Chapter 1

INTRODUCTION

1.1 INTRODUCTION

1.1.1 Purpose and Scope

A connection consists of two or more members joined with one or more mechanical fasteners. In most wood structures, connectionss are one of the most important, but least understood, components. Connections provide continuity to the members and strength and stability to the system. Connections may consist entirely of wood members but frequently involve the connection of wood to steel or other members. Of the failures observed in wood structures, most are attributed to improper connections design, construction (fabrication) detail, or serviceability.

There is a diversity of mechanical fasteners and connections, each having design criteria developed at different times in history. Some design practices are based on substantial research, some on minimal research, some on extrapolated research, and some on rules of thumb. Thus design practices of mechanical connections in wood structures are fragmented, and can be confusing, contradictory, and have various inherent levels of safety.

This manual is a collection of state-of-the-art information on mechanical connectionss in wood structures. Mechanical connectionss are defined as those where fasteners penetrate the wood; adhesive connections are not included. It is intended to help design professionals apply engineering judgment for those many connection details not covered by standard design codes. It will provide an overview of current design basis and related research.

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The mechanical connections included in this manual are generally limited to those constructed with types of fasteners commonly used in the United States.

The mechanical fastener types included are: Chapter 2 — Nails, Spikes, and Staples; Chapter 3 — Lag Screws and Wood Screws; Chapter 4 Bolts, Drift Bolts, and Pins; Chapter 5 — Metal Connector plates; and Chapter 6 — Timber Connectors.

Most design procedures are based on the strength of a single fastener. Single fastener strength is modified for material, geometry, and service conditions. Limited information is available on serviceability or stiffness design criteria.

Design requirements for most mechanical fasteners are specified in the National Design Specification (NDS) for Wood Construction®(American Forest & Paper Association, 1991). There are substantial changes in the NDS from previous editions that are discussed in subsequent chapters. Also under development is a Load and Resistance Factor Design (LRFD) Manual (American Forest & Paper Association) which will parallel NDS.

Design requirements for mechanical fasteners in glulam construction are included in the Timber Construction Manual (TCM) (American Institute of Timber Construction, 1985).

This manual concentrates on design aspects for single or multiple fastened connections. Only limited information is provided on connection detailing and qulaity of workmanship.

1.1.2 Types of Fasteners and Connections

Mechanical connnections are consturcted using two general fastener types – dowel and bearing. Dowel type fasteners, such as nails, screws, and bolts, transmit either lateral or withdrawal loads. Lateral loads are transmitted by bearing stresses developed between the fastener and the members of the connection. Withdrawal loads are axial loads parallel to the fastener axis transmitted through friction or bearing to the connected materials. Metal connector plates are a special case of dowel-type fasteners; they combine the lateral load actions of dowel fasteners and the stength properties of the metal plates.

Bearing-type connections transmit lateral loads only. Bearing-type fasteners, such as shear plates and split ring connetors, transmit shear forces through bearing on the connected materials.

Hanger-type connections are combination of dowel and bearing-type fasteners. They generally support one structural member and are connected to another member by a combination of dowel and bearing action.

Selection of a fastener for a specific design application depends on the type of connection and the requried strength capacity. Each connection must be designed to transmit forces adequately and provide satisfactory performance for the life of the structure without causing splitting, cracking, or excessive deformation of the wood members. A brief description of tie types of fasteners included in subsequent chapters of this manual is given below.

1.1.2.1 Nails, Spikes, and Staples. Nails are the most common type of mechanical fasteners used in construction. Nails resist either lateral or withdrawal forces or a combination of the two. There are many variations in types of nails as well as shapes, treatments, coatings, finishes, sizes, and qualities.

Spikes are long, nail-like fasteners designed to connect larger sized elements. Staples are made of thin wire and consist of two legs and a crown. Staples have a variety of sizes, points, coatings, and quality. They are available in clips and coils to permit use in pneumatically operated staplers. Staples are also used in low-strength or nonstructural connections and resist lateral and withdrawal forces.

