FHWA Bridge Inspections: Timber Components

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(Tabulated design values are for normal load duration and dry service conditions, unless specified otherwise. See NDS 2.3 for a comprehensive description of design value adjustment factors.)

USE WITH TABLE 4C ADJUSTMENT FACTORS

Species and commercial grade	Size classification	Design values in pounds per square inch (psi) Bending F_b	Tension parallel to grain F_t	Compression parallel to grain F_c	Modulus of Elasticity E	Grading Rules Agency
MACHINE STRESS RATED (MSR) LUMBER						
900f-1.0E		900	350	1050	1,000,000	WCLIB, WWPA
1200f-1.2E		1200	600	1400	1,200,000	NLGA, WCLIB, WWPA
1250f-1.4E		1250	800	1475	1,400,000	WCLIB
1350f-1.3E		1350	750	1600	1,300,000	NLGA, WCLIB, WWPA
1400f-1.2E		1400	800	1600	1,200,000	NLGA
1450f-1.3E		1450	800	1625	1,300,000	NLGA, WCLIB, WWPA
1500f-1.3E		1500	900	1650	1,300,000	WWPA
1500f-1.4E		1500	900	1650	1,400,000	NLGA, WCLIB, WWPA
1600f-1.4E		1600	950	1675	1,400,000	NLGA
1650f-1.3E		1650	1020	1700	1,300,000	NLGA, WWPA
1650f-1.5E		1650	1020	1700	1,500,000	NLGA, SPIB, WCLIB, WWPA
1650f-1.6E		1650	1175	1700	1,600,000	WCLIB, WWPA
1700f-1.6E		1700	1175	1725	1,600,000	WCLIB
1750f-2.0E		1750	1125	1725	2,000,000	WCLIB
1800f-1.5E		1800	1300	1750	1,500,000	NLGA, WWPA
1800f-1.6E		1800	1175	1750	1,600,000	NLGA, SPIB, WCLIB, WWPA
1950f-1.5E	2"& less in thickness	1950	1375	1800	1,500,000	SPIB, WWPA
1950f-1.7E		1950	1375	1800	1,700,000	NLGA, SPIB, WCLIB, WWPA
2000f-1.6E		2000	1300	1825	1,600,000	NLGA
2100f-1.8E	2"& wider	2100	1575	1875	1,800,000	NLGA, SPIB, WCLIB, WWPA
2250f-1.7E		2250	1750	1925	1,700,000	NLGA, WWPA
2250f-1.8E		2250	1750	1925	1,800,000	NLGA, WCLIB, WWPA
2250f-1.9E		2250	1750	1925	1,900,000	NLGA, SPIB, WCLIB, WWPA
2400f-1.8E		2400	1925	1975	1,800,000	NLGA, WWPA
2400f-2.0E		2400	1925	1975	2,000,000	NLGA, SPIB, WCLIB, WWPA
2500f-2.2E		2500	1750	2000	2,200,000	WCLIB
2550f-2.1E		2550	2050	2025	2,100,000	NLGA, SPIB, WCLIB, WWPA
2700f-2.0E		2700	1800	2100	2,000,000	WCLIB, WWPA
2700f-2.2E		2700	2150	2100	2,200,000	NLGA, SPIB, WCLIB, WWPA
2850f-2.3E		2850	2300	2150	2,300,000	NLGA, SPIB, WCLIB, WWPA
3000f-2.4E		3000	2400	2200	2,400,000	NLGA, SPIB
MACHINE EVALUATED LUMBER (MEL)						
M-5		900	500	1050	1,100,000	SPIB
M-6		1100	600	1300	1,000,000	SPIB
M-7		1200	650	1400	1,100,000	SPIB
M-8		1300	700	1500	1,300,000	SPIB
M-9		1400	800	1600	1,400,000	SPIB
M-10		1400	800	1600	1,200,000	NLGA, SPIB
M-11		1550	850	1675	1,500,000	NLGA, SPIB
M-12		1600	850	1675	1,600,000	NLGA, SPIB
M-13		1600	950	1675	1,400,000	NLGA, SPIB
M-14		1800	1000	1750	1,700,000	NLGA, SPIB
M-15		1800	1100	1750	1,500,000	NLGA, SPIB
M-16		1800	1300	1750	1,500,000	SPIB
M-17[4]	2"& less in thickness	1950	1300	2050	1,700,000	SPIB
M-18		2000	1200	1825	1,800,000	NLGA, SPIB
M-19	2"& wider	2000	1300	1825	1,600,000	NLGA, SPIB
M-20[4]		2000	1600	2100	1,900,000	SPIB
M-21		2300	1400	1950	1,900,000	NLGA, SPIB
M-22		2350	1500	1950	1,700,000	NLGA, SPIB
M-23		2400	1900	1975	1,800,000	NLGA, SPIB
M-24		2700	1800	2100	1,900,000	NLGA, SPIB
M-25		2750	2000	2100	2,200,000	NLGA, SPIB
M-26		2800	1800	2150	2,000,000	NLGA, SPIB
M-27[4]		3000	2000	2400	2,100,000	SPIB
M-28		2200	1600	1900	1,700,000	SPIB
M-29		1550	850	1650	1,700,000	SPIB

4

DESIGN VALUES

Table 4D Design Values for Visually Graded Timbers (5" x 5" and larger)

(Tabulated design values are for normal load duration and dry service conditions, unless specified otherwise. See NDS 2.3 for a comprehensive description of design value adjustment factors.)

USE WITH TABLE 4D ADJUSTMENT FACTORS

Species and commercial grade	Size classification	Design values in pounds per square inch (psi)						Grading Rules Agency
		Bending F_b	Tension parallel to grain F_t	Shear parallel to grain F_v	Compression perpendicular to grain $F_{c\perp}$	Compression parallel to grain F_c	Modulus of Elasticity E	
BALSAM FIR								
Select Structural	Beams and Stringers	1350	900	65	305	950	1,400,000	NELMA NSLB
No.1		1100	750	65	305	800	1,400,000	
No.2		725	350	65	305	500	1,100,000	
Select Structural	Posts and Timbers	1250	825	65	305	1000	1,400,000	
No.1		1000	675	65	305	875	1,400,000	
No.2		575	375	65	305	400	1,100,000	
BEECH-BIRCH-HICKORY								
Select Structural	Beams and Stringers	1650	975	90	715	975	1,500,000	NELMA
No.1		1400	700	90	715	825	1,500,000	
No.2		900	450	90	715	525	1,200,000	
Select Structural	Posts and Timbers	1550	1050	90	715	1050	1,500,000	
No.1		1250	850	90	715	900	1,500,000	
No.2		725	475	90	715	425	1,200,000	
COAST SITKA SPRUCE								
Select Structural	Beams and Stringers	1150	675	60	455	775	1,500,000	NLGA
No.1		950	475	60	455	650	1,500,000	
No.2		625	325	60	455	425	1,200,000	
Select Structural	Posts and Timbers	1100	725	60	455	825	1,500,000	
No.1		875	575	60	455	725	1,500,000	
No.2		525	350	60	455	500	1,200,000	
DOUGLAS FIR-LARCH								
Dense Select Structural	Beams and Stringers	1900	1100	85	730	1300	1,700,000	WCLIB
Select Structural		1600	950	85	625	1100	1,600,000	
Dense No.1		1550	775	85	730	1100	1,700,000	
No.1		1350	675	85	625	925	1,600,000	
No.2		875	425	85	625	600	1,300,000	
Dense Select Structural	Posts and Timbers	1750	1150	85	730	1350	1,700,000	
Select Structural		1500	1000	85	625	1150	1,600,000	
Dense No.1		1400	950	85	730	1200	1,700,000	
No.1		1200	825	85	625	1000	1,600,000	
No.2		750	475	85	625	700	1,300,000	
Dense Select Structural	Beams and Stringers	1850	1100	85	730	1300	1,700,000	WWPA
Select Structural		1600	950	85	625	1100	1,600,000	
Dense No.1		1550	775	85	730	1100	1,700,000	
No.1		1350	675	85	625	925	1,600,000	
Dense No.2		1000	500	85	730	700	1,400,000	
No.2		875	425	85	625	600	1,300,000	
Dense Select Structural	Posts and Timbers	1750	1150	85	730	1350	1,700,000	
Select Structural		1500	1000	85	625	1150	1,600,000	
Dense No.1		1400	950	85	730	1200	1,700,000	
No.1		1200	825	85	625	1000	1,600,000	
Dense No.2		800	550	85	730	550	1,400,000	
No.2		700	475	85	625	475	1,300,000	
DOUGLAS FIR-LARCH (NORTH)								
Select Structural	Beams and Stringers	1600	950	85	625	1100	1,600,000	NLGA
No.1		1300	675	85	625	925	1,600,000	
No.2		875	425	85	625	600	1,300,000	
Select Structural	Posts and Timbers	1500	1000	85	625	1150	1,600,000	
No.1		1200	825	85	625	1000	1,600,000	
No.2		725	475	85	625	700	1,300,000	
DOUGLAS FIR-SOUTH								
Select Structural	Beams and Stringers	1550	900	85	520	1000	1,200,000	WWPA
No.1		1300	625	85	520	850	1,200,000	
No.2		825	425	85	520	525	1,000,000	
Select Structural	Posts and Timbers	1400	950	85	520	1050	1,200,000	
No.1		1150	775	85	520	925	1,200,000	
No.2		650	400	85	520	425	1,000,000	

Table 5A Design Values for Structural Glued Laminated Softwood Timber

(Members stressed primarily in bending) [1,2,3,4,12] (Tabulated design values are for normal load duration and dry service conditions. See NDS 2.3 for a comprehensive description of design value adjustment factors.)

