VARIANCE FEES
MGO $50.00
COMM $490.00
Priority – Double above

Amount Paid
$490 #1 1.6.15

PETITION FOR VARIANCE APPLICATION

City of Madison
Building Inspection Division
215 Martin Luther King Jr. Blvd.
Madison, WI 53703
(608) 266-4568

Name of Owner Otto Gebhardt	Project Description Type IIB Commercial M Occupancy Grocery Store.	Agent, architect, or engineering firm Bark Design
Company (if applies) Gebhardt Development		No. & Street
No. & Street 222 North Street	Tenant name (if any) Festival Foods	City, State, Zip Code
City, State, Zip Code Madison, WI 53704	Building Address	Phone 608-333-1926
Phone 608-245-0753	800 N. Block East Washington Ave.	Name of Contact Person Chris Gosch, AIA
e-mail	Madison, WI 53703	e-mail chris@bark-design.com

1. The rule being petitioned reads as follows: (Cite the specific rule number and language. Also, indicate the nonconforming conditions for your project.)

IBC 2009 Section 602.2 "Types I and II. Types I and II construction are those types of construction in which the building elements listed in Table 601 are of noncombustible materials." This building will have 2 heavy timber columns with > 1.5hr fire resistance rating supporting th roof system, and 10 heavy timber columns with > 1.5hr fire resistance rating supporting a mezzanine.

2. The rule being petitioned cannot be entirely satisfied because:

Heavy timber columns are categorized as combustible materials. The client has specified these regionally-sourced columns.

3. The following alternatives and supporting information are proposed as a means of providing an equivalent degree of health, safety, and welfare as addressed by the rule:

Type IIB construction allows a 0 fire rating on all primary structural systems (IBC Section 601, Table 601). To counter this lack of prescribed fire resistance, Type IIB construction must minimize the use of combustible fuels allowed in construction. WholeTrees Structures (located in Madison, WI) will provide 12 heavy timber columns that meet and EXCEED the degree of health, safety, and welfare addressed by the Type IIB rule for 3 reasons: 1) Heavy Timber Columns perform better in fire than the fire resistance rating required in Type IIB construction (0 hou required). These 12 Heavy Timber Columns will have a fire resistance rating of >1.5 hours, which EXCEEDS Type IIB column requirements 1.5 hours (see attached documentation); 2) Heavy Timber Columns do not provide the fuel for fires that Type IIB construction is trying to avc when it prohibits combustible materials (see attached documentation); 3) These 12 columns will improve health and welfare of forests and t economies they support because they build a market for the use of superior structural systems sourced regionally, and from sustainably-managed urban and rural forests (See attached documentation).

Note: Please attach any pictures, plans, or required position statements.

VERIFICATION BY OWNER – PETITION IS VALID ONLY IF NOTARIZED AND ACCOMPANIED BY A REVIEW FEE AND ANY REQUIRED POSITION STATEMENTS.

Note: Petitioner must be the owner of the building. Tenants, agents, contractors, attorneys, etc. may not sign the petition unless a Power of Attorney is submitted with the Petition for Variance Application.

Otto Gebhardt III, being duly sworn, I state as petitioner that I have read the foregoing
Print name of owner

petition, that I believe it to be true, and I have significant ownership rights in the subject building or project.

Signature of owner [signature]	Subscribed and sworn to before me this date:
Notary public [signature]	My commission expires: 11-09-18

NOTE: ONLY VARIANCES FOR COMMERCIAL CODES ARE REQUIRED TO BE NOTARIZED.

City of Madison Fire Department Position Statement

Owner: Otto Gebhardt Gebhardt Development	Project Name: The Galaxie – Festival Foods	Contact: Chris Gosch Bark Design
Address: 222 North Street Madison, WI 53704	Building Location: 810 E Washington Ave Madison, WI 53703	Address:
Owner Phone: 608-245-0753 Email:	Building Occupancy or Use: Group M – Mercantile Grocery High-rise mixed use building	Phone: 608-333-1926 Email: chris@bark-design.com

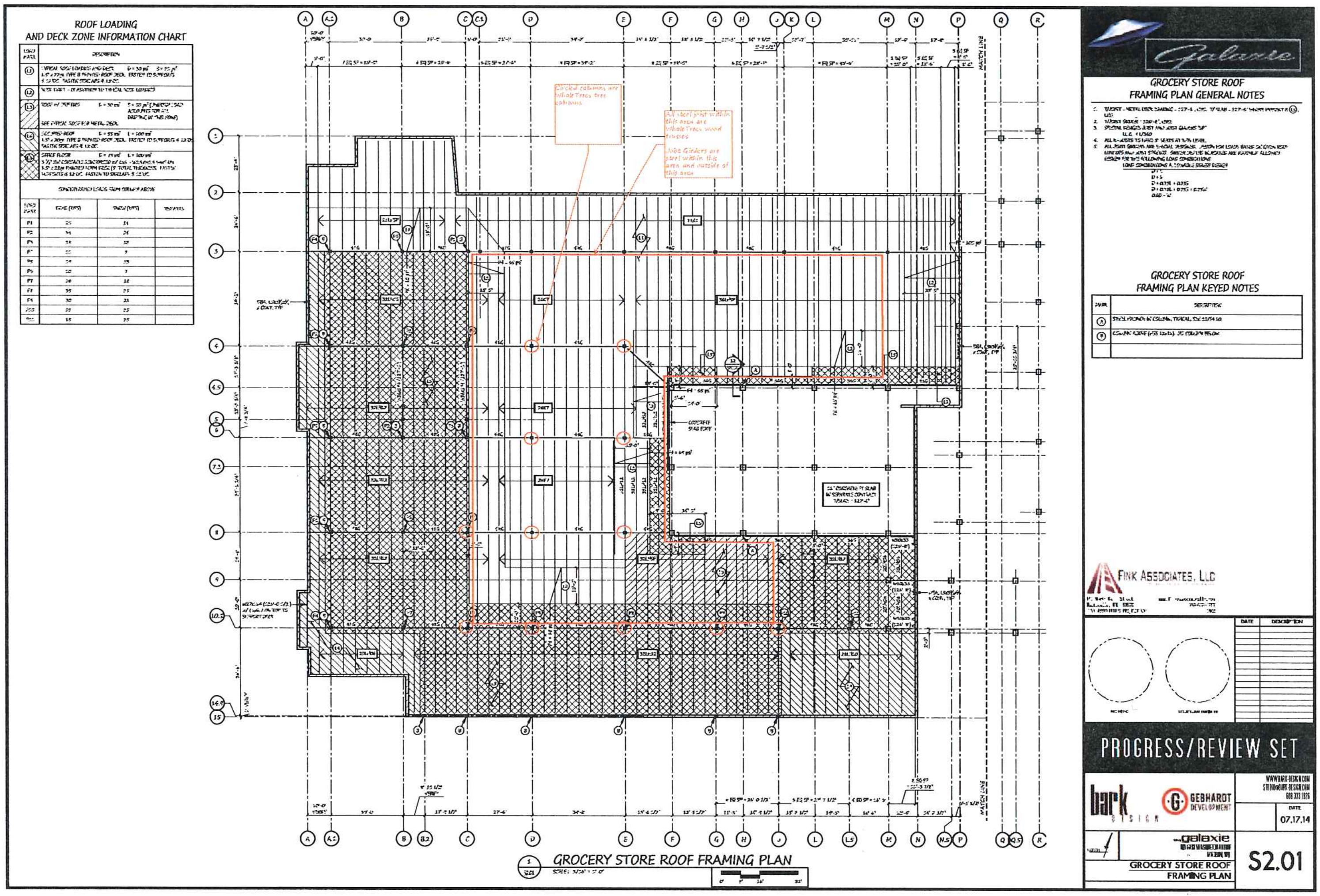
Rule Being Petitioned: IBC 602.2 Building elements shall be noncombustible for Type II construction

I have read the application for variance and recommend: (check appropriate box)
☐ Approval X Conditional Approval ☐ Denial ☐ No Comment

- MFD concurs that heavy timber columns outperform unprotected steel columns in fire conditions.
- The heavy timber columns will be equal to or greater than 18-inches in diameter.
- The heavy timber columns shall be exposed.
- All connections to the heavy timber column shall be via proven methods and acceptable to the Building Inspection Department.
- The building will be fully sprinklered.