1.1.2.2 Lag Screws and Wood Screws. Lag screws are threaded fasteners with a square or hex head that are placed in wood members by turning with a wrench. Although lag screws have a lower lateral strength than comparable bolts, lag screws are advantageous when an excessive bolt length is required or when access to one side of a connection is restricted.

Wood screws are usually made of steel or brass and are classified according to material, type, finish, head shape, and shank diameter. Both lag and wood screws provide lateral and withdrawal resistance.

1.1.2.3 Bolts, Drift Bolts, and Pins. Bolts are the most common wood fastener for connections where moderately high lateral strength is required. They are also used in tension connections where forces are applied parallel to the bolt axis. The bolts used for structural connections are standard machine bolts.

Drift bolts and drift pins are long unthreaded bolts, steel pins, or steel dowels that are driven in prebored holes. Drift bolts include a head on one end while no head is provided on pins. Drift bolts and pins are used in lateral connections for large wood members. They are not suitable for withdrawal connectionss because of their low resistance to withdrawal forces.

1.1.2.4 Metal Connector Plates. Metal connector plates, commonly called metal plate connectors, steel truss plates, truss plates, or plates, are used extensively in wood trusses. These plates are proprietary products but are generally made of light gauge structural quality steel with zinc or zinc-aluminum alloy coatings or stainless steel metal connector plate has integral teeth and is manufactured to various lengths, widths, and thicknesses. It is designed to transmit lateral loads; however, in trusses some moment is transferred as a result of change in geometry of a truss as it deflects.

1.1.2.5 Timber Connectors. Timber connectors are steel, malleable iron, ceramic, or fiberglass rings or plates placed between members and partially inserted into each adjacent member held together by a bolt, lag screw, or spike grid. They are used in lateral connectionss only and provide the highest lateral strength of all fasteners because of the large bearing area provided by the connector.

1.2 MATERIALS

Specification requirements for each type of mechanical fastener are discussed in their respective chapters. In general, most fastener material is specified by ASTM standards and include yield and ultimate tensile strengths.

Allowable wood properties are specified in the NDS (American Forest and Paper Association, 1991).

1.3 BASIC DESIGN CRITERIA — GENERAL PROCEDURE

The strength of wood connectionss is often limited by the resistance of the wood in bearing or withdrawal rather than the strength of the fastener. As a result, connection design is affected by many of the same factors that influence the strength properties of wood. In addition to the type, number, and size of fasteners, connections strength also depends on such factors as the wood species, direction and duration of load, and conditions of use. In some cases the strength of the connection may also be limited by the capacity of the connected members.

Design values for different types of nonproprietary fasteners are given in building codes and specifications in either tabular or equation format. These values are based on one fastener, installed and used under specified conditions. Allowable design loads are determined by adjusting tabulated or calculated values with adjustment factors. When more than one fastener is used in a connection, the design value is the sum of the design values for the individual fasteners times an adjustment factor (1.3.2). It should be noted that the design criteria and tabulated loads are limited to connections involving the same type of fastener. Methods of analysis and test data for connections made with more than one type of fastener have not been developed and this type of connection is not recommended.

The basic design procedures for connections are similar to those for structural components. For a given connection and type of fastener the designer must:

1. Determine the tabulated load for one fastener appropriate for the species group of the connected members.
2. Apply adjustment factors to the tabulated value to reflect specific applications and conditions of use.
3. Adjust the modified value for lateral loading conditions other than parallel or perpendicular to grain, when applicable.
4. Multiply the design load for one fastener by the total number fasteners in the connection and apply a group adjustment factor if justified.
5. Compute the net section and verify the capacity of the members.
6. Detail the connection to ensure adequate fastener placement and performance.

1.3.1 Basic Design Criteria

The strength of a connection is related to the species (specific gravity) of wood in which the fastener is installed and to the strength of the fastener. Lateral strength of small (nails, staples, screws) and large (lag screws, bolts, drift bolts, and pins) diameter dowel connections are theoretically derived from the European yield theory (Aune and Patton-Mallory, 1986; Soltis and Wilkinson, 1987). Lateral strength of metal connector plates and timber connectors are based on experimental values. Withdrawal strength of connections is based on experimental values.