Use with Table 5A Adjustment Factors

Design values in pounds per square inch (psi)

		BENDING ABOUT X-X AXIS (Loaded Perpendicular to Wide Faces of Laminations)						BENDING ABOUT Y-Y AXIS (Loaded Parallel to Wide Faces of Laminations)					AXIALLY LOADED		
		Bending		Compression Perpendicular to Grain											
Combination Symbol[4]	Species Outer Lams/ Core Lams[5]	Tension Zone Stressed in Tension F_{bxx}	Compression Zone Stressed in Tension[6] F_{bxx}	Tension Face[9,10] $F_{c\perp xx}$	Compression Face[9,10] $F_{c\perp xx}$	Shear Parallel to Grain[10] F_{vxx}	Modulus of Elasticity E_{xx}	Bending F_{byy}	Compression Perpendicular to Grain (Side Faces) $F_{c\perp yy}$	Shear Parallel to Grain F_{vyy}	Shear Parallel to Grain (For Members With Multiple Piece Laminations Which are Not Edge Glued)[13] F_{vyy}	Modulus of Elasticity E_{yy}	Tension Parallel to Grain F_t	Compression Parallel to Grain F_c	Modulus of Elasticity E
VISUALLY GRADED WESTERN SPECIES															
16F-V1	DF/WW	1600	800	560[9,10]	560[10]	140	1,300,000	950	255	130[14]	65[14]	1,100,000	675	975	1,100,000
16F-V2	HF/HF	1600	800	500[10]	375[10]	155	1,400,000	1250	375	135	70	1,300,000	875	1300	1,300,000
16F-V3	DF/DF	1600	800	560[9,10]	560[10]	190	1,500,000	1450	560	165	85	1,500,000	950	1550	1,500,000
16F-V4[7]	DF/WW	1600	800	650	560[10]	90[10]	1,500,000	900	255	130[14]	65[14]	1,300,000	650	600	1,300,000
16F-V5[7]	DF/DF	1600	800	650	560[10]	90[10]	1,600,000	1000	470	135	70	1,500,000	750	875	1,500,000
16F-V6[8]	DF/DF	1600	1600	560[9,10]	560[10]	190	1,500,000	1450	560	165	85	1,400,000	950	1550	1,400,000
16F-V7[8]	HF/HF	1600	1600	375[10]	375[10]	155	1,400,000	1200	375	135	70	1,300,000	850	1350	1,300,000
20F-V1	DF/WW	2000	1000	650	560[10]	140	1,400,000	1000	255	130[14]	65[14]	1,200,000	750	1000	1,200,000
20F-V2	HF/HF	2000	1000	500[10]	375[10]	155	1,500,000	1200	375	135	70	1,400,000	950	1350	1,400,000
20F-V3	DF/DF	2000	1000	650	560[10]	190	1,600,000	1450	560	165	85	1,500,000	1000	1550	1,500,000
20F-V4	DF/DF	2000	1000	590[9,10]	560[10]	190	1,600,000	1450	560	165	85	1,600,000	1000	1550	1,600,000
20F-V5[7]	DF/WW	2000	1000	650	560[10]	90[10]	1,600,000	1000	255	135[14]	70[14]	1,300,000	750	725	1,300,000
20F-V7[8]	DF/DF	2000	2000	650	650	190	1,600,000	1450	560	165	85	1,600,000	1000	1600	1,600,000
20F-V8[8]	DF/DF	2000	2000	590[9,10]	590[9,10]	190	1,700,000	1450	560	165	85	1,600,000	1000	1600	1,600,000
20F-V9[8]	HF/HF	2000	2000	500[10]	500[10]	155	1,500,000	1400	375	135	70	1,400,000	975	1400	1,400,000
20F-V12	AC/AC	2000	1000	560	560	190	1,500,000	1200	470	165	80	1,400,000	900	1500	1,400,000
22F-V1	DF/WW	2200	1100	650	560[10]	140	1,600,000	1050	255	130[14]	65[14]	1,300,000	850	1100	1,300,000
22F-V3	DF/DF	2200	1100	650	560[10]	190	1,700,000	1450	560	165	85	1,600,000	1050	1500	1,600,000
22F-V8[8]	DF/DF	2200	2200	590[9,10]	590[9,10]	190	1,700,000	1450	560	165	85	1,600,000	1050	1650	1,600,000
22F-V10	DF/DFS	2200	1100	650	560[10]	190	1,600,000	1600	500	165	85	1,300,000	1000	1400	1,300,000
24F-V1	DF/WW	2400	1200	650	650	140	1,700,000	1250	255	135[14]	70[14]	1,400,000	1000	1300	1,400,000
24F-V2	HF/HF	2400	1200	500[10]	500[10]	155	1,500,000	1250	375	135	70	1,400,000	950	1300	1,400,000
24F-V4	DF/DF	2400	1200	650	650	190	1,800,000	1500	560	165	85	1,600,000	1150	1650	1,600,000
24F-V5	DF/HF	2400	1200	650	650	155	1,700,000	1350	375	140	70	1,500,000	1100	1450	1,500,000
24F-V8[8]	DF/DF	2400	2400	650	650	190	1,800,000	1450	560	165	85	1,600,000	1100	1650	1,600,000
24F-V10[8]	DF/HF	2400	2400	650	650	155	1,800,000	1400	375	140	70	1,600,000	1150	1600	1,600,000
24F-V11	DF/DFS	2400	1200	650	560[10]	190	1,700,000	1600	500	165	85	1,400,000	1150	1700	1,400,000

Section 2

Bridge Materials

Topic 2.1 Timber

2.1.1 Introduction

Approximately 7% of the bridges listed in the National Bridge Inventory (NBI) are classified as timber bridges. Another 7% of the total have a timber deck supported by a steel superstructure. Many of these bridges are very old, but the use of timber structures is gaining new popularity with the use of engineered wood products. (see Figure 2.1.1). To preserve and maintain them, it is important that the bridge inspector understand the basic characteristics of wood. Timber Bridges Design, Construction, Inspection and Maintenance August 1992 manual published by the United States Department of Agriculture, Forest Service is an excellent reference to supplement timber information in this manual. To obtain information on this manual, visit the National Wood in Transportation website: www.fs.fed.us/na/wit. To download publications in PDF format go to http://spfnic.fs.fed.us/wit/WITpubs/PubSearch.cfm.

Figure 2.1.1 Glued-laminated Modern Timber Bridge

2.1.2

Basic Shapes Used in Bridge Construction

Depending on the required structural capacities and geometric constraints, wood can be cut into various shapes.

Round

Because sawmills were not created yet, most early timber bridge members were made out of solid round logs. Logs were generally used as beams, or stacked and used as abutments and foundations. In some parks, bridges that utilize logs as structural members are still in service. Round timber members have been used as piles driven into the ground or waterway bed. Logs have also been used as retaining devices for embankment material.

Rectangular

Once sawmill operations gained prominence, rectangular timber members became commonplace. Rectangular timber members were easier to connect together due to the flat sides and can be used for decking, superstructure beams, arches and truss elements, curbs or railings, and retaining devices (see Figure 2.1.2).

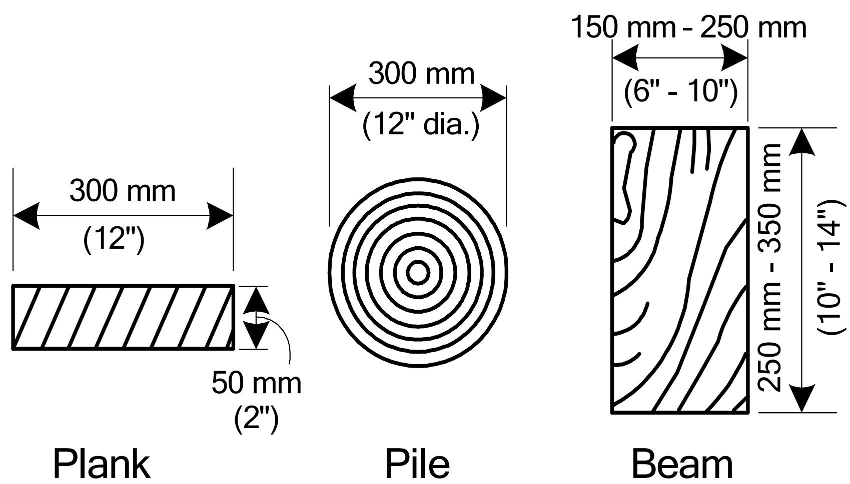

Figure 2.1.2 Timber Shapes

Built-up Shapes

Modern timber bridge members are fabricated from basic rectangular shapes to create built-up shapes, which perform at high capacities. A fundamental example of this is the deck-shaped beam. Two other common examples are T-shaped and box-shaped beams (see Figure 2.1.3). Using glue-laminate technology and stress timber design, these shapes enable modern timber bridges to carry current legal loads.

