above 48°C (118°F), even after almost 3 hours of burning.

Moisture plays a large role in the temperature rise. A temperature rise inside the moist log leveled off slightly above 100°C (212°F), and remained almost unchanged for more then 25 minutes.

Allowable vertical compaction prescribed by ISO 834 – calculated according to the equation C= h/100 – was 28 mm (about 1 in.). The initial height of the log wall was

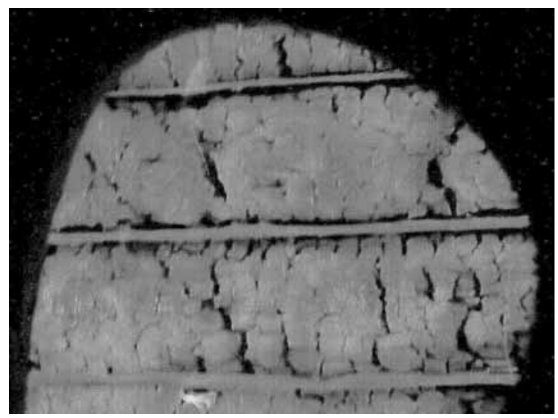


Figure 2.—Inside the furnance.

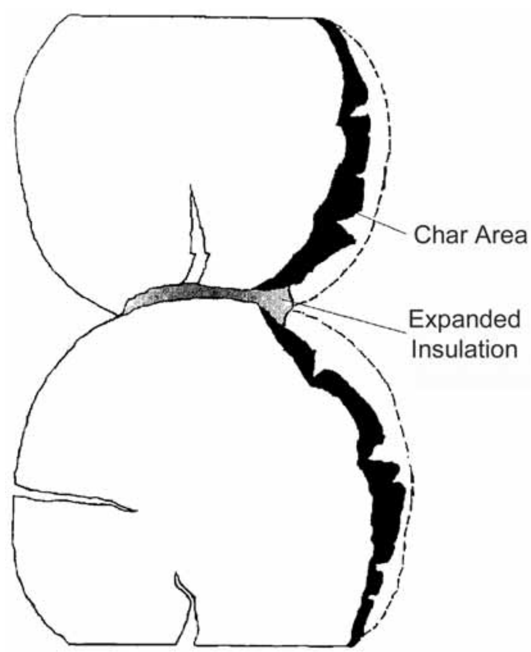


Figure 3.—The fire-exposed edge.

2,800 mm (110 in.), and it reached its ISO 834 allowable limit at the 172nd minute of the test duration.

Shrinkage of the wall logs due to moisture content changes contributed to the amount of compaction. When moist logs are used, it can affect the wall load-bearing capacity during the fire resistance test. Shrinkage, a natural feature of wood, does not decrease the load-bearing capacity.

All professionally manufactured log buildings are fully engineered to account for shrinking and settling. On the other hand, when the load-bearing capacity during the fire test of log walls is evaluated, there is no allowance for wood's natural shrinking due to moisture content changes.

Conclusions

Knowing how log walls react to fire exposure is important for evaluating newly constructed buildings and existing log structures. A large-scale laboratory test showed that a log wall with considerable numbers of lateral wood-to-wood joints can maintain fire safety requirements prescribed by ISO 834 for as long as 172 minutes. The log wall withstood 180 minutes from its integrity and insulation viewpoint, and 172 minutes for its load-bearing capacity.

For further information, or to obtain a reprint of the original article, contact Dalibor Houdek or refer to the *Journal of Fire Protection Engineering*, Vol. 11, August 2001.

Dalibor Houdek, Industry Advisor, Forintek Canada Corp., Vancouver, BC, Canada, e-mail: dalibor@edm.forintek.ca.
Photos and drawing courtesy of Dalibor Houdek.

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PO Box 775
Lumby, British Columbia
V0E 2G0 Canada
(250) 547-8776 phone
info@logassociation.org
www.logassociation.org

Visual Stress Grading of Wall Logs and Sawn Round Timbers Used in Log Structures

Edwin J. Burke

Abstract

This article explains the need for and the history and process of stress grading logs used in construction of log structures and offers practical information for engineers, architects, and code officials working with this type of construction system.

Integrity of Log Structures

With the popularity of modern log structures spreading across the country after World War II, the next several decades saw individual log homeowners, handcrafters, and manufacturers all struggling with the responsibility of complying with building codes written with conventionally framed homes in mind. In addition to a lack of any grading or design standards for assessing and utilizing logs and timbers used in log structures, designers, owners, contractors, and building code officials were reporting a number of problems with log structures such as poor joint fit caused by abnormal log twisting during log drying and wall settlement, buckling of prow-front walls under wind loads, and failures of wall openings and roofs caused by inappropriately sized or structurally defective logs.