The design basis for laterally loaded dowel fasteners was fundamentally changed with the 1991 edition of the NDS. Prior editions of the NDS up to and including the 1986 edition based lateral strength requirements on empirical fits to experimental data. The 1991 edition based lateral strength requirements on the European yield theory calibrated to the experimental data. Thus, both approaches must be discussed to give the reader an understanding of NDS values. Throughout this manual, the approaches taken by prior editions of the NDS are referenced as NDS-86; approaches taken by the 1991 edition are referenced as NDS-91.

The European yield theory is a strength of materials approach that assumes the lateral strength of a connection is attained when either (a) the dowel bearing strength of the wood or steel main or side member is exceeded, or (b) one or more plastic hinges form due to yielding of the fastener. These assumptions provide for several modes of failure depending on connection member dimensions, member strength, and fastener strength. Failure modes are displayed in NDS-91 Appendix I; equations for small diameter dowels are given in Chapter 2 and for large diameter dowels in Chapter 4.

The strength of a connection is directly related to the species (specific gravity) of wood in which the fastener is installed. The NDS-91 give direct strength vs. specific gravity relationships whereas the NDS-86 grouped species (usually having similar specific gravities). In the NDS-86, for lateral connections, there were 12 species groups for bolts, four groups for timber connectors and four groups for lag screws, nails, spikes, and drift bolts. For withdrawal connections there are no group designations and design values are based on the specific gravity of the connected members.

The TCM also groups species and grades used in glulam layups; glulam axial combination species groups for fastener design are given in table 1.3.2 and for bending combination species groups in table 1.3.3. For bending combinations of glulam, the species and grade of laminations may vary for different locations in the member, and fastener groups and specific gravity may be specified separately for the tension face, location in the side face, and compression face.

Table 1.3.1 Glulam Axial Combination Species Groups for Fastener Design (AITC 1994).

Combination Symbol	Bolt Group	Timber Connector Group	Lag Screws, Nails, Spikes, Drift Bolts, and Pins	
			Specific Group	Gravity
Visually graded Douglas Fir				
1	3	B	II	0.51
2	3	B	II	0.51
3	1	A	II	0.51
4	3	B	II	0.51
5	1	A	II	0.51
Visually graded Southern Pine				
46	3	B	II	0.55
47	3	B	II	0.55
48	1	A	II	0.55
49	3	B	II	0.55
50	1	A	II	0.55

Applicable to fasteners placed in any face of the member. This table represents a partial listing of selected combination symbols. Refer to AITC 117-Design (1987) and the AITC Timber Construction Manual (1994) for a complete listing of all combination symbols.

TABLE 1.3.2 Glulam Bending Combination Species Groups for Fastener Design (AITC 1994).

Species (Visually graded)	Combination Symbol[a]	Bolt Group	Timber Connector Group	Other Connector Group[b]
Tension face				
Western species[c]	16F-V3	3	B	II
	16F-V6	3	B	II
	20F-V3	1	A	II
	20F-V7	1	A	II
	24F-V4	1	A	II
	24F-V8	1	A	II
Southern Pine[d]	16F-V2	3	B	II
	16F-V3	3	B	II
	20F-V3	3	B	II
	20F-V5	1	A	II
	24F-V3	1	A	II
	24F-V5	1	A	II
Side face				
Western species[c]	16F-V3	3	B	II
	16F-V6	3	B	II
	20F-V3	3	B	II
	20F-V7	3	B	II
	24F-V4	3	B	II
	24F-V8	3	B	II
Southern Pine[d]	16F-V2	3	B	II
	16F-V3	3	B	II
	20F-V3	3	B	II
	20F-V5	3	B	II
	24F-V3	3	B	II
	24F-V5	3	B	II
Compression face				
Western species[c]	16F-V3	3	B	II
	16F-V6	3	B	II
	20F-V3	3	B	II
	20F-V7	3	B	II
	24F-V4	3	B	II
	24F-V8	3	B	II
Southern Pine[d]	16F-V2	3	B	II
	16F-V3	3	B	II
	20F-V3	3	B	II
	20F-V5	3	B	II
	24F-V3	3	B	II
	24F-V5	3	B	II

[a] This table represents a partial listing of selected combination symbols. Refer to AITC-117-Design (1987) and the AITC Timber Construction Manual (1994) for a complete listing of all combinations symbols.