Refer to Section 6 for further information on timber superstructures and Topic 5.1 for timber decks.

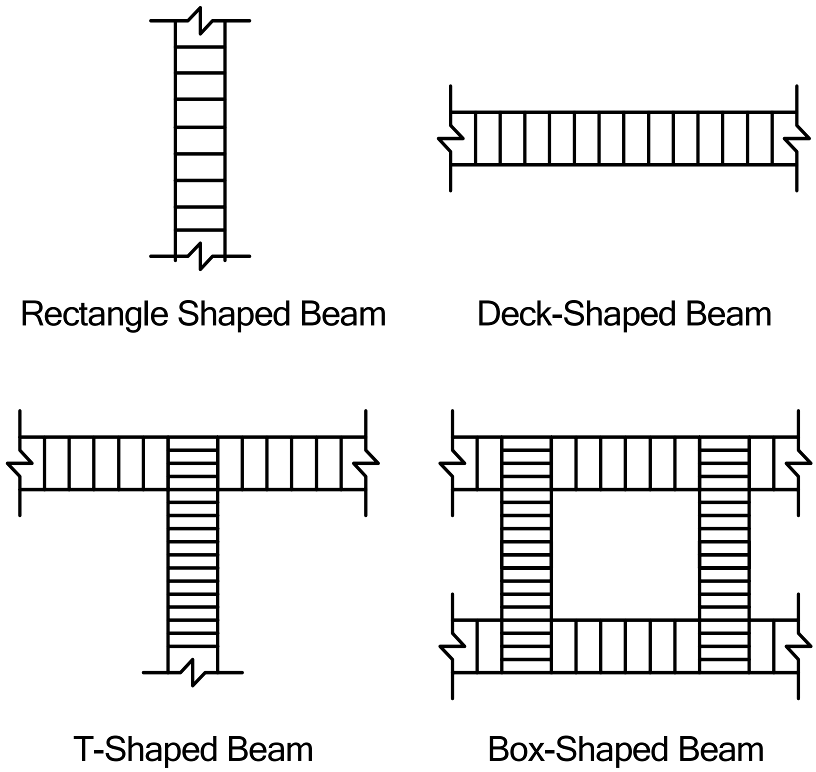

Figure 2.1.3 Built-up Timber Shapes

2.1.3 Properties of Timber

Because of its physical characteristics, wood is in many ways an excellent engineering material for use in bridges. Perhaps foremost is that it is a renewable resource. In addition, wood is:

- Strong, with a high strength to weight ratio
- Economical
- Aesthetically pleasing
- Readily available in many locations
- Easy to fabricate and construct
- Resistant to deicing agents
- Resistant to damage from freezing and thawing
- Able to sustain overloads for short periods of time (shock resistant)

However, wood also has some negative properties:

- Excessive creep under sustained loads
- Vulnerable to insect attack
- Vulnerable to fire

These characteristics stem from the unique physical and mechanical properties of wood, which vary with the species and grade of the timber.

Physical Properties

There are four basic physical properties that define timber behavior. These properties are timber classification, anatomy, growth features, and moisture content.

Timber Classification

Wood may be classified as hardwood or softwood. Hardwoods have broad leaves and lose their leaves at the end of each growing season. Softwoods, or conifers, have needle-like or scale-like leaves and are evergreens. The terms "hardwood" and "softwood" are misleading because they do not necessarily indicate the hardness or softness of the wood. Some hardwoods are softer than certain softwoods and vice versa.

Timber Anatomy

Wood is a non-homogeneous material. Wood, although an extremely complex organic material, has dominant and fundamental patterns to its cell structure. Some of the physical properties of this cell structure include (see Figure 2.1.4):

- Hollow cell composition - cell walls consist of cellulose and lignin, and are formed in an oval or rectangular shape which accounts for the high strength-to-weight ratio of wood; wood with thick cell walls is dense and strong; lignin bonds the cells together
- Growth rings - revealed in the cross section of a tree are distinct rings of wood produced during a tree’s growing season. One annual ring is composed of a ring of earlywood or springwood (light in color, cells have thin walls and large diameter) and a ring of latewood or summerwood (dark in color, cells have thick walls and small diameter). The rings can be easily seen in some trees (Douglas fir and southern pine) and exhibit little color difference in other species (spruces and true firs).
- Sapwood - the active, outer part of the tree that conducts sap and stores food throughout the tree; is generally permeable and easier to treat with preservatives; sapwood is of lighter color than heartwood
- Heartwood - the inactive, inner part of the tree which serves to support the tree; may be resistant to decay due to toxic materials deposited in the heartwood cells; usually of darker color than sapwood
- Wood rays - groups of cells, running from the center of the tree horizontally to the bark, which are responsible for cross grain strength
- Grain - the wood fibers oriented along the long axis of logs and timbers; the direction of greatest strength

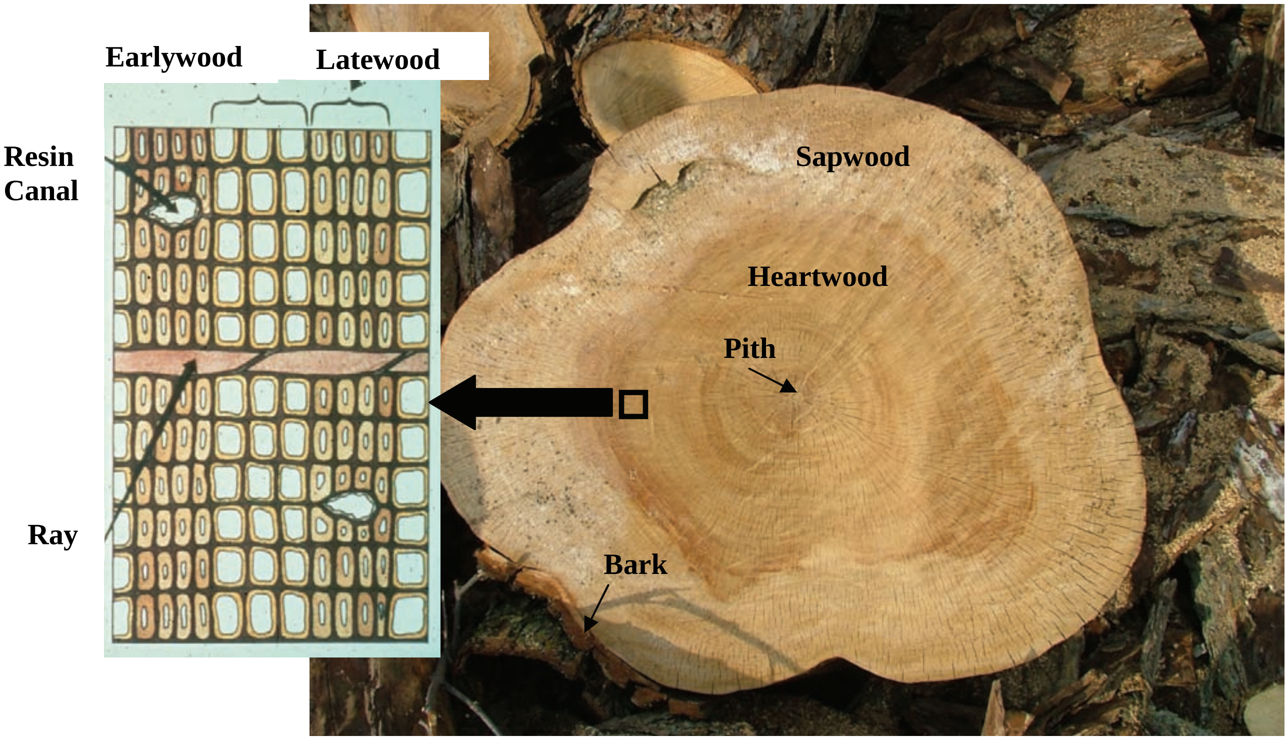

Figure 2.1.4 Anatomy of Timber

Growth Features

A variety of growth features adversely affect the strength of wood. Some of these features include:

- Knots and knot holes - due to intergrown limbs and associated grain deviation
- Sloping grain - caused by the normal taper of a tree or by sawing in a direction other than parallel to the grain
- Splits, checks, and shakes - separation of the cells along the grain, primarily due to rapid or uneven drying and differential shrinkage in the radial and tangential directions during seasoning; checks and splits occur across the growth rings; a shake is a type of check which occurs between the growth rings, peculiar to a few species
- Reaction wood - a type of abnormal wood that is formed in leaning trees; the pith is off center; the wood is gelatinous and displays cross grain shrinkage checks when seasoned

Moisture Content

Moisture content affects wood. It causes dimensional instability and fluctuations of weight and affects the strength and decay resistance of wood. It is most desirable for wood to have the least moisture content as is possible. This is done naturally over time (seasoning) or using kiln drying.