Other less dramatic and less life-threatening problems such as air and water leaks, decay, uneven settling, insect infestations, and finished appearance were also seen as problems arising from the use of inappropriate logs and/or lack of understanding of what constitutes quality in logs used for wall, floor, and roof construction.

Who lacked understanding of logs and log structures? Obviously, builders of these problem structures were often using undersized or defective logs that should never have been used in a structurally demanding location. Architects and engineers were also identified as lacking sufficient knowledge of whole-log physical and mechanical properties to make appropriate design decisions. Methods of determining design strengths of various species, sizes, and qualities of logs were not as well-defined as they had been for rectangular-section lumber.

Architects and engineers, as well as building officials, were identified as needing training and experience in the use of whole logs in structural applications. Typically, engineering and architecture students lacked advanced coursework in solid timber construction beyond a course in general wood design. Uncertainty as to which, if any, structural provisions of the building codes addressed log structures was common. More importantly, what assurance did the engineer and architect have that the materials chosen by the supplier would meet the strength requirements set forth in the plans? And also to that end, how did the building code official know that the logs used at the building site were of the grade needed to meet the same requirements set forth by the approved plans?

While most serious structural problems were found in structures built by owners or contractors with little experience in design and construction of log structures, all manufacturers, architects, engineers, contractors, and building officials working with whole logs needed the same type of fundamental structural grading and design criteria enjoyed with lumber, steel, and concrete. Without the ability to critically evaluate all round and profiled log building materials, the structural integrity of log structures would continue to lack the confidence of architects, engineers, and code officials. Clearly, the use of logs and timbers graded for structural integrity was necessary, but a method of grading most styles and shapes of logs used in log structures was lacking.

Industry Seeks a Solution

In 1977, a group of log home manufacturing companies formed the Log Homes Council, a member of the Building Systems Councils of the National Association of Home Builders. The Council's original goal was to help the industry supply engineers, architects, and code officials with the information and tools they needed to more easily design and build better structures that complied with structural provisions of the nation's building codes. The most important tool to be developed was a system for structurally evaluating individual logs that would give architects and engineers design values they needed by developing a formal method for evaluating logs and timbers used in log structures. In 1979, the Log Homes Council teamed up with Steven Winters Associates, a consulting structural engineering firm, and the American Society for Testing and Materials (ASTM) in a multi-year effort to develop a standard for grading and assigning strength values to logs and timbers. The results were the first definitive set of criteria used to evaluate the structural suitability of logs and timbers for use in log homes, officially known as ASTM *Standard D3957-90, Standard Methods for Establishing Stress Grades for Structural Members Used in Log Buildings* (ASTM 1993a). Once the feasibility of the Council's grading program was shown, Timber Products Inspection Co., long known for its grading services in the lumber and plywood industries, joined the Council in providing third-party certification and grading-program monitoring for the log home industry.

The Log Home Council immediately implemented the new standard by requiring member companies to grade every log in each home package. For the first time, both machined log producers and hand-crafters who use logs in their natural stem form had the means to evaluate the strength and durability of their logs using standardized criteria from accredited programs.

ASTM D-3957 has been shown to be versatile, yet uniform, in its evaluation of the large number of log profiles and construction systems encountered by engineers, architects, and building officials. Today, architects and engineers can specify the appropriate quality, size, and species of log for a particular use, or conversely, design the structure around a particular species, size, and grade of log available to the builder. Building code officials can now evaluate and approve structures with confidence, knowing that each council-member plant's graders and grading practices are constantly monitored by the grading agencies.

Summary of Important Strength-Reducing Factors

Species and Density

Durable species such as the "cedars" can add value to a home by virtue of their resistance to decay and insect attack. Owing to inherent density, species such as the southern pines, Douglas-fir, western larch, and oak usually provide higher design strength values than do lighter-weight woods such as eastern white pine and spruce of the same grade. Span tables for round and profiled logs, as well as rectangular solid timbers have been developed by the two agencies certified by the International Accreditation Service (IAS) to grade logs, the Log Homes Council Log Grading Program (LHC), and Timber Products Inspection (TPI). Based on clear wood strength values and implementation of reduction factors to account for natural wood features, design value tables and span tables serve as principle sources of data for the design professional.