Name of Fire Chief or Designee (type or print)
Bill Sullivan, Fire Protection Engineer

City of Madison Fire Department	Telephone Number 608-261-9658
Signature of Fire Chief or Designee	Date Signed January 7, 2015


ROOF LOADING
AND DECK ZONE INFORMATION CHART
Circled columns are WholeTrees tree columns
All steel joist within this area are WholeTrees wood trusses
Joist Girders are steel within this area and outside of this area
GROCERY STORE ROOF FRAMING PLAN
GROCERY STORE ROOF
FRAMING PLAN GENERAL NOTES
GROCERY STORE ROOF
FRAMING PLAN KEYED NOTES
FINK ASSOCIATES, LLC
DATE
DESCRIPTION
PROGRESS/REVIEW SET
bark DESIGN
GEBHARDT DEVELOPMENT
DATE
07.17.14
galaxie
GROCERY STORE ROOF
FRAMING PLAN
S2.01

WholeTrees®
Architecture & Structures

www.wholetrees.com 800 Williamson Street, Madison, WI 53703 info@wholetrees.com 608.310.5282

Column Variance Application_Attachment A: Documentation

1) Heavy Timber Columns perform better in fire than the fire resistance rating required in Type IIB construction (0 hours required). These 12 Heavy Timber Columns will have a fire resistance rating ≥1.5 hours, which EXCEEDS Type IIB column requirements by 1.5 hours.

REFERENCES:
Provisions for designing fire-resistance-rated timber members are included in the National Design Specification® (NDS®) for Wood Construction [4]. These provisions define the basis for calculations in the IBC 2009. The NDS® procedure includes provisions for 1-1/2-hour and 2-hour fire-rated members. Development of the NDS® procedure is detailed in AWC Technical Report 10 Calculating the Fire Resistance of Exposed Wood Members [1]. WholeTrees® Structures can provide these references for review electronically or in hard copy.

DOCUMENTATION:
This petition for variance uses the following sections and equations from the 2009 IBC to demonstrate fire-resistance ratings for ≥18"diameter columns that are 27' tall. WholeTrees has partnered with Strategic Structural Design, LLC to engineer these columns for this project.

IBC 2009 Section 721.6.3 Design of Fire Resistant Exposed Wood Members
"The *fire-resistance rating*, in minutes, of timber beams and columns with a minimal nominal dimension of 6 inches (152mm) is equal to:

Columns: 2.54Zb [3-(d/b)] for columns which may be exposed to fire on four sides **(Equation 7-19)**

For this project, all round timber columns are ≥ 18" in diameter. D (depth)= 18". B (width)= 18". We will conservatively assume that the load on the columns is 100 percent of the design load (capacity), in which case Z = 1.0 for a lower bound for beams and columns with $K_e l/d>11$. Equation 7-19 then yields:

2.54 (1.0)(18)[3-(18/18)]= **90 minutes= 1.5 hr fire-resistance rating**

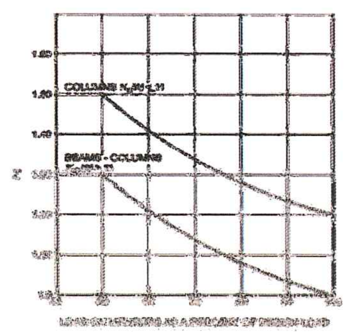


Figure 721.6.3 (1)

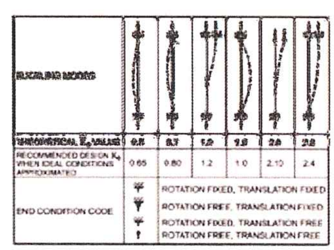


FIGURE 721.6.3(2) EFFECTIVE LENGTH FACTORS

Figure 721.6.3 (2)

The above calculations are backed by historic performance of heavy timber:

"The self-insulating quality of wood, particularly in the large wood sections of heavy timber construction, is an important factor in providing a degree of fire resistance. In

Type IV or heavy timber construction, the need for fire resistance requirements is achieved in the codes by specifying minimum for the various members or portions of a building and other prescriptive requirements. In this type of construction, the wood members are not required to have specific fire resistance ratings. The acceptance of heavy timber construction is based on historical experience with its performance in actual fires... **The availability and code acceptance of a procedure to calculate the fire resistance ratings for large timber beams and columns have allowed their use in fire-rated buildings not classified as Type IV (heavy timber) construction."[1]**

In addition to historic performance of sawn heavy timber, data on round timber boasts even better fire resistance ratings. Round timbers, as tested with equivilent cross-sections of square timbers, have 50% more strength in bending.[2] This added stength contributes to an added safety factor. Additionally, round timbers have 16% smaller surface area to support combustion, and no edges that act to form convections.

2) Heavy Timber Columns do NOT provide the fuel for fires that Type IIB construction is trying to avoid when it prohibits combustible materials within 20' of the floor, and thus do not create the risks inherent in many materials defined as combustible.

DOCUMENTATION:

WholeTrees®columns are thick heavy timber, and have the flame-spread characteristics of Type IV construction. The inclusion of Heavy Timber Type IV Construction in the building codes is based on excellent historical performance in building fires, and documented material properties based on density, thickness, and distribution of combustible contents in the building area. This petition for a variance points out that the density and thickness of 18" Ash columns will not only have a 1.5 hour fire-resistance rating, but the charring that occurs when heavy timber is exposed to fire will diminish access by fire to the majority of the wood that makes up the column., spaced 25'-38' apart from one another in this building.

To back up this claim, WholeTrees Structures uses char-rate data included in the Wood Handbook, and attached here, which not only explains why 18"-diameter columns have such good fire-resistance ratings, but also explains why the majority of the wooden column becomes inaccessible to fire during the early and critical moments of fire within a building:

> "When wood is first exposed to fire, the wood chars and eventually flames. Ignition occurs in about 2 min under the standard ASTM E 119 fire-test exposures. Charring into the depth of the wood then proceeds at a rate of approximately 0.8 mm/minfor the next 8 min (or 1.25 min/mm). Thereafter, the char layer has an insulating effect, and the rate decreases to 0.6 mm/min (1.6 min/mm). Considering the initial ignition delay, the fast initial charring, and then the slowing down to a constant rate, the average constant charring rate is about 0.6 mm/min(or 1.5 in/hr) (Douglas-fir, 7% moisture content). In the standard fire resistance test,this linear charring rate is generally assumed for solid wood directly exposed to fire." [3]

Hard Maple is a hard wood with similar material properties to the Ash Columns in this project, and better performance properties than Douglas fir, as depicted in the below table 18-3 from the Wood Handbook. Thus, 18" Ash columns have a linear charring rate of 1.46min/mm and a non-linear charring rate of about .66min*mm$^{-1.23}$, diminishing the combustibility of the material.

Appended to this Attachment A:

- **Excerpt pages on Flame Spread, Charring and Fire Resistance from the Wood Handbook: Wood as an Engineering Material.**
- **Fire Resistive Design of Exposed Wood Structures, a Presentation by the Wood Products Council.**

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[1]Forest Products Laboratory (US). *Wood handbook: wood as an engineering material.* Pg 18-6 No. 72.United States Government Printing, 1987.

[2]Wolfe, R. and C. Moseley.(2000). *Small-diameter log evaluation for value-added structural applications.*Forest Products Journal. 50(10), 48-58.

[3]Forest Products Laboratory (US). *Wood handbook: wood as an engineering material.* No. 72.United States Government Printing, 1987.