Mechanical Properties

There are four basic mechanical properties that define timber behavior. These properties are orthotropic behavior, fatigue characteristics, impact resistance and creep characteristics.

Orthotropic Behavior

Wood is considered a non-homogeneous and an orthotropic material. It is non-homogeneous because of the random occurrences of knots, splits, checks, and the variance in cell size and shape. It is orthotropic because wood has mechanical properties that are unique to its three principal axes of anatomical symmetry (longitudinal, radial, and tangential). This orthotropic behavior is due to the orientation of the cell fibers in wood (see Figure 2.1.5).

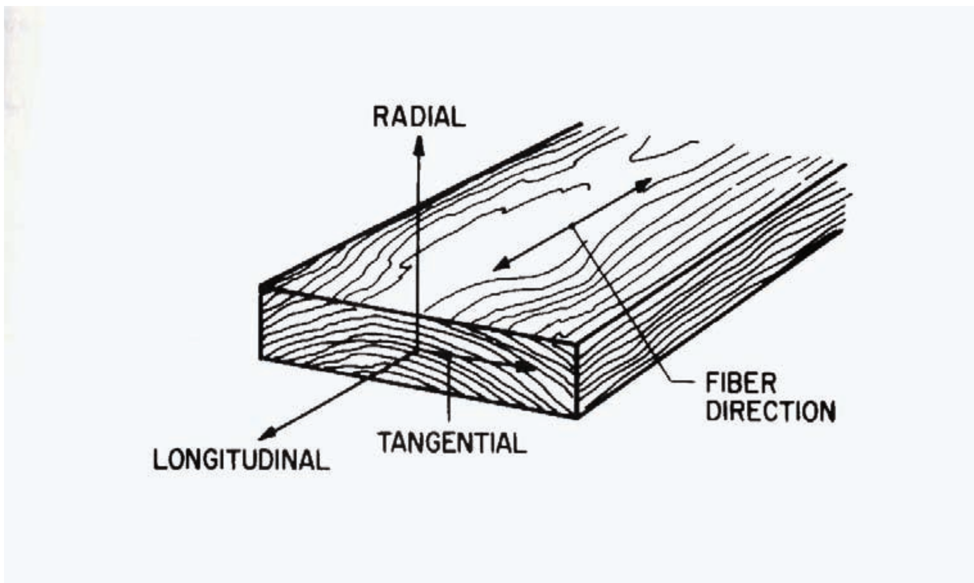

Figure 2.1.5 Three Principal Axes of Wood

As a result of its orthotropy, wood has three distinct sets of strength properties. Because timber members are longitudinal sections of wood, strength properties are commonly defined for the longitudinal axis. American Society for Testing and Materials (ASTM) Standards and American Forest and Paper Association (AF&PA) Standards are issued which present strength properties for various types of wood.

Fatigue Characteristics

Because wood is a fibrous material, it tends to be less sensitive than steel or iron to repeated loads. Therefore, it is somewhat fatigue resistant. The presence of knots and sloping grain reduces the strength of wood considerably more than does fatigue; therefore, fatigue is generally not a limiting factor in timber design.

Impact Resistance

Wood is able to sustain short-term loads of approximately twice the level it can bear on a permanent basis, provided the cumulative duration of such loads is limited.

Creep Characteristics

Creep occurs when a load is maintained on wood. That is, the initial deflection of the member increases with time. Green timbers may sag appreciably, if allowed to season under load. Initial deflection of unseasoned wood under permanent loading can be expected to double with the passage of time. Therefore, to accommodate creep, twice the initial elastic deformation is often assumed for design. Partially seasoned material may also creep to some extent. However, thoroughly seasoned wood members will exhibit little permanent increase in deflection with time.

2.1.4 Timber Grading

Douglas fir and southern pines are the most widely used species of wood for bridge construction. The southern pines include several species graded and marketed under identical grading rules. Other species, such as western hemlock and eastern spruce, are suitable for bridge construction if appropriate allowable stresses are used. Some hardwoods are also used for bridge construction.

Timber is given a grading so that the following can be established:

- Modulus of elasticity
- Tensile stress parallel to grain
- Compressive stress parallel to grain
- Compressive stress perpendicular to grain
- Shear stress parallel to grain (horizontal shear)
- Bending stress

Timber used for outdoor applications needs to be designed for wet service condition. Refer to *Timber Bridges: Design, Construction, Inspection, and Maintenance*, Forest Service, United States Department of Agriculture.

The ultimate strength properties of wood in the tables at the beginning of this topic are for air-dried wood, which is clear, straight grained, and free of strength-reducing defects. Reduction factors need to be applied to these values based on use.

Preservative treatment for decay resistance does not alter the allowable stresses for design, provided any moisture associated with the treatment process is removed.

Unlike steel, the elastic modulus of wood varies with the grades and species.

Sawn Lumber

The grading of sawn timber is accomplished by either a visual grading or a mechanical stress grading (MSR). Refer to the tables at the beginning of this topic.

Visual Grading

This type of grading is the most common and is performed by a certified lumber grader. The lumber grader inspects each sawn and surfaced piece of lumber. The individual pieces of lumber must meet particular grade description requirements in order to be classified at a certain grade. If the requirements are not met, the piece of sawn and surfaced lumber is compared to lower grade description requirements until the piece of lumber fits into the appropriate grade. Mechanical properties are predetermined for each grade. Therefore, once the piece of lumber has been graded, the mechanical properties are known.

Mechanical Stress Grading

Mechanical stress grading or mechanical stress rating (MSR) grades lumber by the relationship between the modulus of elasticity and the bending strength of lumber. A machine measures the bending strength and then assigns an elastic modulus. The grading mainly depends on the elastic modulus but can be changed by visual observance of edge knots, checks, shakes, splits, and warps. Mechanical stress grading has a different set of grading symbols than visual grading.

Glued-Laminated Lumber

Glued-laminated lumber or glulam is not graded in the same way as sawn lumber (see the tables at the beginning of this topic). Members have a combination symbol that represents the combination of lamination grades used to manufacture the member. The symbols are divided into two general classifications which are bending combinations or axial (tension or compression) combinations. The classifications are based in the anticipated use of the member, either in bending as a beam or axial combination as a column or tension member.

Bending combinations are used for resisting bending stress caused by loads applied perpendicular to the wide faces of the laminations. In this case, a lower grade lamination is used for the center portion of the member (near the neutral axis) while a higher grade lamination is placed on the outside faces where bending stresses are higher.

Axial combinations are used for resisting axial forces and bending stress applied parallel to the wide faces of the laminations. In this case, the same grade lamination is used throughout the member.

2.1.5 Types and Causes of Timber Deterioration

Although wood is an excellent material for use in bridges, untreated wood is vulnerable to damage from fungi, parasites, and other sources. The untreated inner cores of surface treated timbers and poles are vulnerable to these predators if they can gain access through the outer treated shell. The degree of vulnerability varies with the species and grade of the timber. Bridge inspectors must be able to recognize the signs of the various types of damage and be able to evaluate their effect on the structure.

Natural Defects

Defects that form from abnormal growth or from the lumber drying process include (see Figure 2.1.6):

- Checks - separations of the wood fibers, normally occurring across or through the annual growth rings, and generally parallel to the grain direction
- Splits - similar to checks except the separations of the wood fibers extend completely through the piece of wood; a split is also known as a through check

- Shakes - separations along the grain which occur between the annual growth rings
- Knots – inter grown limbs which cause the separation of wood fibers

These four defects provide openings for decay to begin and in some cases indicate reduced strength in the member when the defect is in an advanced state.

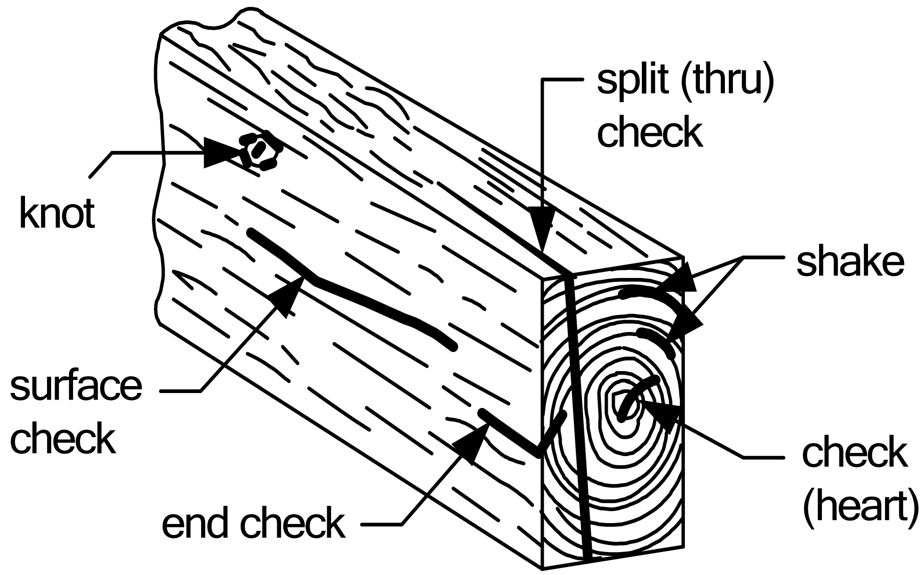

Figure 2.1.6 Natural Timber Defects

Fungi

Decay is the primary cause of timber bridge replacement. Decay is the process of living fungi, which are plants feeding on the cell walls of wood (see Figure 2.1.7). The initial process is started by the deposition of spores or microscopic seeds. Fruiting bodies (e.g., mushrooms and conks) produce these spores by the billions. The spores are distributed by wind, water, or insects.