Slope of Grain and Knot Type, Size and Distribution

Slope of grain is defined as the orientation of wood fibers relative to the edge or centerline of a log or timber (**Fig. 1**), and is usually caused by spiral grain in the living tree, and/or machining at an angle to the stem centerline during manufacture. Slope of grain is usually expressed numerically as a ratio, for example, 1:14, referring to a 1-inch deviation from parallel to the edge or centerline in 14 inches of length along the log. Steep slope of grain dramatically affects the bending strength of wall logs and sawn round timbers and is one of the most important characteristics examined during log grading. The highest-quality, strongest houselogs of a given species will have a grain orientation that is nearly parallel to the length of the piece.

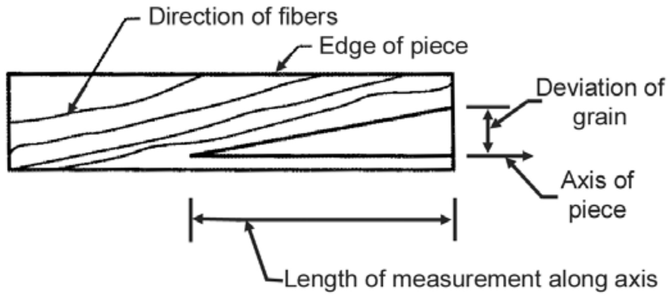


Figure 1.—Slope of grain deviation and its measurement.

Knots also greatly affect the strength and suitability of a log for a particular application. Knots are by far the most numerous and variable of features evaluated in log grading, and their evaluation is the most demanding of the grading steps. Knots are branches incorporated into the stem of the tree. When the branch is living, the tree produces a layer of wood covering the stem and branch with a continuous layer of wood. Once the limb dies, generally from lack of light, the tree continues to produce wood in the immediate area of the limb, but the growth ring does not extend out into the branch. A board cut from the tree in this location would have a knot that can become loose and fall from the board upon drying.

In addition to measuring their size and location, as well as checking for the presence of decay in knots, the grader must also evaluate the type and distribution of knots on each face in order to assign the appropriate grade. Knots decrease strength by causing realignment of the trunkwood in their immediate vicinity, thus increasing slope of grain adjacent the knot. While the knot itself can actually be stronger than surrounding wood because of its higher density, in most situations, especially bending, knots are seen as defects and limited in size, location, and type.

Ring Shake, Checks, and Splits

A ring shake is defined as a separation between two growth rings, parallel to the circumference of the growth rings, with partial or entire encirclement of the pith (**Fig. 2a**), and is common in species such as western larch and tamarack.

Checks are radially oriented separations across growth rings (**Fig. 2b**), caused by natural stresses generated in round logs and timbers during drying. Checks are usually not limiting factors in log grading for the same reasons explained for ring shake.

A split is defined as radially or non-radially oriented separation of wood fibers extending across the end-grain of the piece and along the grain for a variable distance (**Fig. 2c**). Splits are usually caused by mechanical damage incurred during harvesting or manufacturing.

All wall log grades assume the presence of ring shakes, checks, and splits, and reduce the allowable design stress levels for all pieces, including the large number of pieces not showing these defects. In sawn round timber grades, ring shake and splits are measured, and their number and size are limited in both grades. This very conservative approach highlights the grading program's philosophy of safety.

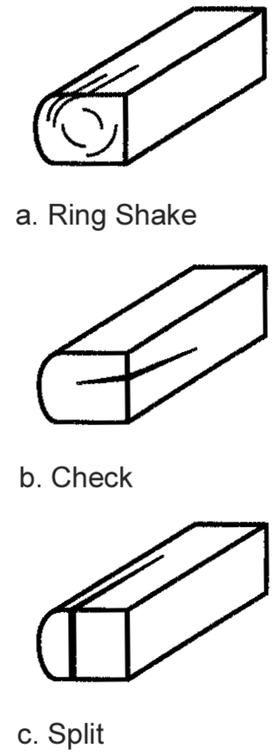


Figure 2.—Typical ring shakes, checks, and splits found in structural logs.