[b] Lag screws, nails, spikes, drift bolts, and drift pins.

[c] Specific gravity = 0.51.

[d] Specific gravity = 0.55.

1.3.2 Basic Design Criteria – Adjustment Factors

Tabulated design values for all fasteners are based on the strength of the wood components for specfic applications and conditions of use. To adjust tabulated values for actual design requirements, adjustment factors are applied to fastener values in the same manner as those for strength properties of wood.

The adjustment factors for fasteners consist of

C_M	Wet Service factor
C_D	Load duration factor
C_t	Temperature factor
C_{fr}	Fire retardant factor
C_d	Penetration depth factor
$C_{\Delta e}$	Edge distance factor
$C_{\Delta n}$	End distance factor
$C_{\Delta s}$	Spacing factor
C_g	Group action factor
C_{st}	Steel side plate factor
C_d	Penetration depth factor
C_{eg}	End grain factor

A summary of all modifiers and their applicability to various fasteners is shown in table 1.3.4. Adjustment factors are in most cases cumulative.

13.2.1 Wet Service, C_M. The strength and stiffness of wood are increased as moisture content decreases. To compensate for this effect, tabulated stresses are adjusted by the wet service factor CM This factor, which is also referred to as a "moisture content factor" or "condition-of-use factor," is applicable to all tabulated stresses for strength and modulus of elasticity.

It adjusts values for changes in strength and stiffness and compensates for variations in gross section due to shrinkage. The moisture content of wood components has an effect on connection strength similar to that for strength properties of wood. For sawn lumber, moisture content must be considered at the time of fabrication (when the fastener is installed) and in service. For glulam, all laminations are dry (about 12 percent moisture content) when fabricated, and moisture effects are considered for service conditions only. Allowable fastener values are based on fasteners that are installed and used in continuously dry conditions that do not exceed 19 percent moisture content for sawn lumber and 16 percent moisture content for glued laminated members. For other conditions, tabulated values must be adjusted by the wet service factor C_M (table 1.3.5). Values of C_M for fasteners may vary from those used for strength properties of wood components.

13.2.2 Load DurationlTime Effect Factor, C_D. Wood is capable of withstanding larger magnitude loads for short time durations than for long time durations. The tabulated stresses for structural lumber and glued laminated timber are based on an assumed "normal" Load Duration. In this case, a "normal" Load Duration contemplates that members will be

TABLE 1.3.3 Applicability of Adjustment Factors for Fasteners.

	Adjustment factor			
Fastener type	Load Duration C_D	Wet Service C_M	Tempera-ture C_t	Fire Retardant C_{fr}
Timber connectors:				
Split rings	X[1]	X	X	X
Shear plates	X	X	X	X
Bolts	X	X	X	X
Lag screws	X	X	X	X
Wood screws	X	X	X	X
Nails and spikes	X	X	X	X
Drift bolts and drift pins	X	X	X	X

	Adjustment factor					
Fastener type	Edge Distance $C_{\Delta e}$	End Distance $C_{\Delta n}$	Spacing $C_{\Delta s}$	Group Action C_g	Metal side Plate C_{st}	Penetration Depth C_d
Timber connectors:						
Split rings	X	X	X	X	—[2]	X
Shear plates	X	X	X	X	X	X
Bolts	X	X	X	X	—	—
Lag screws	X	X	X	X	—	—
Wood screws	—	—	—	—	—	—
Nails and spikes	—	—	—	—	—	—
Drift bolts and drift pins	X	X	X	X	—	—

[1] x = adjustment factor is applicable.