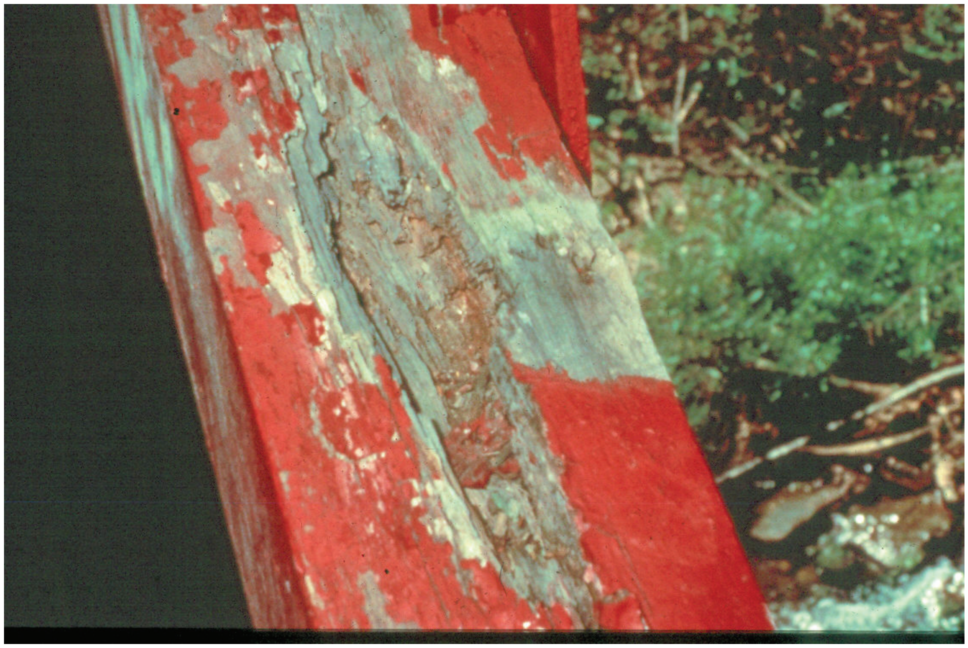

Figure 2.1.7 Decay of Wood by Fungi

Spores that survive and experience favorable growth conditions can penetrate timber members in a few weeks. Favorable conditions for fungi to grow can only occur when these four requirements exist:

- Oxygen - Sufficient oxygen must be available for the fungi to breathe. A minimal amount of free oxygen can sustain them in a dormant state, but at least 20 percent of the volume of wood must be occupied by air for fungi to become active. The air we breathe contains about 21 percent oxygen. Absence of oxygen in bridge members would only occur in piling or bents placed below the permanent low water elevation or water table, or buried in the ground.

- Temperature - A favorable temperature range must be available for the growth of fungi to occur. Below freezing, 0ºC (32ºF), the fungi become dormant but resumes its growth as the temperature rises above freezing to the 24ºC to 29ºC (75ºF to 85ºF) range, where growth is at its maximum. Above 32ºC (90ºF), growth tapers off rapidly, and temperatures in excess of 49ºC (120ºF) become lethal to the fungi. These killing temperatures could only occur in bridge members during kiln drying or preservative treating.

- Food - An adequate food supply must be available for the fungus to feed on. As the entire bridge serves as the food supply, the only prevention is to poison the wood supply with preservatives.

- Moisture - The fourth and probably the most controlling requirement is an adequate supply of moisture. The term "dry-rot" is misleading because dry wood will not rot. Wood must have a moisture content of 20 percent or greater for the growth of fungi to become active. Rain or snow is the main source of wood wetting. Secondary sources are condensation, ground water, and stream water. Exposed surfaces allow moisture to evaporate harmlessly. However seasoning shakes, checks and splits, interfaces between timber members, and fastener holes are ideal for localized moisture accumulation which allow fungi to grow.

Although there are numerous types and species of fungi, only a few cause decay in timber bridge members. Some fungi types that do not cause damage include:

- Molds - cottony or powdery circular growths varying from white or light colors to black; molds themselves do not cause decay but their presence is an indication that conditions favorable to the growth of fungi exist (see Figure 2.1.8)
- Stains - specks, spots, streaks, or patches, varying in color, which penetrate the sap wood; sapstain is harmless to wood; it is usually a surface phenomenon and, like molds, implies conditions where harmful fungi can flourish
- Soft rot - attacks the wood, making it soft and spongy; only the surface wood is affected, and thus it does not significantly weaken the member; occurs mostly in wood of high water content and high nitrogen content

Some fungi types that weaken the wood include:

- Brown rot - degrades the cellulose and hemi-cellulose leaving the lignin as a framework which makes the wood dark brown and crumbly (see Figure 2.1.9)
- White rot - feeds upon the cellulose, hemi-cellulose, and the lignin and makes the wood white and stringy (see Figure 2.1.9).

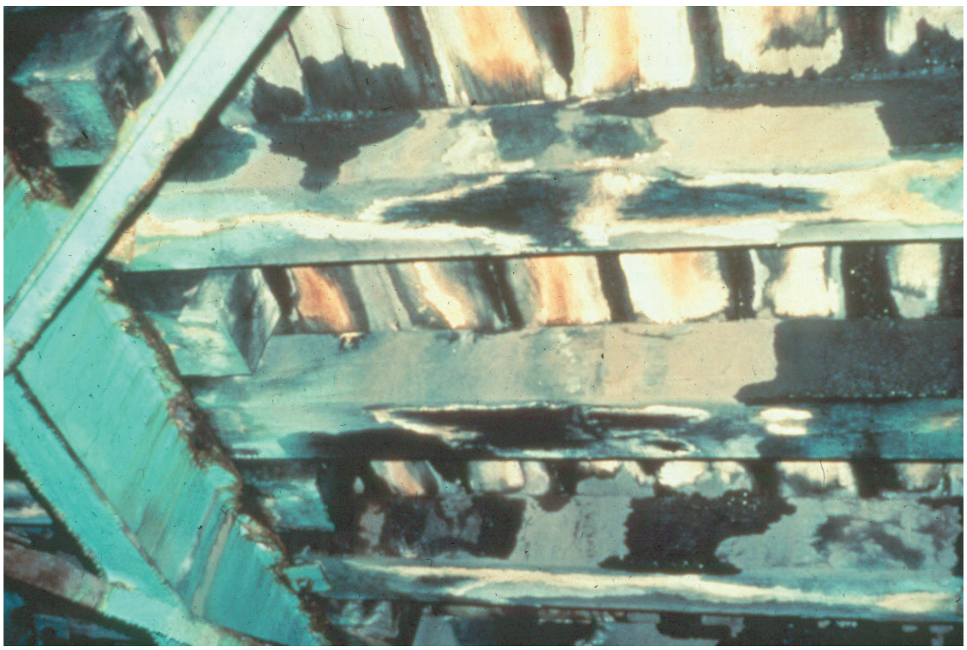

Figure 2.1.8 Mold and Stain on Underside of Timber Bridge

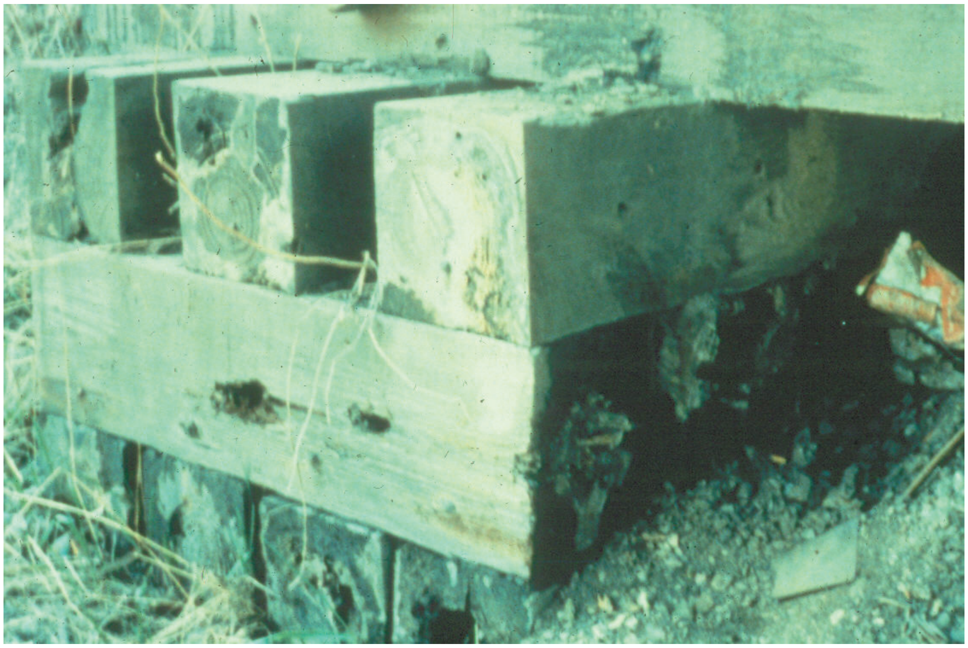

Figure 2.1.9 Brown and White Rot

Brown and white rots are responsible for structural damage to wood.