Biological Pathogens

Biological pathogens such as bacteria, stain fungi, decay fungi, and insects are an integral part of the forest ecosystem. Diseased, dying, and dead trees are often identified for removal by foresters in order to improve forest health and become part of the raw material supply of sawmills and log home plants throughout the country. Recognition of both staining and decay fungi in logs is one of the most important jobs of the log grader. Presence of the early (incipient) stage of decay would lower the grade of a wall log, while presence of advanced stages of decay ("dry rot") alone is cause for culling in both the wall log and sawn round timber classification. Reduction in strength caused by decay in the incipient stage can be as significant as high slope of grain and large knots, and is limited to lower grades in houselogs. Presence of advanced decay is also cause for rejection of the log since reduction in bending and compression strength is 80 to 100 percent.

Some forms of decay present in living trees, however, are quite isolated and scattered, and, unlike other forms of fungal decay, die when the tree is cut down and moisture removed with drying. These pocket rots, the cause of "pecky" cedar and cypress, do not necessarily preclude use of a houselog in low-stress applications, and are generally found in lower grades.

Sapstains are the result of an infection of the outer, sapwood portion of the tree by benign fungi that feed on the stored sugar content of wood cells rather than on the structure of cells walls. Their activity does not effectively reduce the strength of wood, but merely colors it a shade of blue, black, or red. Because the wood's strength has not been altered, the amount of stained sapwood is not limited in any of the grades of wall logs or sawn round timbers.

The potential for strength reduction from insects present in a house log prior to construction ranges from high to very low, depending on the type of insect. With the exception of termite, carpenter ant, and carpenter bee infestations, the grading rules offer few restrictions relative to insect borings. Treated as a hole from any source, holes from the larvae of boring beetles (primarily) generally have a minimum effect on the strength of a wall log or sawn round timber.

Log Grading Procedures

The purpose of visual stress grading of structural logs is to provide designers of log homes and commercial buildings the design values they require to build a safe and economical structure that meets the requirements of the nation's building codes. These design values, similar to those used for rectangular lumber, are suitable for further engineering analysis without additional refinement or safety factors. The grading process also allows the building code official or designer to readily determine that the logs have been certified through use of grade stamps on the logs (**Figs. 3a and 3b**) and/or a Certificate of Inspection (COI) accompanying the logs (**Fig. 3c**).

How Log Grades Are Developed and Used

The ASTM Standard D3957-90 distinguishes between two types of sawn or machined timbers, with different grading procedures and rules for each. These two types, "Sawn Round Timbers" and "Wall Logs", are defined in terms of cross-section and use.

A *sawn round timber* is a structural log that meets both of the following criteria:

- Shaved or sawn on one side only within the limits set forth in D3957-90, and
- Normally loaded on the flat side as a beam primarily stressed in bending and shear.

A *wall log* is a structural log that meets one or more of the following criteria:

- Sawn or unsawn, stacked horizontally or vertically to form a load-bearing wall, or
- Sawn on one side only, but does not meet the definition of a sawn round timber, or

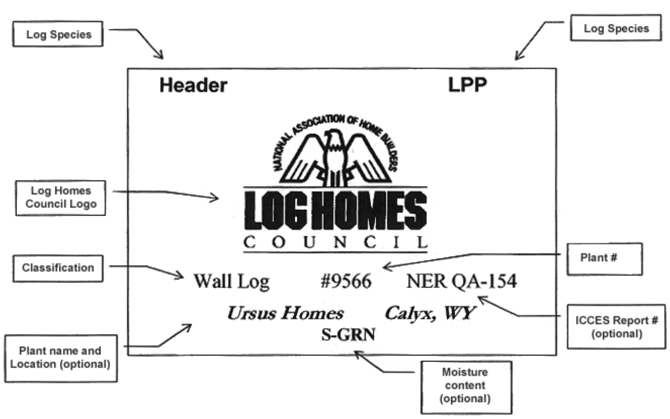


Figure 3a.—Sample of Log Homes Council program grade stamp.