[2] — = adjustment factor does not apply.

stressed to the full maximum stress level (either continuously or cumulatively) for a period of approximately ten years. When the maximum design loads act for durations which are more or less than the assumed normal duration, tabulated stresses are adjusted by a Load Duration factor, C_D(table 1.3.6.). C_D applies to tabulated strength properties but does not apply to compression perpendicular to grain ($F_{c\perp}$) or modulus of elasticity (E).

The Load Duration factor equals unity for ten year "normal" durations. The Load Duration factor for a design life less than ten years is a number greater than unity. The planned LRFD manual is based on a "normal" duration of five minutes. This factor is called a time effect factor since it equals unity at a five minute "normal" duration as opposed to the Load

TABLE 1.3.4 Fastener Load Adjustment Factors for Wet Service, C_M.

Type of Fastener	Condition of Wood[1]				
	Sawn Lumber		C_M	Glued Laminated Timber In Service	C_M
	At Time of Fabrication	In Service			
Timber connectors	Dry	Dry	1.0	Dry	1.0
	Wet	Dry	.8	Wet	.67
	Dry or wet	Partially seasoned or wet	.67		
Bolts or lag screws	Dry	Dry	1.0	Dry	1.0
	Dry or wet	Exposed to weather	.75	Wet	.67
	Dry or wet	Wet	.67		
Drift bolts or pins — laterally loaded	Dry or wet	Dry	1.0	Dry	1.0
	Dry or wet	Partially seasoned, wet or subject to wetting and drying	.70	Wet	.7
Wire nails and spikes					
— Withdrawal loads	Dry	Dry	1.0	Dry	1.0
	Partially seasoned or wet	Will remain wet	1.0	Wet	.25
	Partially seasoned or wet	Dry	.25		
	Dry	Subject to wetting and drying	.25		
— Lateral loads	Dry	Dry	1.0	Dry	1.0
	Partially seasoned or wet	Dry or wet	.75	Wet	.75
	Dry	Partially seasoned or wet	.75		
Threaded, hardened steel nails	Dry or wet	Dry or wet	1.0	Dry	1.0
				Wet	1.0

[1] Condition of wood definitions applicable to fasteners are: "Dry" wood has a moisture content of 19% or less for sawn lumber and 16% or less for glued laminated timber.

Duration factor which equals unity at a ten year duration. The time effect factor for a design life greater than five minutes is a number less than unity. In summary, both the Load Duration and the time effect factors describe the same phenomenon but each is based on a different "normal" basis.

The Load Duration factor applies to wood members only and is not used for metal components. As a result, increases in tabulated values due to $C_D$maybe limited for wood connectors in cases where the capacity of the connection is controlled by the strength of the metal connector rather than the strength of the wood.

The stresses produced in structural members are commonly the result of a combination of loads rather than a single load. Individual factors for each load in a group are not summed to adjust the tabulated stresses for that group. For a combination of loads of different durations, $C_D$for the entire group is the single value associated with the shortest load duration. When applying $C_D$the designer must recognize that for a given combination of loads, the most restrictive allowable stresses may result from some lesser combination involving loads of longer duration and C_D’S cumulative effect over the life of the structure.

1.3.2.3 Temperature, C_t. The strength of wood increases as it is cooled and decreases as it is warmed. These changes in strength due to temperature occur immediately and depend on the magnitude of the temperature change and the moisture content of the member. For temperatures up to approximately 150 degrees F, the immediate effects of strength loss are reversible and the member will essentially recover to initial strength levels as the temperature is lowered. Prolonged exposure to temperatures above 150°F may cause a permanent and irreversible loss in member strength.

Fastener values should be adjusted by the temperature factor, C_t (table 1.3.7) if the connection will experience sustained exposure to elevated temperatures.

1.3.2.4 Fire Retardant, C_{fr}. Fire retardant formulations are proprietary products. Their effects on strength properties must be determined for each treatment. The NDS advises that manufacturers’ recommendations should be followed. For glued laminated timbers, C_{fr} depends on the species and treatment combinations involved. The manufacturer of the treatment should be contacted for more specific values of C_{fr} for glulam based on the specific material and design application.