Table 18–3. Charring rate data for selected wood species

		Wood exposed to ASTM E 119 exposure[a]				Wood exposed to a constant heat flux[b]					
						Linear charring rate[e] (min mm^{-1})		Thermal penetration depth d[g] (mm)		Average mass loss rate (g m^{-2} s^{-1})	
Species	Density[c] (kg m^{-3})	Char con-traction factor[d]	Linear charring rate[e] (min mm^{-1})	Non-linear charring rate[f] (min mm$^{-1.23}$)	Thermal penetra-tion depth[g] (mm)	18-kW m^{-2} heat flux	55-kW m^{-2} heat flux	18-kW m^{-2} heat flux	55-kW m^{-2} heat flux	18-kW m^{-2} heat flux	55-kW m^{-2} heat flux
Softwoods											
Southern Pine	509	0.60	1.24	0.56	33	2.27	1.17	38	26.5	3.8	8.6
Western redcedar	310	0.83	1.22	0.56	33	—	—	—	—	—	—
Redwood	343	0.86	1.28	0.58	35	1.68	0.98	36.5	24.9	2.9	6.0
Engelmann spruce	425	0.82	1.56	0.70	34	—	—	—	—	—	—
Hardwoods											
Basswood	399	0.52	1.06	0.48	32	1.32	0.76	38.2	22.1	4.5	9.3
Maple, hard	691	0.59	1.46	0.66	31	—	—	—	—	—	—
Oak, red	664	0.70	1.59	0.72	32	2.56	1.38	27.7	27.0	4.1	9.6
Yellow-poplar	504	0.67	1.36	0.61	32	—	—	—	—	—	—

[a]Moisture contents of 8% to 9%.
[b]Charring rate and average mass loss rate obtained using ASTM E 906 heat release apparatus. Test durations were 50 to 98 min for 18-kW m^{-2} heat flux and 30 to 53 min for 55-kW m^{-2} heat flux. Charring rate based on temperature criterion of 300 °C and linear model. Mass loss rate based on initial and final weight of sample, which includes moisture driven from the wood. Initial average moisture content of 8% to 9%.
[c]Based on weight and volume of ovendried wood.
[d]Thickness of char layer at end of fire exposure divided by original thickness of charred wood layer (char depth).
[e]Based on temperature criterion of 288 °C and linear model.
[f]Based on temperature criterion of 288 °C and nonlinear model of Equation (18–3).
[g]As defined in Equation (18–6). Not sensitive to moisture content.

3) These 12 columns will improve health and welfare of forests and the economies they support because they build a market for the use of superior structural systems sourced regionally, and from sustainably-managed urban and rural forests.

DOCUMENTATION:

> "Life-cycle analyses, energy analyses, and a range of utilization efficiencies were developed to determine the carbon dioxide (CO2) and fossil fuel (FF) saved by various solid wood products, wood energy, and unharvested forests… Avoided emissions (using wood in place of steel and concrete) contributes the most to CO2 and FF savings compared to the product and wood energy contributions… Using wood substitutes could save 14 to 31% of global CO2 emissions and 12 to 19% of global FF consumption by using 34 to 100% of the world's sustainable wood growth."[4]

The applicants of this petition understand that issues of regional forest health and economies are not relevant to the Building Safety Commission, but we want to highlight that, when regional timber has the opportunity to out-perform imported, energy intensive structural materials in Wisconsin buildings, this can be a good thing for the state's people and environment.

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[4]Chadwick Dearing Oliver, Nedal T. Nassar, Bruce R. Lippke& James B. McCarter(2014) **Carbon, Fossil Fuel, and Biodiversity Mitigation With Wood and Forests**,Pg 248, Journal of Sustainable Forestry, 33:3, 248-275, DOI: 10.1080/10549811.2013.839386

Space Holder for Fire Marshall's Position Statement.

Harry Salzar has said he can wait until later this week for a signed position statement as long as all other portions of the application are submitted along with a check by the deadline, this Tuesday.

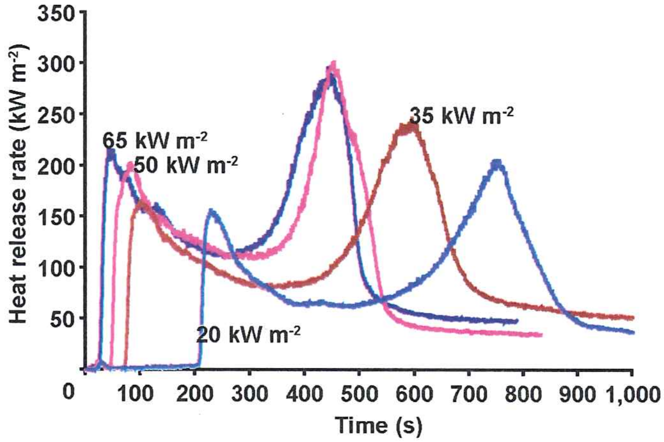

Figure 18–2. Heat release rate curves for 12-mm-thick oriented strandboard (OSB) exposed to constant heat flux of 20, 35, 50 and 65 kW m^{-2}.

The cone calorimeter is ideal for product development with its small specimen size of 100 by 100 mm. The specimen is continuously weighed by use of a load cell. In conjunction with HRR measurements, the effective heat of combustion as a function of time is calculated by the ASTM E 1354 method. Basically, the effective heat of combustion is the HRR divided by the mass loss rate as determined from the cone calorimeter test as a function of time. Typical HRR profiles, as shown in Figure 18–2, begin with a sharp peak upon ignition, and as the surface chars, the HRR drops to some minimum value. After the thermal wave travels completely through the wood thickness, the back side of a wood sample reaches pyrolysis temperature, thus giving rise to a second, broader, and even higher HRR peak. For FRT wood products, the first HRR peak may be reduced or eliminated.

Heat release rate depends upon the intensity of the imposed heat flux. Generally, the averaged effective heat of combustion is about 65% of the oxygen bomb heat of combustion (higher heating value), with a small linear increase with irradiance. The HRR itself has a large linear increase with the heat flux. This information along with a representation of the heat release profile shown in Figure 18–2 has been used to model or correlate with large scale fire growth such as the Steiner tunnel test and the room-corner fire test (Dietenberger and White 2001)

The cone calorimeter is also used to obtain dynamic measurements of smoke consisting principally of soot and CO in the overventilated fires and of white smoke during unignited pyrolysis and smoldering. The measurements are dynamic in that smoke continuously flows out the exhaust pipe where optical density and CO are measured continuously. This contrasts with a static smoke test in which the specimen is tested in a closed chamber of fixed volume and the light attenuation is recorded over a known optical path length. In the dynamic measurements of smoke, the appropriate smoke parameter is the smoke release rate (SRR), which is the optical density multiplied by the volume flow rate of air into the exhaust pipe and divided by the product of exposed surface area of the specimen and the light path length. Often the smoke extinction area, which is the product of SRR and the specimen area, is preferred because it can be correlated linearly with HRR in many cases. This also permits comparison with the smoke measured in the room-corner fire test because HRR is a readily available test result (Dietenberger and Grexa 2000). Although SRR can be integrated with time to get the same units as the specific optical density, they are not equivalent because static tests involve the direct accumulation of smoke in a volume, whereas SRR involves accumulation of freshly entrained air volume flow for each unit of smoke. Methods investigated to correlate smoke between different tests included alternative parameters such as particulate mass emitted per area of exposed sample. As pertaining to CO production, some amount of correlation has been obtained between the cone calorimeter's CO mass flow rate as normalized by HRR to the corresponding parameter measured from the post flashover gases during the room-corner fire test. Thermal degradation of white smoke from wood into simpler gases within the underventilated fire test room during post flashover is not presently well understood and can have dramatic effects on thermal radiation within the room, which in turn affects wood pyrolysis rates.

Flame Spread

The spread of flames over solids is a very important phenomenon in the growth of compartment fires. Indeed, in fires where large fuel surfaces are involved, increase in HRR with time is primarily due to increase in burning area. Much data have been acquired with the flame spread tests used in building codes. Table 18–1 lists the FSI and smoke index of ASTM E 84 for solid wood. Some consistencies in the FSI behavior of the hardwood species can be related to their density (White 2000). Considerable variations are found for wood-based composites; for example, the FSI of four structural flakeboards ranged from 71 to 189.