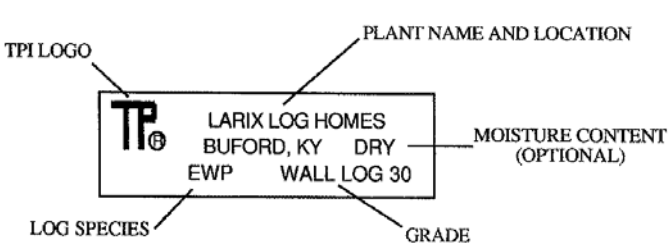
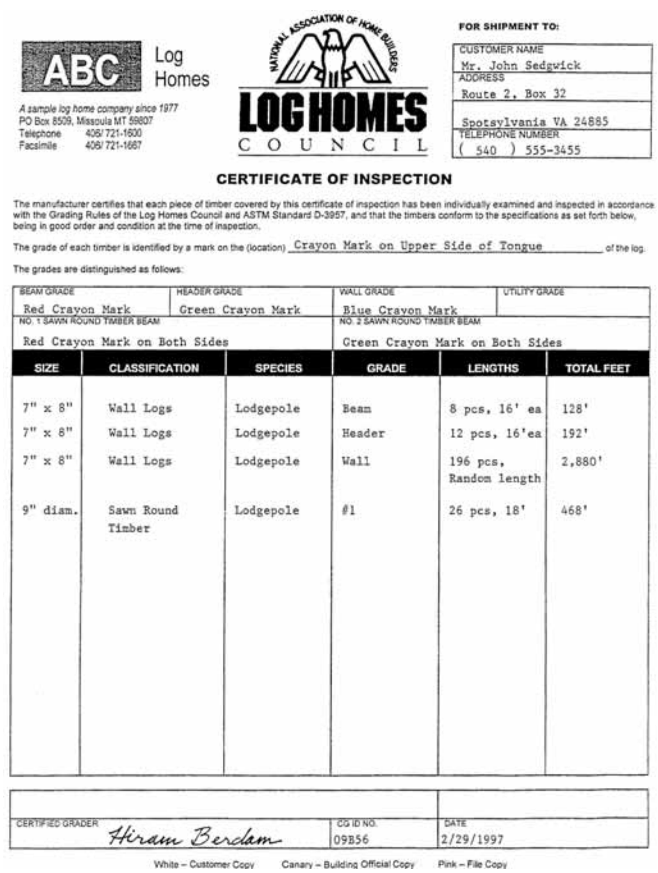


Figure 3b.—Sample of the Timber Products Inspection program grade stamp.



ABC Log Homes

A sample log home company since 1977
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Telephone 406/ 721-1600
Facsimile 406/ 721-1667

NATIONAL ASSOCIATION OF HOME BUILDERS
LOG HOMES COUNCIL

FOR SHIPMENT TO:
CUSTOMER NAME Mr. John Sedgwick
ADDRESS Route 2, Box 32
Spotsylvania VA 24885
TELEPHONE NUMBER (540) 555-3455

CERTIFICATE OF INSPECTION

The manufacturer certifies that each piece of timber covered by this certificate of inspection has been individually examined and inspected in accordance with the Grading Rules of the Log Homes Council and ASTM Standard D-3957, and that the timbers conform to the specifications as set forth below, being in good order and condition at the time of inspection.

The grade of each timber is identified by a mark on the (location) Crayon Mark on Upper Side of Tongue of the log.

The grades are distinguished as follows:

BEAM GRADE: Red Crayon Mark
HEADER GRADE: Green Crayon Mark
WALL GRADE: Blue Crayon Mark
UTILITY GRADE:
NO. 1 SAWN ROUND TIMBER BEAM: Red Crayon Mark on Both Sides
NO. 2 SAWN ROUND TIMBER BEAM: Green Crayon Mark on Both Sides

SIZE	CLASSIFICATION	SPECIES	GRADE	LENGTHS	TOTAL FEET
7" x 8"	Wall Logs	Lodgepole	Beam	8 pcs, 16' ea	128'
7" x 8"	Wall Logs	Lodgepole	Header	12 pcs, 16'ea	192'
7" x 8"	Wall Logs	Lodgepole	Wall	196 pcs, Random length	2,880'
9" diam.	Sawn Round Timber	Lodgepole	#1	26 pcs, 18'	468'

CERTIFIED GRADER Hiram Berdam
CG ID NO. 09B56
DATE 2/29/1997

White – Customer Copy Canary – Building Official Copy Pink – File Copy

Figure 3c.—Sample of the Log Homes Council Certificate of Inspection.

• Sawn and machined on more than one side

Figure 4 compares requirements of sawn round timbers and wall logs to other structural elements and their governing standards.

In order to relate round log grading and design to existing lumber grading techniques and methods of determining allowable properties, the inscribed-rectangle method (**Fig. 5**) is used to approximate the shape of rectangular lumber. In this method, an imaginary rectangle is projected onto the end of the round or profiled log to present a uniform geometric shape. Engineers assume this shape for design stress assignment purposes, and the grading rules use it for establishing maximum knot sizes in each of the grades. As an example of the inherently conservative approach taken in grading structural logs, any weakening character outside the rectangle reduces the log's strength, but the additional strength contributed by the wood in this zone is ignored.