The natural decay resistance of wood exposed under conditions favorable for decay is distinctly variable, and it can be an important factor in the service life of timber bridges.

The heartwood of many tree species possesses a considerable degree of natural decay resistance, while the sapwood of all commercial species is vulnerable to decay.

Each year, when an inner layer or ring of sapwood dies and becomes heartwood, fungi-toxic compounds are deposited. These compounds provide natural decay resistance and are not present in living sapwood.

Most existing timber bridges in this country have been constructed from either Douglas fir or southern pine. Older bridges may contain such additional species as larch, various pines, and red oak. The above named species are classified as moderately decay resistant. Western red cedar and white oak are considered very decay resistant.

In the last 25 years, bridge materials have been obtained increasingly from smaller trees in young-growth timber stands. As a result, recent supplies of lumber and timbers have contained increased percentages of decay-susceptible sapwood.

Insects

Insects tunnel in and hollow out the insides of timber members for food and shelter. Some common types of insects include:

- Termites
- Powder-post beetles or lyctus beetles
- Carpenter ants
- Caddisflies

Termites

Termites are pale-colored, soft-bodied insects that feed on wood (see Figure 2.1.10). All damage is inside the surface of the wood; hence, it is not visible. The only visible signs of infestation are white mud shelter tubes or runways extending up from the earth to the wood and on the sides of masonry substructures. Termite attack of bridge members, however, is rare or nonexistent in bridges throughout most of the country due to the constant vibration caused by traffic travelling over timber bridges.

Figure 2.1.10 Termites

Powder-post Beetles or Lyctus Beetles

Powder-post beetle larvae also hollow out the insides of timber members and leave the outer surface pocked with small holes (see Figure 2.1.11). Often a powdery dust is dislodged from the holes. The inside may be completely excavated as the larvae of these beetles bore through the wood for food and shelter.

Figure 2.1.11 Powder Post Beetle

Carpenter Ants

Carpenter ants are large, black ants up to 19 mm (3/4 inches) long that gnaw galleries in soft or decayed wood (see Figure 2.1.12). The ants may be seen in the vicinity of the infested wood, but the accumulation of sawdust on the ground at the base of the timber is also an indicator of their presence. The ants do not use the wood for food but build their galleries in the moist and soft or partially decayed wood.

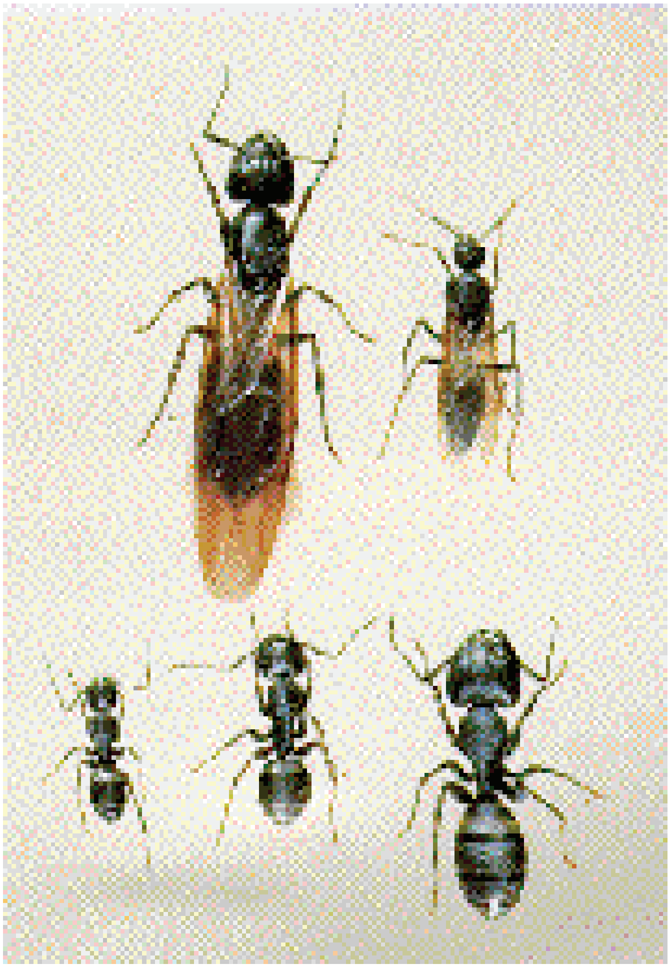

Figure 2.1.12 Carpenter Ants

Caddisflies

The caddisfly is another insect that can damage timber piles. It is generally found in fresh water but can also be found in brackish water. Bacterial and fungal decay make the timber attractive to the caddisfly.

The caddisfly is an aquatic insect that is closely related to the moth and butterfly (see Figure 2.1.13). During the larva and pupa stage of their life cycle, they can dig small holes in the timber for protection. The larvae do not feed on the timber, but rather use it as a foundation for their silken shelters. This explains why caddisfly larvae have been known to exist on creosote treated timber.

Figure 2.1.13 Caddisfly Larva

Marine Borers

Marine borers are found in sea water and brackish water only and cause severe damage to timber members in the area between high and low water, although damage may extend to the mud line (see Figure 2.1.14). They can be very destructive to wood and have been known to consume piles and framing in just a few months.

One type of marine borer is the mollusk borer, or shipworm (see Figure 2.1.15). The shipworm is one of the most serious enemies of marine timber installations. The most common species of shipworm is the teredo. This shipworm enters the timber in an early stage of life and remains there for the rest of its life. Teredos are gray and slimy and can typically reach a length of 380 mm (15 inches) and a diameter of 10 mm (3/8 inch). Some species of shipworm have been known to grow to a length of 1.8 m (6 feet) and up to 25 mm (1 inch) in diameter. The teredo maintains a small opening in the surface of the wood to obtain nourishment from the sea water.

Figure 2.1.14 Marine Borer Damage to Wood Piling

Figure 2.1.15 Shipworms (Mollusks)

Another type of marine borer is the crustacean borer. The most commonly encountered crustacean borer is the limnoria or wood louse (see Figure 2.1.16). It bores into the surface of the wood to a shallow depth. Wave action or floating debris breaks down the thin shell of timber outside the borers' burrows, causing the limnoria to burrow deeper. The continuous burrowing results in a progressive deterioration of the timber pile cross section, which will be noticeable by an hourglass shape developed between the tide levels. These borers are about 3 to 6 mm (1/8 to 1/4 inches) long and 2 to 3 mm (1/16 to 1/8 inches) wide.

Figure 2.1.16 Limnoria (Wood Louse)

Chemical Attack

Most petroleum based products and chemicals do not cause structural degradation to wood. However, animal waste can cause some damage, and strong alkalis will destroy wood fairly rapidly. Highway bridges are seldom exposed to these substances. Timber structures normally do not come in contact with damaging chemicals unless an accidental spill occurs.

Acids

Wood resists the effects of certain acids better than many materials and is often used for acid storage tanks. However, strong acids that have oxidizing properties, such as sulphuric and sulphureous acid, are able to slowly remove a timber structure's fiber by attacking the cellulose and hemi-cellulose. Acid damaged wood has weight and strength losses and looks as if it has been burned by fire.

Bases or Alkalis

Strong bases or alkalis attack and weaken the hemi-cellulose and lignin in the timber structure. Attack by strong bases leaves the wood a bleached white color. Mild alkalis do little harm to wood.

Other Types and Sources of Deterioration

Delaminations

Delaminations occur in glued-laminated members when the layers separate due to failure within the adhesive or at the bond between the adhesive and the laminate. They provide openings for decay to begin and may cause a reduction in strength (see Figure 2.1.17).

Loose connections

Loose connections may be due to shrinkage of the wood, crushing of the wood around the fastener, or from repetitive impact loading (working) of the connection. Loose connections can reduce the bridge's load-carrying capacity (see Figure

2.1.18).

Surface depressions

Surface depressions indicate internal collapse, which could be caused by decay.