As a prescriptive regulation, the ASTM E 84 tunnel test is a success in the reduction of fire hazards but is impractical in providing scientific data for fire modeling or in useful bench-scale tests for product development. Other full-scale tests (such as the room-corner test) can produce quite different results because of the size of the ignition burner or test geometry. This is the case with foam plastic panels that melt and drip during a fire test. In the tunnel test, with the test material on top, a material that melts can have low flammability because the specimen does not stay in place. With an adequate burner in the room-corner test, the same material will exhibit very high flammability.

A flame spreads over a solid material when part of the fuel, ahead of the pyrolysis front, is heated to the critical condition of ignition. The rate of flame spread is controlled by how rapidly the fuel reaches the ignition temperature in response to heating by the flame front and external sources. The material's thermal conductivity, heat capacitance, thickness, and blackbody surface reflectivity influence the material's thermal response, and an increase in the values of these properties corresponds to a decrease in flame spread rate. On the other hand, an increase in values of the flame features, such as the imposed surface fluxes and spatial lengths, corresponds to an increase in the flame spread rate.

Flame spread occurs in different configurations, which are organized by orientation of the fuel and direction of the main flow of gases relative to that of flame spread. Downward and lateral creeping flame spread involves a fuel orientation with buoyantly heated air flowing opposite of the flame spread direction. Related bench-scale test methods are ASTM E 162 for downward flame spread, ASTM E 648 for horizontal flame spread to the critical flux level, and ASTM E 1321 (LIFT apparatus) for lateral flame spread on vertical specimens to the critical flux level. Heat transfer from the flame to the virgin fuel is primarily conductive within a spatial extent of a few millimeters and is affected by ambient conditions such as oxygen, pressure, buoyancy, and external irradiance. For most wood materials, this heat transfer from the flame is less than or equal to surface radiant heat loss in normal ambient conditions, so that excess heat is not available to further raise the virgin fuel temperature; flame spread is prevented as a result. Therefore, to achieve creeping flame spread, an external heat source is required in the vicinity of the pyrolysis front (Dietenberger 1994).

Upward or ceiling flame spread involves a fuel orientation with the main air flowing in the same direction as the flame spread (assisting flow). Testing of flame spread in assisting flow exists in both the tunnel tests and the room-corner burn tests. The heat transfer from the flame is both conductive and radiative, has a large spatial feature, and is relatively unaffected by ambient conditions. Rapid acceleration in flame spread can develop because of a large, increasing magnitude of flame heat transfer as a result of increasing total HRR in assisting flows (Dietenberger and White 2001). These complexities and the importance of the flame spread processes explain the many and often incompatible flame spread tests and models in existence worldwide.

Charring and Fire Resistance

As noted earlier in this chapter, wood exposed to high temperatures will decompose to provide an insulating layer of char that retards further degradation of the wood (Figure 18–3). The load-carrying capacity of a structural wood member depends upon its cross-sectional dimensions. Thus, the amount of charring of the cross section is the major factor in the fire resistance of structural wood members.

When wood is first exposed to fire, the wood chars and eventually flames. Ignition occurs in about 2 min under the standard ASTM E 119 fire-test exposures. Charring into the depth of the wood then proceeds at a rate of approximately 0.8 mm min^{-1} for the next 8 min (or 1.25 min mm^{-1}). Thereafter, the char layer has an insulating effect, and the rate decreases to 0.6 mm min^{-1} (1.6 min mm^{-1}). Considering the initial ignition delay, the fast initial charring, and then the slowing down to a constant rate, the average constant charring rate is about 0.6 mm min^{-1} (or 1.5 in. h^{-1}) (Douglas-fir, 7% moisture content). In the standard fire resistance test, this linear charring rate is generally assumed for solid wood directly exposed to fire. There are differences among species associated with their density, anatomy, chemical composition, and permeability. In a study of the fire resistance of structural composite lumber products, the charring rates of the products tested were similar to that of solid-sawn lumber. Moisture content is a major factor affecting charring rate. Density relates to the mass needed to be degraded and the thermal properties, which are affected by anatomical features. Charring in the longitudinal grain direction is reportedly double that in the transverse direction, and chemical composition affects the relative thickness of the char layer. Permeability affects movement of moisture being driven from the wood or that being driven into the wood beneath the char layer. Normally, a simple linear model for charring where t is time (min), C is char rate (min mm^{-1}), and x_c is char depth (mm) is

$$t = Cx_c \qquad (18\text{–}1)$$

The temperature at the base of the char layer is generally taken to be 300 °C or 550 °F (288 °C). With this temperature criterion, empirical equations for charring rate have

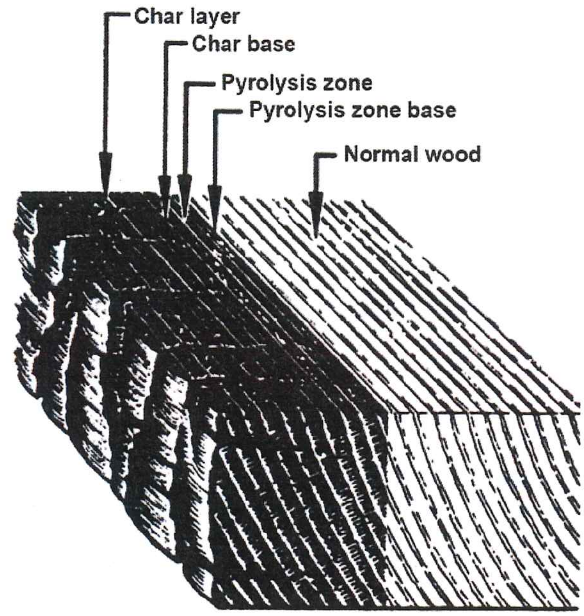

Figure 18–3. Illustration of charring of wood slab.

Table 18–3. Charring rate data for selected wood species

Species	Density[c] ($kg\ m^{-3}$)	Char con-traction factor[d]	Linear charring rate[e] ($min\ mm^{-1}$)	Non-linear charring rate[f] ($min\ mm^{-1.23}$)	Thermal penetra-tion depth[g] (mm)	Linear charring rate[e] ($min\ mm^{-1}$), 18-$kW\ m^{-2}$ heat flux	Linear charring rate[e] ($min\ mm^{-1}$), 55-$kW\ m^{-2}$ heat flux	Thermal penetration depth d^g (mm), 18-$kW\ m^{-2}$ heat flux	Thermal penetration depth d^g (mm), 55-$kW\ m^{-2}$ heat flux	Average mass loss rate ($g\ m^{-2}\ s^{-1}$), 18-$kW\ m^{-2}$ heat flux	Average mass loss rate ($g\ m^{-2}\ s^{-1}$), 55-$kW\ m^{-2}$ heat flux
	Wood exposed to ASTM E 119 exposure[a]					Wood exposed to a constant heat flux[b]					
Softwoods											
Southern Pine	509	0.60	1.24	0.56	33	2.27	1.17	38	26.5	3.8	8.6
Western redcedar	310	0.83	1.22	0.56	33	—	—	—	—	—	—
Redwood	343	0.86	1.28	0.58	35	1.68	0.98	36.5	24.9	2.9	6.0
Engelmann spruce	425	0.82	1.56	0.70	34	—	—	—	—	—	—
Hardwoods											
Basswood	399	0.52	1.06	0.48	32	1.32	0.76	38.2	22.1	4.5	9.3
Maple, hard	691	0.59	1.46	0.66	31	—	—	—	—	—	—
Oak, red	664	0.70	1.59	0.72	32	2.56	1.38	27.7	27.0	4.1	9.6
Yellow-poplar	504	0.67	1.36	0.61	32	—	—	—	—	—	—