Using the inscribed rectangle of a particular profile, the grading-program committee determines the number of grades desired and the hypothetical ratio of the strength of timbers in those grades compared to clear, unseasoned wood. This strength ratio determines the maximum slope of grain and the type, size and location of knots, checks, splits, and saw cuts and all other characteristics that will be allowed in that particular grade. With this information, the grader now has a set of groupings or grades with limiting characteristics he or she can use to evaluate structural logs.

Stress values for each of the grades available to the designer are based on published values for clear, unseasoned wood strength of the desired species (ASTM 1993b). These clear wood strength values are further adjusted to account for a factor of safety, duration of load, and natural variability, and calculated so that at least 95 percent of the timbers in a random sample will have higher stress values than this "Allowable Unit Stress" (AUS). The "Allowable Design Stress Value" (ADSV) used in design calculations is a reduction of the AUS due to seasoning effects and strength-reducing effects such as slope of grain, knots, checks, shakes, etc. (ASTM 1993c).

Design values, therefore, account for species, grade, size, and conditions of use and are tabulated as shown on a Limiting Characteristics Sheet (**Fig. 6**). Every size and profile of log requires a separate computation of inscribed rectangle

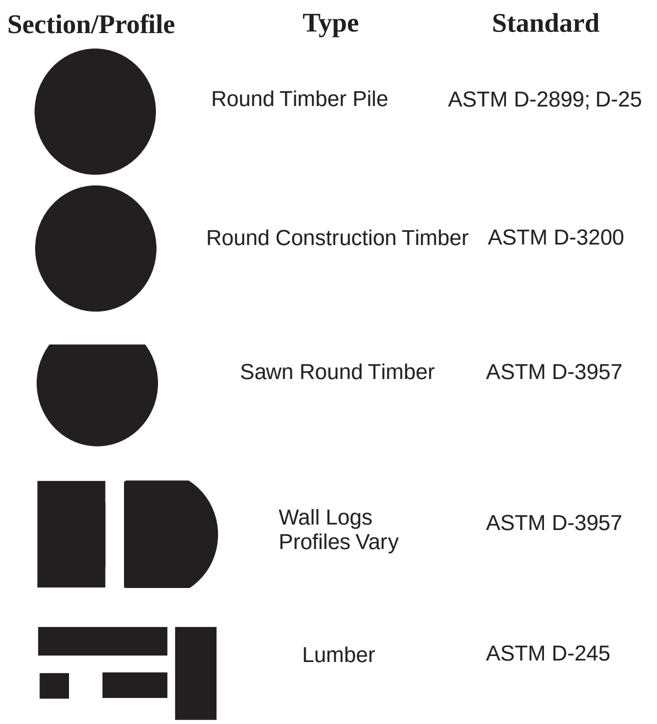


Figure 4.—Building log and timber profiles and the standards governing their grading.

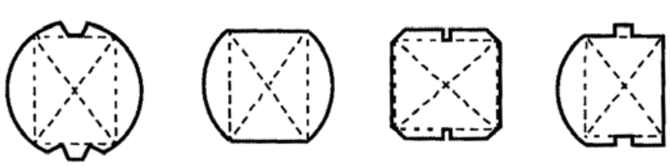
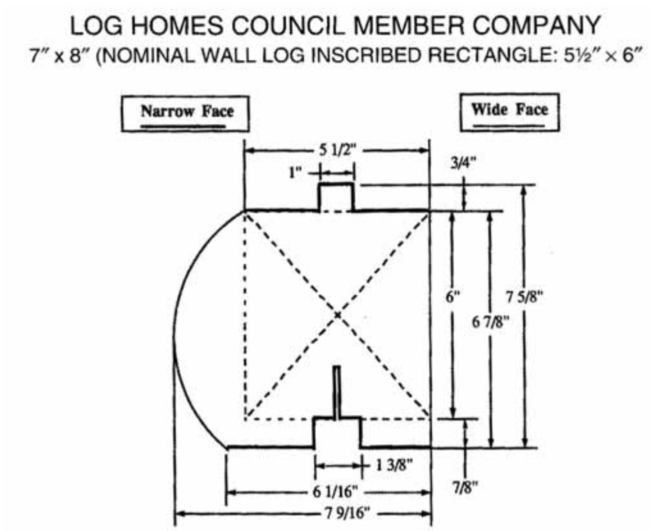


Figure 5.—The inscribed rectangle for several wall-log profiles.