Fire

Fire consumes wood at a rate of about 1 mm (0.05 inches) per minute during the first 30 minutes of exposure, and 0.5 mm (0.021 inches) per minute thereafter (see Figure 2.1.19). Large timbers build a protective coating of char (carbon) after the first 30 minutes of exposure. Small size timbers do not have enough volume to do this before they are, for all practical purposes, consumed by fire. Preservative treatments are available to retard fire damage.

Figure 2.1.17 Delamination in a Glue Laminated Timber Member

Figure 2.1.18 Loose Hanger Connection Between the Timber Truss and Floorbeam

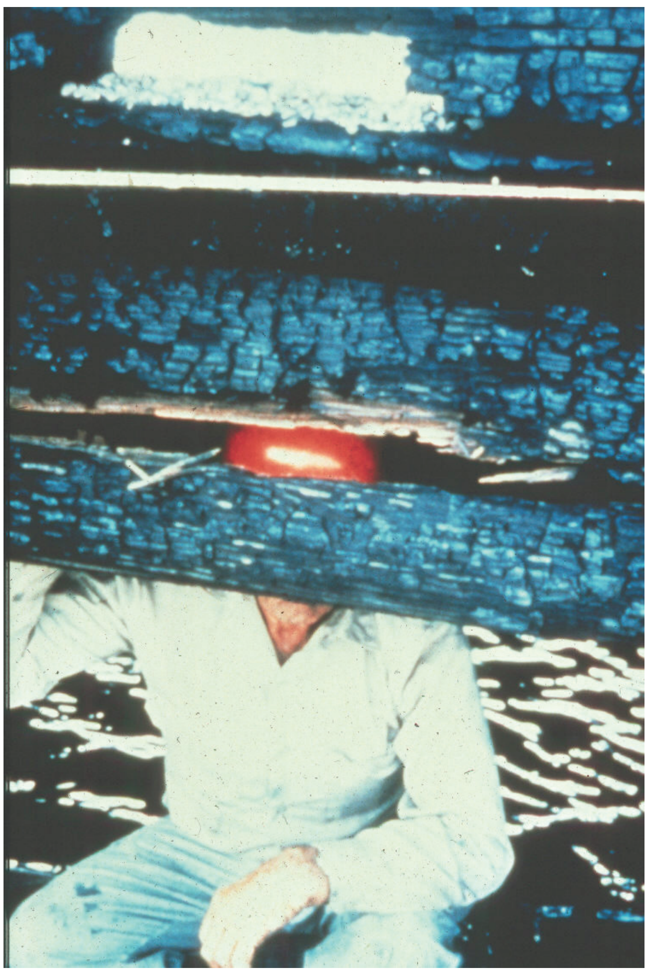

Figure 2.1.19 Fire Damaged Timber Member

Impact or Collisions

Severe damage can occur to truss members, railings, and columns when an errant vehicle strikes them (see Figure 2.1.20).

Figure 2.1.20 Impact/Collision Damage to a Timber Member

Wear, Abrasion and Mechanical Wear

Vehicular traffic is the main source of wear on timber decks (see Figure 2.1.21). Abrasion occurs on timber piles that are subjected to tidal flows. Mechanical wear of timber members sometimes occurs due to movement of the fasteners against their holes when connections become loose.

Figure 2.1.21 Wear of a Timber Deck

Overstress

Each timber member has a certain ultimate load capacity. If this load capacity is exceeded, the member will fail (see Figures 2.1.22 and 2.1.23).

Figure 2.1.22 Horizontal Shear Failure in Timber Member

Figure 2.1.23 Failed Timber Floor Beam due to Excessive Bending Moment

Weathering or Warping

Weathering is the affect of sunlight, water, and heat. Weathering can change the equilibrium moisture content in the wood in a non-uniform fashion, thereby resulting in changes in the strength and dimensions of the wood. Uneven reduction in moisture content causes localized shrinkage, which can lead to warping, checking, splitting, or loosening of connectors (see Figure 2.1.24).

Figure 2.1.24 Weathering on Timber Deck

Protective Coating Failure

The following paint failures are common on wood:

- Cracking and peeling extend with the grain of the wood. They are caused by different shrinkage and swell rates of expansion and contraction between springwood and denser summerwood.
- Decay fungi penetrate through cracks in the paint to cause wood to decay.
- Blistering is caused by paint applied over an improperly cleaned surface. Water, oil, or grease typically are responsible for blistering.
- Chalking is a degradation of the paint, usually by the ultraviolet rays of sunlight, leaving a powdery residue.
- Erosion is general thinning of the paint due to chalking, weathering, or abrasion.
- Mold fungi and stain fungi grow on the surface of paint, usually in warm, humid, shaded areas with low air flow. They appear as small green or black spots.

2.1.6 Protective Systems

Protective systems are a necessity when using timber for bridge construction. Proper preparation of the timber surface is required for the protective system to penetrate the wood surface and perform adequately. Untreated timber generally has a unit weight of about 640 to 800 kilograms per cubic meter (40 to 50 pounds per cubic foot (pcf)).

Types and Characteristics of Wood Protectants

Water Repellents

Water repellents retard water absorption and maintain low moisture content in wood. This helps to prevent decay by molds and to slow the weathering process. Laminated wood (plywood) is particularly susceptible to moisture variations, which cause stress between plies due to swelling and shrinkage.

Preservatives

Wood preservatives prevent biological deterioration that can penetrate into timber. To be effective, the preservatives have to be applied to wood by vacuum-pressure treatment. This is done by placing the timber to be treated in a sealed chamber up to 2.4 m (8 feet) in diameter and 43 m (140 feet) long. The chamber is evacuated, drawing the air from the wood pores and cells. The treatment chemical is then fed into the chamber and pressure up to 1380 kPa (200 psi) is applied, forcing the chemical into the wood (see Figure 2.1.25). Preservatives are the best means to prevent decay but do not prevent weathering. A paint or water repellent coating is required for this. Treated timber generally has a unit weight of about 800 kilograms per cubic meter (50 pounds per cubic foot (pcf)).

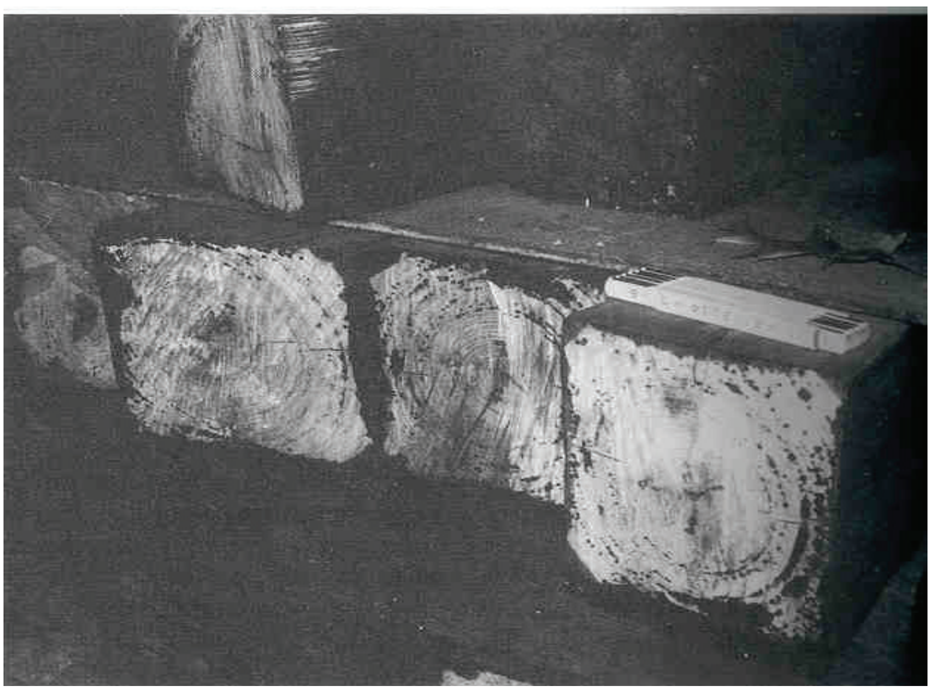

Figure 2.1.25 Bridge Timber Member Showing Penetration Depth of Preservative Treatment

Coal tar-creosote is a dark, oily protectant used in structural timber such as pilings and beams. Coal tar-creosote treated timber has a dark, oily appearance (see Figure 2.1.26). Unless it has weathered for several years, it cannot be painted, since paint adheres poorly to the oily surface, and the oils bleed through paint.

Figure 2.1.26 Coal-Tar Creosote Treated Timber Beams (Source: Barry Dickson, West Virginia University)

Pentachlorophenol (in a light oil solvent) is an organic solvent solution used as a decay inhibitor. It also leaves an oily surface, like creosote, but can be painted after all of the solvent has evaporated, usually in one or two years of normal service.

Chromated copper arsenate (CCA) is the most common waterborne salt decay inhibitor and is also applied by vacuum-pressure treatment. Timber treated with CCA has a green appearance. It is the only pressure-applied preservative that readily accepts painting. CCA also provides limited protection against the ultraviolet rays in sunlight.