1.3.2.5 Edge Distance, $C_{\Delta e}$. Edge distance is the distance from the center of a fastener to the edge of the member, measured perpendicular to grain. For loading conditions perpendicular to grain, the loaded edge is the edge toward which the load induced by the fastener acts. The unloaded edge is the opposite edge. Tabulated design values for bolts, lag screws, timber connectors, and drift bolts and pins are based on the full edge distance requirements specified for the fastener. For timber connectors it is permis-

TABLE 1.3.5 Adjustment Factors for Load Duration (AF&PA, 1991).

Load Duration	Load Duration Factor, C_D
50 years (dead load)	0.9
10 years (normal)	1.0
2 months (snow)	1.15
7 days (construction loads)	1.25
Ten minutes (wind or earthquake)	1.6
Impact	**2.0**[1]

[1] The Load Duration factor for impact does not apply to connections or to members pressure-impregnated with preservative salts to the heavy retentions required for marine exposure, or lumber treated with fire retardant chemicals.

TABLE 1.3.6 Temperature Factor C_t (AF&PA, 1991).

Property	In service Moisture Conditions	C_t		
		T≤100°F	100°F<T≤125°F	125°F<T≤150°F
Tension parallel-to-grain and Modulus of elasticity	Wet or dry	1.0	0.9	0.9
Other properties and connections	Dry	1.0	0.8	0.7
Other properties and connections	Wet	1.0	0.7	0.5

sible to reduce the edge distance provided the capacity of the connector is reduced by $C_{\Delta e}$. Examples for large diameter dowels and timber connectors are given in tables 1.3.8 and 1.3.9.

1.3.2.6 End Distance, $C_{\Delta n}$. End distance is the distance from the center of a fastener to the end of the member. Tabulated values for bolts, lag screws, timber connectors, drift bolts, and drift pins are based on the full end distance requirements for the fastener (tables 1.3.8, 1.3.9). A reduced end distance is permitted provided the tabulated value for the fastener is reduced by the end distance factor, $C_{\Delta n}$. The NDS defines a geometry factor which is the worse case of either end distance or spacing requirements.

1.3.2.7 Spacing, $C_{\Delta s}$. Fastener spacing is the center-to-center distance between fasteners, measured parallel or perpendicular to grain. Tabulated design values for bolts, lag screws, timber connectors, and drift bolts or pins are based on minimum spacing requirements between fasteners (tables 1.3.8, 1.3.9).

When spacings are less than minimum, fastener design values must be reduced by the spacing factor $C_{\Delta s}$. Spacing requirements and values of $C_{\Delta s}$ depend on the type of fastener and are discussed later in this manual. The NDS defines a geometry factor which is the worse case of end distance, edge distance or spacing requirements.

1.3.2.8 Group Action, C_g A row of fasteners consists of two or more bolts, lag screws, timber connectors and drift bolts or pins aligned in the direction of the applied load. When three or more of these fasteners are used in a row, the capacity of an individual fastener is reduced as the number of

TABLE 1.3.7 Summary of Edge Distance, End Distance, and Spacing Requirements for Bolted Connections (AF&PA, 1991).

Loading Parallel to Grain	
	Minimum Dimension for Full Tabulated Load
Edge distance:	
$l/D \leq 6$	1.5D
$l/D > 6$	1.5D or 1/2 row spacing perpendicular to grain, whichever is greater
End distance:	
Tension members (softwoods)	7D
Compression members	4D
Spacing:	
Parallel to grain	4D
Row spacing perpendicular to grain[1]	1.5D
Loading Perpendicular to Grain	
	Minimum Dimension for Full Tabulated Load
Edge distance:	
Loaded edge	4D
Unloaded edge	1.5D
End distance	4D
Spacing:	
Row spacing parallel to grain[2,3]	
$l/D \leq 2$	2.5D
$l/D \geq 6$	5D
Perpendicular to grain	See note 4

[1] For distances and spacings between tabulated load and reduced load use straight line interpolation to compute adjustment factor value.