LIMITING CHARACTERISTICS				
General	**Beam**	**Header**	**Wall**	**Utility**
Slope of Grain	1:14	1:10	1:6	1:4
Max. narrow face knot	1 1/2"	2 1/4"	3 1/4"	4^2
Max. wide face knot	1 1/2"	2 1/2"	3 1/2"	4 1/4"
Max. kerfed face knot	1 1/8"	2 1/8"	3 1/8"	3 7/8"
Lodgepole pine	**Design Values in P.S.I.**			
F_b' lateral load	1300	1100	725	475
F_b' vertical load	1300	1100	725	475
F_t	775	650	425	275
F_v	65	65	65	65
F_c (perp.to grain)	170	170	170	170
F_c (para. to grain)	850	725	550	475
E	1.1×10^6	1.1×10^6	0.9×10^6	0.9×10^6

Figure 6.—Sample Limiting Characteristics Sheet for a hypothetical log showing the inscribed rectangle as well as allowable slope of grain and knot size for various grades.

and ADSV, therefore requiring a separate Limiting Characteristics Sheet.

With many of a project's structural logs exhibiting defects much smaller than the maximum allowable size, and ignoring the contribution to the log's strength by wood outside of the grading rectangle, engineers/architects, and building officials can be confident that graded logs are likely to be significantly stronger than design stress values associated with their assigned grades.

Structural Log Grading Process

The first step in the grading process is training of graders by a council-recognized third-person certification agency, known as a Quality Supervisory Agency (QSA), and mentoring by a certified grader at the plant. Final certification as a "Certified Houselog and Round Timber Grader" comes only after the candidate passes a comprehensive written examination and demonstrates 95 percent accuracy in a practical examination administered by the third-party conducting the training. Work of the certified grader is inspected on a regular basis during unannounced inspection visits, and this 95 percent accuracy rate (typical for lumber grading agencies) must be maintained in order to remain certified. A company cannot certify logs as graded if it does not employ a certified grader or utilize on-site grading services from a recognized outside grading agency.

During manufacture, each log is individually evaluated by visual inspection of all sides and ends according to the agencies' grading rules that are based on ASTM Standard D3957-90. In addition to ensuring the evaluation of each individual log in a particular package, the certified grader is also responsible for providing a certificate of inspection for the building package and maintaining the grading and manufacturing records of every package produced. The certified grader(s)' grading and record-keeping procedures are checked quarterly by a QSA. Continued insufficiency in any of these critical areas of a grading program will result in loss of grading certification for the grader, and/or the company.

The combination of visual examination and stress grading of each and every log in a package by a regularly evaluated certified grader, proper use of grades by engineers and architects, and the building code official's enforcement of building code compliance by requiring use of stress-graded logs, assures the building owner that logs used to construct the structure meet the strength requirements specified in the engineering design.

Design Professional's Role

The engineer/architect should always require use of graded logs in all dwellings and commercial buildings. Current building codes require use of graded materials, and the upcoming International Code Council's *Standard for Design and Construction of Log Structures* will also require this fundamental element. Engineers and architects must ensure that species, size, and grade of logs are all specified in the plans, and that all who read the plans will be aware of how the grade of individual logs will be designated. In their communication with building officials, the engineer should make certain that the official knows that the package will contain graded logs, should indicate how grade marks, if present, will be displayed on the logs, and if a Certificate of Inspection (COI) will accompany the package. Manufacturers grading under the Log Homes Council program supply two copies of the COI that certify the log grading and specifies the log-marking system. Structural logs graded using the Timber Products Inspection program are usually marked with comprehensive grade marks, and a COI is not included in the package unless specified in the contract. The COI must be made available to the code official during the course of all site-inspection visits.

What can be done if a package does not have an accompanying Certificate of Inspection or grade marks on the logs? The building official should not allow placement of any logs until a replacement COI is received or until logs are graded at the site by a certified grader. If logs have been graded, and the certificate has been lost, a replacement is usually only a phone call away. If the logs have not been graded, however, an on-site inspection and grading should be arranged for by the contractor. Since grading cannot be completed unless all surfaces and ends are visible, the official's refusal to allow any log placement is actually a time and cost-saving action. The Grading Program Coordinator is an excellent resource for code officials with questions concerning log grading in general, a manufacturer's Log Homes Council membership status, or questions regarding on-site grading options.