[a]Moisture contents of 8% to 9%.
[b]Charring rate and average mass loss rate obtained using ASTM E 906 heat release apparatus. Test durations were 50 to 98 min for 18-kW m^{-2} heat flux and 30 to 53 min for 55-kW m^{-2} heat flux. Charring rate based on temperature criterion of 300 °C and linear model. Mass loss rate based on initial and final weight of sample, which includes moisture driven from the wood. Initial average moisture content of 8% to 9%.
[c]Based on weight and volume of ovendried wood.
[d]Thickness of char layer at end of fire exposure divided by original thickness of charred wood layer (char depth).
[e]Based on temperature criterion of 288 °C and linear model.
[f]Based on temperature criterion of 288 °C and nonlinear model of Equation (18–3).
[g]As defined in Equation (18–6). Not sensitive to moisture content.

been developed. Equations relating charring rate under ASTM E 119 fire exposure to density and moisture content are available for Douglas-fir, Southern Pine, and white oak. These equations for rates transverse to the grain are

$$C = (0.002269 + 0.00457\mu)\rho + 0.331 \quad \text{for Douglas-fir} \qquad (18\text{–}2a)$$

$$C = (0.000461 + 0.00095\mu)\rho + 1.016 \quad \text{for Southern Pine} \qquad (18\text{–}2b)$$

$$C = (0.001583 + 0.00318\mu)\rho + 0.594 \quad \text{for white oak} \qquad (18\text{–}2c)$$

where μ is moisture content (fraction of ovendry mass) and ρ is density, dry mass volume at moisture content μ (kg m^{-3}).

A nonlinear char rate model has been found useful. This alternative model is

$$t = m x_c^{1.23} \qquad (18\text{–}3)$$

where m is char rate coefficient (min $mm^{-1.23}$).

A form of Equation (18–3) is used in the NDS Method for calculating the fire resistance rating of an exposed wood member. Based on data from eight species (Table 18–3), the following equation was developed for the char rate coefficient:

$$m = -0.147 + 0.000564\rho + 1.21\mu + 0.532 f_c \qquad (18\text{–}4)$$

where ρ is density, ovendry mass and volume, and f_c is char contraction factor (dimensionless).

The char contraction factor is the thickness of the residual char layer divided by the original thickness of the wood layer that was charred (char depth). Average values for the eight species tested in the development of the equation are listed in Table 18–3. These equations and data are valid when the member is thick enough to be a semi-infinite slab. For smaller dimensions, the charring rate increases once the temperature has risen above the initial temperature at the center of the member or at the unexposed surface of the panel. As a beam or column chars, the corners become rounded.

Charring rate is also affected by the severity of the fire exposure. Data on charring rates for fire exposures other than ASTM E 119 have been limited. Data for exposure to constant temperatures of 538, 815, and 927 °C are available in Schaffer (1967). Data for a constant heat flux are given in Table 18–3.

The temperature at the innermost zone of the char layer is assumed to be 300 °C. Because of the low thermal conductivity of wood, the temperature 6 mm inward from the base of the char layer is about 180 °C. This steep temperature gradient means the remaining uncharred cross-sectional area of a large wood member remains at a low temperature and can continue to carry a load. Once a quasi-steady-state charring rate has been obtained, the temperature profile beneath the char layer can be expressed as an exponential term or a power term. An equation based on a power term is

$$T = T_i + (300 - T_i)\left(1 - \frac{x}{d}\right)^2 \qquad (18\text{–}5)$$

where T is temperature (°C), T_i initial temperature (°C), x distance from the char front (mm), and d thermal penetration depth (mm).

In Table 18–3, values for the thermal penetration depth parameter are listed for both the standard fire exposure and the constant heat flux exposure. As with the charring rate, these temperature profiles assume a semi-infinite slab. The equation does not provide for the plateau in temperatures that often occurs at 100 °C in moist wood. In addition to these empirical data, there are mechanistic models for estimating the charring rate and temperature profiles. The temperature profile within the remaining wood cross section can be used with other data to estimate the remaining load-carrying capacity of the uncharred wood during a fire and the residual capacity after a fire.

Fire-Retardant-Treated Wood

Wood products can be treated with fire retardants to improve their fire performance. Fire-retardant treatments results in delayed ignition, reduced heat release rate, and slower spread of flames. HRRs are markedly reduced by fire-retardant treatment (Fig. 18–4). In terms of fire performance, fire-retardant treatments are marketed to improve the flame spread characteristics of the wood products as determined by ASTM E 84, ASTM E 108, or other flammability tests. Fire-retardant treatment also generally reduces the smoke-developed index as determined by ASTM E 84. A fire-retardant treatment is not intended to affect fire resistance of wood products as determined by an ASTM E 119 test in any consistent manner. Fire-retardant treatment does not make a wood product noncombustible as determined by ASTM E 136 nor does it change its potential heat as determined by NFPA 259.

Because fire-retardant treatment does reduce the flammability of the wood product, FRT wood products are often used for interior finish and trim in rooms, auditoriums, and corridors where codes require materials with low surface flammability. Although FRT wood is not a noncombustible material, many codes have specific exceptions that allow the use of FRT wood and plywood in fire-resistive and noncombustible construction for framing of non-load-bearing partitions, nonbearing exterior walls, and roof assemblies. Fire-retardant-treated wood is also used for such special purposes as wood scaffolding and for the frame, rails, and stiles of wood fire doors.

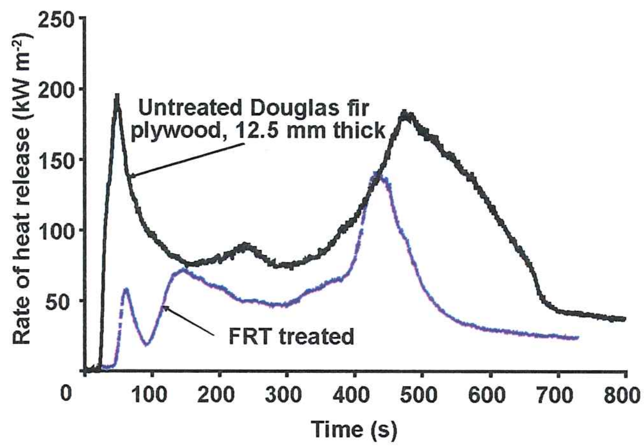

Figure 18–4. Heat release curves for untreated and fire-retardant-treated (FRT) Douglas-fir plywood, 12.5 mm thick.

To meet specifications in building codes and various standards, FRT lumber and plywood is wood that has been pressure treated with chemicals to reduce its flame spread characteristics. In the case of other composite wood products, chemicals can be added during the manufacture of the wood product. Fire-retardant treatment of wood generally improves the fire performance by reducing the amount of flammable volatiles released during fire exposure or by reducing the effective heat of combustion, or both. Both results have the effect of reducing HRR, particularly during the initial stages of fire, and thus consequently reducing the rate of flame spread over the surface. The wood may then self-extinguish when the primary heat source is removed. FRT products can be found in the Underwriters Laboratories, Inc., "Building Materials Directory," evaluation reports of ICC Evaluation Service, Inc. (ICC–ES), and other such listings.

Pressure Treatments

In impregnation treatments, wood is pressure impregnated with chemical solutions using pressure processes similar to those used for chemical preservative treatments. However, considerably heavier absorptions of chemicals are necessary for fire-retardant protection. Penetration of chemicals into the wood depends on species, wood structure, and moisture content. Because some species are difficult to treat, the degree of impregnation needed to meet the performance requirements for FRT wood may not be possible.

Inorganic salts are the most commonly used fire retardants for interior wood products, and their characteristics have been known for more than 50 years. These salts include monoammonium and diammonium phosphate, ammonium sulfate, zinc chloride, sodium tetraborate, and boric acid. Guanylurea phosphate is also used. Chemicals are combined in formulations to develop optimum fire performance yet still retain acceptable hygroscopicity, strength, corrosivity, machinability, surface appearance, glueability, and

Fire Resistive Design of Exposed Timber Structures

Heavy Timber & One Hour Fire Rating

Paul C. Gilham, P.E., S.E.
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Questions related to specific materials, methods, and services will be addressed at the conclusion of this presentation.