Pole-fuming is used to kill decay fungi in timber pilings which are already in-service. The treatment chemical, injected through bore holes drilled into the piling, spreads along wood fibers for up to 2.7 m (9 feet) from the injection site. It stops existing decay and prevents further decay for up to nine years.

Fire Retardants

Fire retardants will not indefinitely prevent wood from burning but will retard the spread of fire and prolong the time to ignite wood. The two main classes of fire retardants are pressure impregnated fire retardant salts and intumescent coatings (paints). The intumescent paints expand upon intense heat exposure, forming a thick, puffy, charred coating which insulates the wood from the intense heat. Application of fire retardants may change some wood properties of glued-laminated timber.

Paint

Wood must be sufficiently dry to permit painting. A few months of seasoning will satisfactorily dry new wood. The wood surface must be free of dirt and debris prior to painting. Old, poorly adherent paint must be removed and the edges of intact paint feathered for a smooth finish. Mildew shows up as green or black spots on bare wood or paint. It is a fungus which typically grows in warm, humid, shaded areas with low air movement. Mildew must be removed with a solution of sodium hypochlorite (bleach) and water.

There are several common methods to prepare wood for painting:

- Hand tool cleaning is the simplest but slowest method. Sandpaper, scrapers, and wire brushes are used to clean small areas.
- Power tool cleaning utilizes powerized versions of the hand tools. They are faster than hand tools, but care must be exercised not to damage the wood substrate.
- Heat application with an electric heat gun softens old paint for easier removal to bare wood.
- Solvent-based and caustic chemical paint removers can efficiently clean large areas quickly. Some of the chemicals may, however, present serious fire or exposure hazards. Extreme caution must be exercised when working around chemical paint removers.
- Open nozzle abrasive blast cleaning and water blast cleaning remove old paint and foreign material, leaving bare wood. However, they can easily damage wood unless used carefully.

Paint protects wood from both moisture and weathering. By precluding moisture from wood, paint prevents decay. However, paint applied over unseasoned wood seals in moisture, accelerating, rather than retarding, decay. Oil-based paint and latex paint are both commonly used on wood bridges.

Oil-based paint provides the best shield from moisture. It is not, however, the most durable. It does not expand and contract as well as latex, and it is more prone to cracking. Oil/alkyd paints cure by air oxidation. These paints are low cost, with good durability, flexibility, and gloss retention. They are resistant to heat and solvents. Alkyd paints often contain lead pigments, known to cause numerous health hazards. The removal and disposal of lead paint is a regulated activity in all states.

Latex paint consists of a latex emulsion in water. Latex paint is often referred to as water-based paint. There are many types of latex paint, each formulated for a different application. They have excellent flexibility and color retention, with good adhesion, hardness, and resistance to chemicals.

2.1.7 Inspection Procedures for Timber

There are three basic procedures used to inspect a timber member. Depending on the type of inspection, the inspector may be required to use only one individual procedure or all procedures. They include:

- Visual
- Physical
- Advanced inspection techniques

Visual Examination

There are two types of visual inspections that may be required of an inspector. The first, called a routine inspection, involves reviewing the previous inspection report and visually examining the members from beneath the bridge. A routine inspection involves a visual assessment to identify obvious defects.

The second type of visual inspection is called an in-depth inspection. An in-depth inspection is an inspection of one or more members above or below the water level to identify any deficiencies not readily detectable using routine procedures. Hands-in inspection may be necessary at some locations. This type of visual inspection requires the inspector to visually assess all defective timber surfaces at a distance no further than an arm's length. The timber surfaces are given close visual attention to quantify and qualify any defects. The hands-in inspection technique may be supplemented by non-destructive testing.

For timber members, visual inspections reveal areas that need further investigation such as checks, splits, shakes, fungus decay, deflection, or loose fasteners.

Physical Examination

Once the defects are identified visually, physical procedures must be used to verify the extent of the defect. Most physical inspection procedures for timber members involve destructive methods. An inspection hammer, on the other hand, does not damage timber and can be used to tap on areas and determine the extent of internal decay. This is done by listening to the sound the hammer makes. If it sounds hollow, internal decay may be present. Some methods or areas of physical examination include:

Pick or Penetration Test

A pick or penetration test involves lifting a small sliver of wood with a pick or pocketknife and observing whether or not it splinters or breaks abruptly. Sound wood splinters, while decayed wood breaks abruptly (see Figure 2.1.27).

Figure 2.1.27 Inspector Performing a Pick Test

Timber Boring and Drilling Locations

The following are common timber boring and drilling locations (see Figure 2.1.28):

- Deck planks - in the bottom, next to a beam.
- Beams - in sides near the deck and in the bottom over the bent cap.
- Cap - under the beams and over posts and piles.
- Post/pile - top under cap and bottom just above ground or water line.

An inspector may be required to take samples to determine the condition of the wood. When drilling or boring vertical faces, always drill at a slight upward angle so that any drainage will flow away from the plugged hole.

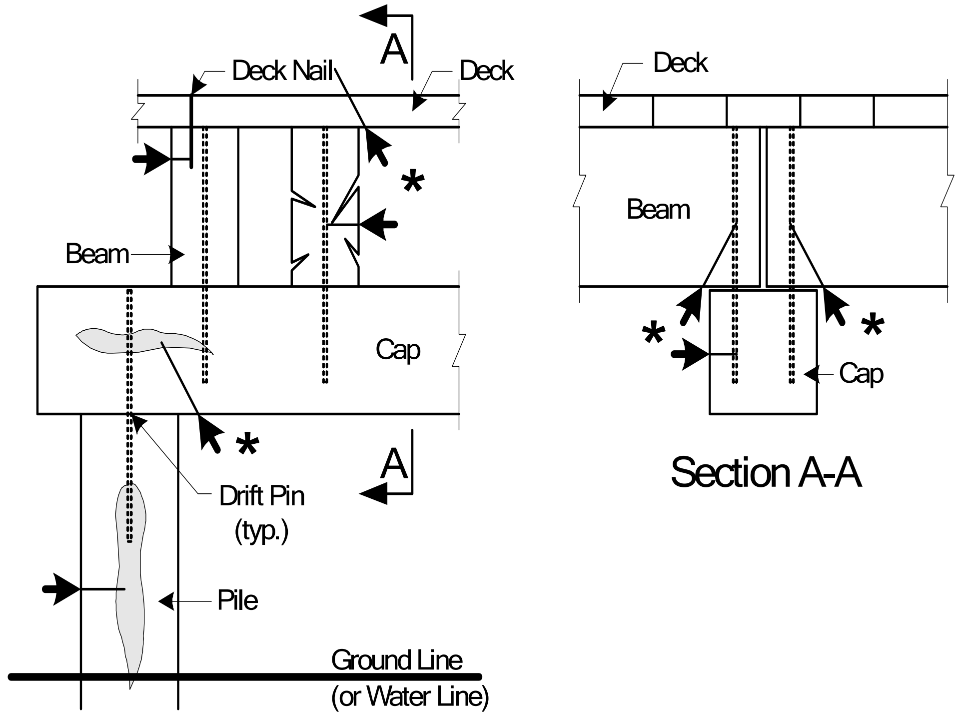

Figure 2.1.28 Timber Boring and Drilling Locations

Protective Coatings

When inspecting timber bridges, keep in mind the environment surrounding the bridge and how this can cause failures leading to rapid decay of the underlying wood members.

Paint Adhesion

Probe the paint with the point of a knife to test paint adhesion to wood. Attempt to lift the paint. Adhesion failure may occur between wood and paint or between layers of paint.

A more quantitative paint adhesion assessment is performed in accordance with American Society for Testing and Materials (ASTM) D-3359 "Measuring Adhesion by Tape Test". An "X" is cut through the paint to the wood surface. Adhesive test tape is applied over the "X" and removed in a continuous motion. The amount of paint (if any) removed is noted. Adhesion is rated on a scale of 0 to 5. Refer to ASTM D-3359 for the rating criteria.

Paint Dry Film Thickness

Paint dry film thickness is measured with a Tooke Gage (see Figure 2.1.29). With this instrument, a groove is cut at a known angle with the grain through the paint to expose the wood substrate. The thickness of each layer of paint is measured through a 50-power microscope built into the gage.

Figure 2.1.29 Tooke Gage Used to Measure Coating Dry Film Thickness

Repainting

If the coating is to be repainted, the type of paint in the existing topcoat must be known, since paints of different type may not adhere well to each other. Two methods to determine the type of existing paint are:

- Check historical records of previous painting
- Obtain paint samples from the bridge for laboratory analysis

Alternately, a test patch may be coated with new paint over intact existing paint. After the paint thoroughly dries in accordance with the manufacturer's specification, inspect the appearance and adhesion of the new paint.

Advanced Inspection Techniques

In addition, several advanced techniques are available for timber inspection. Nondestructive methods, described in Topic 13.1.1, include:

- Pol-Tek
- Spectral analysis
- Ultrasonic testing
- Vibration

Other methods, described in Topic 13.1.3, include:

- Boring or drilling
- Moisture content
- Probing
- Shigometer