Summary

Building codes require the use of graded wood structural components in occupied structures. Current grading programs used by industry use well-established methods for evaluating the structural integrity of each log utilized in a structure and give a high level of assurance that the finished structure will provide a home that will endure for many generations. Visual stress grading of a log structure's components allows the engineer and architect to design with confidence in the specified stress values. Grade marks on individual logs and the presence of a Certificate of Inspection for the package allow the code official to easily determine if logs have been graded, and if they are placed in the correct locations within the structure. A log structure project that begins with good design and engineering, utilizes materials graded by certified graders, employs skilled labor using well-established manufacturing techniques and equipment, and provides for appropriate long-term maintenance, will produce a log structure that will endure for many years.

References

American Society for Testing and Materials (ASTM). 1993a. Standard Methods for Establishing Stress Grades for Structural

Members Used in Log Buildings. Standard D3957-90. Philadelphia, Pennsylvania.

American Society for Testing and Materials (ASTM). 1993b. Standard Methods for Establishing Clear Wood Strength Values. Standard D2555-88. Philadelphia, Pennsylvania.

American Society for Testing and Materials (ASTM). 1993c. Standard Methods for Establishing Structural Grades and Related Allowable Properties for Visually Graded Lumber. Standard D245-92. Philadelphia, Pennsylvania.

Further Information

For information or questions involving lumber and log grading, or other questions regarding wood or wood products, contact:

Edwin J. Burke
Wood Science Laboratory
College of Forestry and Conservation
University of Montana
Missoula, MT 59812
eburke@forestry.umt.edu
(406) 243-5157 FAX (406) 243-4845

For information on log-grading programs contact:

Log Grading Program Coordinator
Log Homes Council
National Association of Homebuilders
1201 15th St. NW
Washington, DC 20006
www.loghomes.org
(800) 368-5242 ext. 8576

Timber Products Inspection. Inc.
PO Box 919
Conyers, GA 30207
www.tpinspection.com
(770) 922-8000

Edwin Burke, Professor, University of Montana, Missoula, Montana.

News

New Timber Design Codes in China

On January 1 of 2004 China adopted a Timber Design Code modeled after North American performance requirements. The code is applicable for light-frame residential construction and potentially for small commercial and institutional wood frame structures of up to two stories and includes wood design values and requirements taken directly from North American practices. The new code provisions are the result of efforts by a consortium of U.S. and Canadian organizations, including APA – The Engineered Wood Association, the American Forest & Paper Association, the Western Wood Products Association, Forintek Canada Corporation, the Canadian Plywood Association, and the Council of Forest Industries of British Columbia. The consortium effort, which culminated in the presentation of a draft of the proposed code to the Chinese Ministry of Construction over two years ago, is the first attempt by the U.S. and Canada to harmonize the two countries' national codes for adoption by a foreign country. Since China does not currently recognize trademarks, efforts to overcome that hurdle with a new labeling plan are underway. Also being planned are additional trade missions, seminars, trade shows, and other activities designed to capitalize on the substantial interest in China in North American wood products and construction technologies.

Moisture Management in Housing

The Residential Moisture Management Network (RMMN), an industry – government alliance formed by APA – The Engineered Wood Association, Tacoma, Washington and the Advanced Housing Research Center of the USDA Forest Products Laboratory, Madison, Wisconsin, now has a website that lists all the members of the RMMN and describes the goals of the organization. RMMN was established as a clearinghouse to identify and catalogue moisture management research, education, and communications programs drawn from more than 25 industry associations, government agencies, and private research organizations. New resources to be added to the site in the future include a calendar of coming events related to mold and moisture management and a listing of printed and electronic information on mold and moisture issues that are available to residential builders and designers. The RMMN website is located at www.rmmn.org.

Engineering Design Values for Cypress

The first-ever certified engineering design values for cypress have been published in a brochure from the Southern Cypress Manufacturers Association. The design values are recognized in all model codes and have been added to the *Design Values for Wood Construction*, the Supplement to the *National Design Specification® (NDS®) for Wood Construction*. For a free copy of the brochure, visit www.cypressinfo.org or phone 877-607-7262.

2004 WoodWorks® Design Software Available

The 2004 version of WoodWorks® U.S. Design Office is now available. A joint project of the American Forest & Paper Association and the Canadian Wood Council, this design software has been updated to reflect changes made to AWC's *National Design Specification® (NDS®) for Wood Construction* and *Wood Frame Construction Manual*, ASCE's *Minimum Design Loads for Buildings and Other Structures*, the ICBO's *Uniform Building Code* and ICC's *International Building Code*. For more informationor to order, visit www.woodworks-software.com.