WoodWorks

Fire Resistive Design of Wood Structures

Learning Objectives

1. Learn where exposed timber fire resistive construction is allowed in the IBC.
2. Learn the characteristics of Heavy Timber Construction
3. Learn the methods of obtaining 1 hour fire resistive rating for exposed timber members using IBC section 7.21.6.3
4. Learn the methods of obtaining 1 hour fire resistive rating for exposed timber members using NDS chapter 16

Fire Resistive Design of Wood Structures

Fire Resistive Design of Wood Structures

Fire Resistive Design of Wood Structures

- Overview
  - Heavy Timber Construction
    - Background of Heavy Timber Construction
    - Minimum Sizes
    - Connections
    - Approved Uses
  - One Hour Fire Rated Wood Members
    - IBC section 721.6.3
    - Details
    - NDS Chapter 16
    - Examples

Heavy Timber Construction

- Background of heavy timber construction.

"Heavy-timber construction," as applied to buildings, means that in which walls are of approved masonry or reinforced concrete; And in which the interior structural elements, including columns, floors and roof construction, consists of heavy timbers with smooth flat surfaces, assembled to avoid thin sections, sharp projections and concealed spaces; And which all structural members which support masonry walls shall have a fire-resistance rating of not less than three hours; And other structural members of steel or reinforced concrete, if used in lieu of timber construction, shall have a fire resistance rating of not less than one hour."

1943 national building code.

Heavy Timber Construction

Minimum size of members (UBC table 602.4)

Member	Nominal	Solid Sawn	GLULAM
Columns			
Supporting Floor	8x8	7½" x 7½"	6¾" x 8¼"
Supporting Roof	6x8	5½" x 7½"	5" x 8¼"
Beams			
Floor	6x10	5½" x 9½"	5" x 10½"
Roof	4x6	3½" x 5½"	3" x 7½"
Arches springing from floor			
Supporting floor	8x8/8x8	7½" x 7½"	6¾" x 9"
Not supporting floor	6x8/6x6	5½" x 7½"/5½"	5" x 8¼"/6"
Arches springing from top of wall	4 x 6	3½" x 5½"	3" x 6 7/8"
Trusses			
Floor	8x8	7½" x 7½"	6¾" x 9"
Roof	4x6	3½" x 5½"	3" x 6 7/8"

Heavy Timber Construction

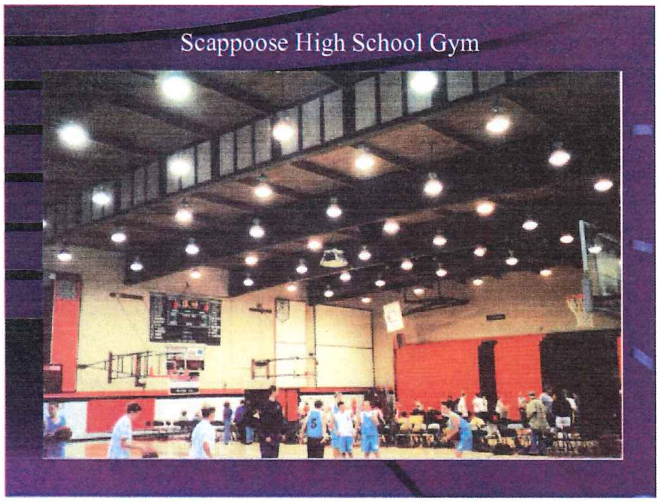
- Floors.
  - Without concealed spaces.
  - Sawn or glued-laminated planks, T&G or splined of not less than 3 in. nominal, covered with 1" T&G laid crosswise or diagonally or 15/32" wood structural panels.
  - Planks not less than 4 in. nominal on edge close together, well spiked (nail laminated) with 1" flooring or 15/32" wood structural panels.
  - The lumber shall be laid so that no continuous line of joints will occur except at points of support.
  - Floors shall not extend closer than ½ inch to walls. Such ½ inch space shall be covered by a molding fastened to the wall and arranged so that it will not obstruct the swelling and shrinking movements of the floor. Corbeling of masonry walls under floors may be used in place of of such molding.

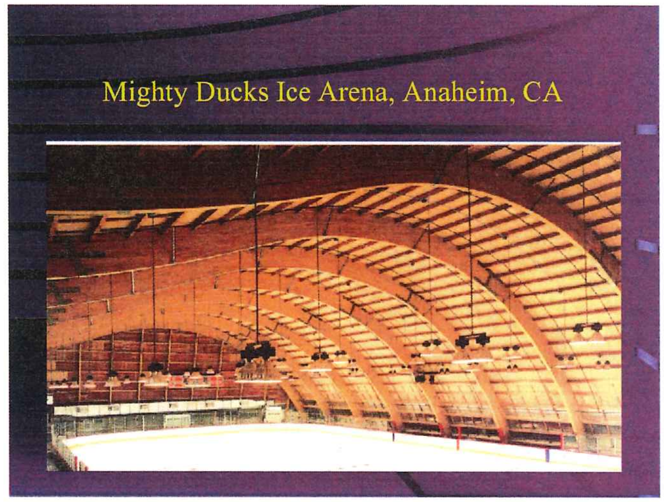
Heavy Timber Construction

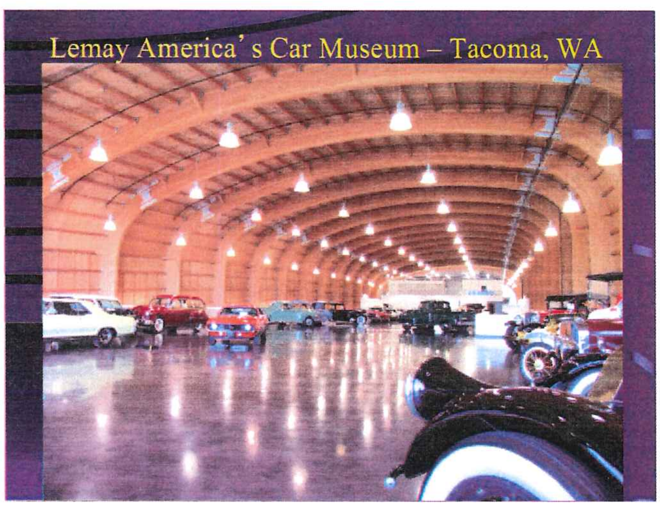
- Roofs.
  - No concealed spaces.
  - Sawn or glued-laminated plank, T&G or splined not less than 2 in. nominal or 1 1/8" wood structural panels or 3 in. nominal on edge close together, well spiked (nail laminated).
  - Laid as required for floors

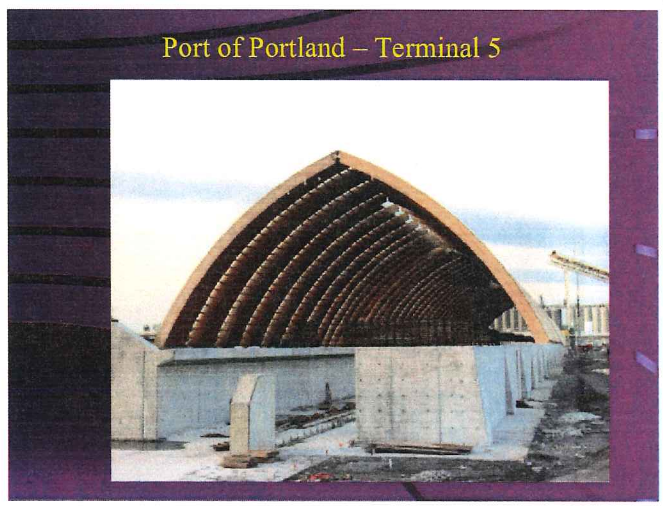
Heavy Timber Construction

- Construction Details.
  - Approved wall plate boxes or hangers at walls.
  - Girders & beams shall fit closely around columns and adjoining ends shall be cross tied to each other or intertied by caps or ties.
  - Where intermediate beams are used to support a floor, they shall rest on top of girders or shall be supported by ledgers or blocks securely fastened to the sides of the girders , or they may be supported by **approved metal hangers** into which the beams shall be closely fitted.
  - Every roof girder and at least every other roof beam shall be anchored to its supporting member.
  - Roof decks supported by a wall shall be anchored every 20' max.


Scappoose High School Gym


Mighty Ducks Ice Arena, Anaheim, CA


Lemay America's Car Museum – Tacoma, WA


Port of Portland – Terminal 5

Ashiro Dome – Ashiro, Japan

		Table 503 Allowable Building Heights and Areas								
		Type of Construction								
		Type I		Type II		Type III		Type IV	Type V	
		A	B	A	B	A	B	HT	A	B
	Height (ft)	UL	160	65	55	65	55	65	50	40
Group		Stories (S)/Area (A)								
A-1	S	UL	5	3	2	3	2	3	2	1
	A	UL	UL	15,500	8,500	14,000	8,500	15,000	11,500	5,500
A-2	S	UL	11	3	2	3	2	3	2	1
	A	UL	UL	15,500	9,500	14,000	9,500	15,000	11,500	6,000
A-3	S	UL	11	3	2	3	2	3	2	1
	A	UL	UL	15,500	9,500	14,000	9,500	15,000	11,500	6,000
A-4	S	UL	11	3	2	3	2	3	2	1
	A	UL	UL	15,500	9,500	14,000	9,500	15,000	11,500	6,000
A-5	S	UL	UL	UL	UL	UL	UL	UL	UL	UL
	A	UL	UL	UL	UL	UL	UL	UL	UL	UL
B	S	UL	11	5	3	5	3	5	3	2
	A	UL	UL	37,500	23,000	28,500	19,000	36,000	18,000	9,000
E	S	UL	5	3	2	3	2	3	1	1
	A	UL	UL	26,500	14,500	23,500	14,500	25,500	18,500	9,500
F-1	S	UL	11	4	2	3	2	4	2	1
	A	UL	UL	25,000	15,500	19,000	12,000	33,500	14,000	8,500
F-2	S	UL	11	5	3	4	3	5	3	2

TABLE 601
FIRE-RESISTANCE RATING REQUIREMENTS FOR BUILDING ELEMENTS (hours)

Building Element	Type I		Type II		Type III		Type IV	Type V	
	A	B	A[d]	B	A[d]	B	HT	A[d]	B
Primary Structural Frame (See Section 202)	3[a]	2[a]	1	0	1	0	HT	1	0
Bearing Walls Exterior[f,g] Interior	 3 3[a]	 2 2[a]	 1 1	 0 0	 2 1	 2 0	 2 1/HT	 1 1	 0 0
Nonbearing walls and partitions Exterior	See Table 602								
Nonbearing walls and partitions Interior	0	0	0	0	0	0	See Section 602.4.6	0	0
Floor construction and secondary members (see Section 202)	2	2	1	0	1	0	HT	1	0
Roof construction and secondary members (see Section 202)	1½[b]	1[b,c]	1[b,c]	0[c]	1[b,c]	0	HT	1[b,c]	0

a. Roof supports: Fire-resistive ratings of primary structural frame and bearing walls are permitted to be reduced by 1 hour where supporting a roof only.

b. Except in Group F-1, H, M and S-1 occupancies, fire protection of structural members shall not be required, including protection of roof framing and decking where every part of the roof construction is 20 feet or more above any floor immediately below. Fire-retardant-treated wood members shall be allowed to be used for such unprotected members.

c. In all occupancies, heavy timber shall be allowed where a 1-hour or less fire-resistance rating is required.

TABLE 601
FIRE-RESISTANCE RATING REQUIREMENTS FOR BUILDING ELEMENTS (hours)

Building Element	Type I		Type II		Type III		Type IV	Type V	
	A	B	A[d]	B	A[d]	B	HT	A[d]	B
Primary Structural Frame (See Section 202)	3[a]	2[a]	1	0	1	0	HT	1	0
Bearing Walls Exterior[f,g] Interior	 3 3[a]	 2 2[a]	 1 1	 0 0	 2 1	 2 0	 2 1/HT	 1 1	 0 0
Nonbearing walls and partitions Exterior	See Table 602								
Nonbearing walls and partitions Interior	0	0	0	0	0	0	See Section 602.4.6	0	0
Floor construction and secondary members (see Section 202)	2	2	1	0	1	0	HT	1	0
Roof construction and secondary members (see Section 202)	1½[b]	1[b,c]	1[b,c]	0[c]	1[b,c]	0	HT	1[b,c]	0

a. Roof supports: Fire-resistive ratings of primary structural frame and bearing walls are permitted to be reduced by 1 hour where supporting a roof only.

b. Except in Group F-1, H, M and S-1 occupancies, fire protection of structural members shall not be required, including protection of roof framing and decking where every part of the roof construction is 20 feet or more above any floor immediately below. Fire-retardant-treated wood members shall be allowed to be used for such unprotected members.

c. In all occupancies, heavy timber shall be allowed where a 1-hour or less fire-resistance rating is required.

One Hour Fire Resistive Timber Construction

- IBC Section 721.6.3.
  - Based on work by T.T. Lee at the National Research Council of Canada in the 1970s.
  - Assumptions.
    - 1.42 in../hr char rate.
    - Reduction of strength and stiffness for 1.5 in. ahead of char front.
    - .8 factor used to account for reduction of strength and stiffness.
    - Accounts for design to ultimate strength ratio.
    - Ignores increased rate of charring at corners.

One Hour Fire Resistive Timber Construction

- Equation 1 – relates size to time

$$t = (B-b)/2\beta = (D-d)/\beta$$

- Equation 2 – relates Ultimate strength to Design strength

$$KZ\frac{BD^2}{6} = \sigma\frac{bd^2}{6}$$

One Hour Fire Resistive Timber Construction

- Fire resistive rating of Timber members IBC Section 721.6.3
  - Beams

$$t_f = 2.54Zb(4 - \frac{2b}{d})$$ 4-sided exposure

$$t_f = 2.54Zb(4 - \frac{b}{d})$$ 3-sided exposure

$$Z = 1.3$$ For $R < 0.5$

$$Z = 0.7 + \frac{0.3}{R}$$ For $R \geq 0.5$

One Hour Fire Resistive Timber Construction

- Fire resistive rating of Timber members per UBC Std. 7-7
  - Columns

$$t_f = 2.54Zd(3 - \frac{d}{b})$$ 4-sided exposure

$$t_f = 2.54Zd(3 - \frac{d}{2b})$$ 3-sided exposure

For $K_e l/d \leq 11$

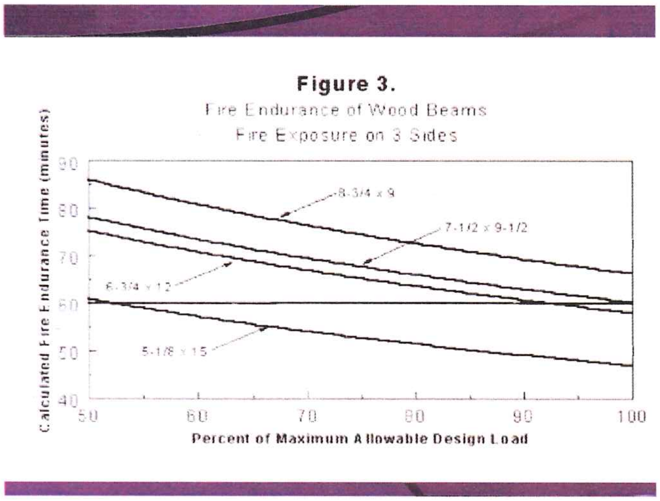
$$Z = 1.5$$ For $R < 0.5$

$$Z = 0.9 + \frac{0.3}{R}$$ For $R \geq 0.5$

For $K_e l/d > 11$

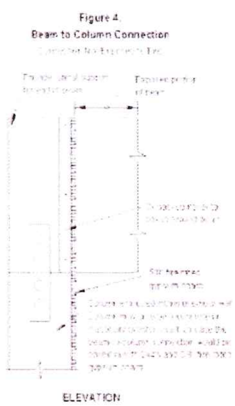
$$Z = 1.3$$ For $R < 0.5$

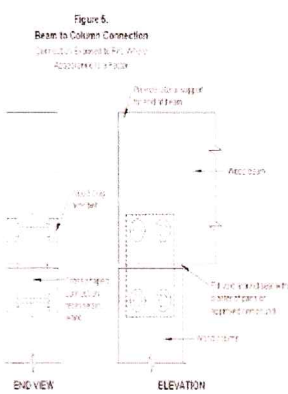
$$Z = 0.7 + \frac{0.3}{R}$$ For $R \geq 0.5$

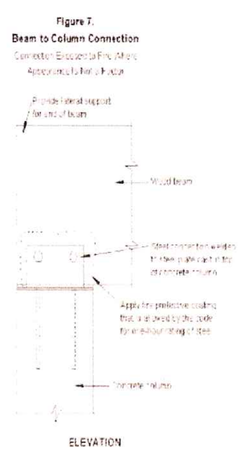


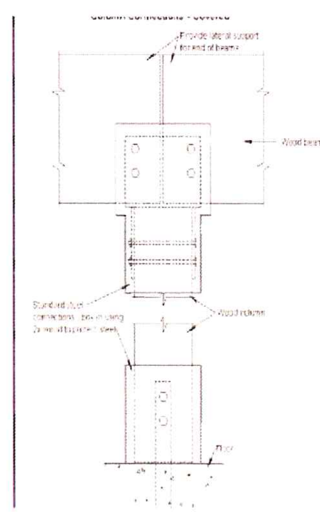
One Hour Fire Resistive Timber Construction

- Additional details.
  1. Minimum nominal width = 6."
  2. Connections and fastenings supporting members shall be protected for equivalent fire resistance.
  3. Replace one core lamination with an extra tension lamination.
  4. Glued-laminated timber members shall be marked "Fire-rated One-hour."

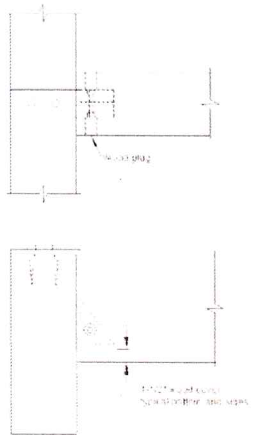






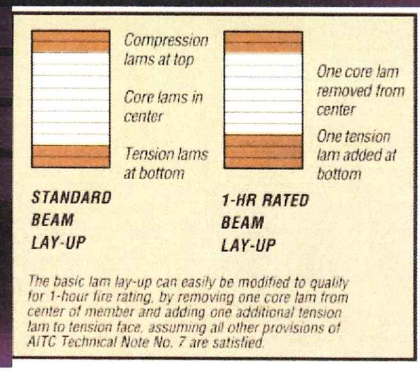


Beam to Girder - Concealed Connection



ELEVATION

One Hour Fire Resistive Timber Construction



One Hour Fire Resistive Timber Construction

- Fire resistive rating of Timber members per NDS Chapter 16
  - Calculates the capacity of fire-resistive members using same mechanics.
  - Assumes failure occurs when applied load exceeds member capacity based on reduced size.
  - Section properties are computed assuming an effective char rate, β_{eff}, at a given time, t.
  - Effective char rate accounts for rounding of the member at the corners and reduction of strength and stiffness of the heated zone.
  - $D + L \leq K\ R_{ASD}$

One Hour Fire Resistive Timber Construction

- Fire resistive rating of Timber members per NDS Chapter 16

Reduced Cross Sectional Properties

Section Property	Four sided exposure	Three sided exposure
Area	$A(t)= (B-2\beta_{eff}t)(D-2\beta_{eff}t)$	$A(t)= (B-\beta_{eff}t)(D-2\beta_{eff}t)$
Section Modulus	$S(t)= (B-2\beta_{eff}t)(D-2\beta_{eff}t)^2/6$	$A(t)= (B-2\beta_{eff}t)(D-\beta_{eff}t)^2/6$
Moment of Inertia	$I(t)= (B-2\beta_{eff}t)(D-2\beta_{eff}t)^3/12$	$I(t)= (B-2\beta_{eff}t)(D-\beta_{eff}t)^3/12$

Where: $\beta_{eff} = \frac{1.2\beta_n}{t^{0.187}}$ and: $\beta_n = 1.5$ in/hr

One Hour Fire Resistive Timber Construction

Fire resistive rating of Timber members per NDS Chapter 16

Allowable Design Stress to Average Ultimate Strength Adjustment Factors

	1/k	c	Assumed COV	K
Bending, F_b	2.1	$1-1.645COV_b$	0.16	2.85
Tensile, F_t	2.1	$1-1.645COV_t$	0.16	2.85
Compression F_c	1.9	$1-1.645COV_c$	0.16	2.58
Buckling, E_{05}	1.66	$1-1.645COV_E$	0.11	2.03

One Hour Fire Resistive Timber Construction

- Fire resistive rating of Timber members per NDS Chapter 16

Design a one hour beam to span 18' -0", spacing = 6' -0" o.c., q_{dead}=25psf, q_{live}=100 psf

w_{total} = 6(25+100) = 750 plf

M = $wL^2/8$ = 30,375 ft. lbs.

Try a 6¾" x 13½" GLULAM DF 24F-V4 C_V =0.98

S = $bd^2/6$ = 205.0 in^3

$F'_b = F_b * (C_L \text{ or } C_V)$ = 2400 * 0.98 = 2343 psi

$M' = F'_b * S$ = 2343 * 205/12 = 40,032 ft-lbs. **OK**

One Hour Fire Resistive Timber Construction

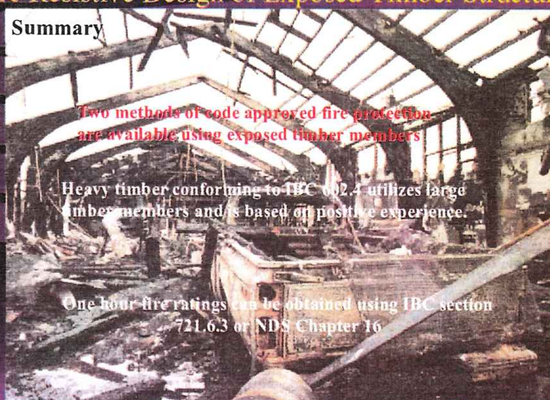
Fire Check

1. Choose required fire endurance
2. Calculate depth of char
3. Calculate reduced section property
4. Calculate Average Ultimate Stress
5. Calculate Allowable Capacity

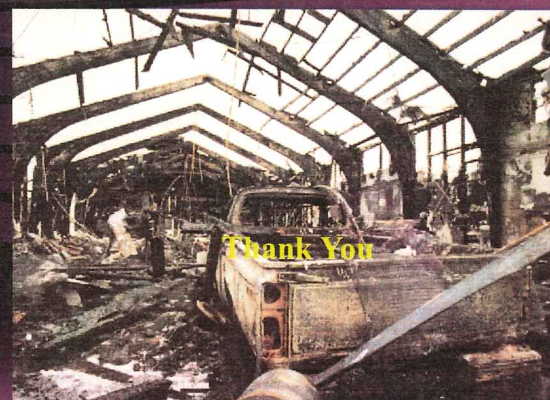
1. Choose one hour fire endurance
2. $\beta_{eff} = \dfrac{1.2(1.5)}{1.0^{0.187}} = 1.8\text{in.}$
3. $S_f = (b-2a)(d-a)^2/6 = (6.75-3.6)(13.5-1.8)^2/6 = 71.9\ in^3$
4. $F'_{bf} = F_b\,(C_V \text{ or } C_L)(2.85) = 6678.43$ psi
5. $M'_f = F'_{bf} * S_f$ = 6678.43 * 71.9/12 = 40,015 ft. lbs. > 30,375 ft. lbs. **OK**

Birchwood Community Church Anchorage, Alaska

Fire Resistive Design of Exposed Timber Structures



Fire Resistive Design of Exposed Timber Structures



Questions?

This concludes The American Institute of Architects Continuing Education Systems Course

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