[2] The spacing between rows of bolts shall not be more than 5 inches (12.7 cm) unless separate splice plates are used for each row of bolts.

[3] For l/D ratios between 2 and 6, spacing requirements are obtained by straight line interpolation.

[4] The spacing of bolts perpendicular-to-grain is limited by the spacing requirements of the attached member or members (whether of metal or of wood loaded parallel-to-grain). All dimensions are measured from the center of the bolt hole.

fasteners in a row increases. To compensate for this effect, tabulated values for individual fasteners in the row are reduced by the group action factor, C_g. Values of C_g are given by equation and in tables in the NDS and

TABLE 1.3.8 Summary of Edge Distance, End Distance, and Spacing Requirements for Timber Connectors (AF&PA 1991)

Loading Parallel to Grain

	2-1/2" split rings or 2-5/8" shear plates		4" split rings and shear plates	
	Minimum Dimension for Full Tabulated Load	Minimum Dimension for Reduced Load[1]	Minimum Dimension for Full Tabulated Load	Minimum Dimension for Reduced Load[1]
Edge distance	1-3/4	N/A	2-3/4	[illegible]
End distance:				
Tension members	5-1/2"	2-3/4"	7"	3-1/2"
Compression members	4"	2-1/2"	5-1/2"	3-1/4"
Spacing:				
Parallel to grain	6-3/4"	3-1/2"	9"	5"
Row spacing perpendicular to grain	3-1/2≤	N/A	5≤	N/A

Loading Perpendicular to Grain

	2-1/2" split rings or 2-5/8" shear plates		4" split rings and shear plates	
	Minimum Dimension for Full Tabulated Load	Minimum Dimension for Reduced Load[1]	Minimum Dimension for Full Tabulated Load	Minimum Dimension for Reduced Load[1]
Edge distance:				
Unloaded edge	1-3/4"	N/A	2-3/4"	N/A
Loaded edge	2-3/4"	1-3/4"	3-3/4"	2-3/4"
End distance:				
Tension members	5-1/2"	2-3/4"	7"	3-1/2"
Compression members	5-1/2"	2-3/4"	7"	3-1/2"

Spacing:				
Row spacing parallel to grain	3-1/2″	N/A	5″	N/A
Perpendicular to grain	4-1/4″	3-1/2″	6″	5″

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[1] For dimensions between tabulated load and reduced load use straight line interpolation to compute adjustment factor value.

[2] 1 inch = 25.4 mm.

All dimensions are measured from the center of the connector.

are based on the gross areas of the members and the total number of fasteners in the row.

1.3.2.9 Metal Side Plate, C_{st}. The lateral strength of a connection with metal side or main members is accounted for by the European yield theory. The bearing strength of metal is used in lieu of the dowel bearing strength of wood in the yield equations.

A metal side plate factor, C_{st}, is tabulated in the NDS for use with shear plate timber connectors.

1.3.2.10 Penetration Depth Factor, C_d. A minimum penetration depth into a main member is required to develop the full lateral strength for lag screw, wood screw, and nail connections. Allowable lateral strength values are reduced if the minimum penetration depth is not attained. The reduction is defined in the NDS by the penetration depth factor, C_d. This factor is also applied to split ring connectors when lag screws with inadequate penetration are used in lieu of bolts.

1.3.2.11 End Grain, C_{eg}. Dowel-type fastengers inserted into end grain have less lateral and withdrawal strength than when inserted into side grain. Allowable lateral strength values are reduced by the end grain factor, C_{eg}, defined in the NDS. Allowable withdrawal strength values for lag screws are also reduced by the end grain factor, C_{eg}, whereas nails and screws should not be used when loaded in withdrawal from the end grain of wood.

1.3.2.12 Penetration Depth Factor, C_d. Tabulated values for timber connectors are based on a bolted connection. When lag screws are used instead of bolts, tabulated design values are adjusted by the penetration depth factor, C_d(table 1.3.10). This is called the penetration depth factor in the NDS-91.

1.3.3 Basic Design Criteria — Other Parameters

1.3.3.1 Loads at an Angle to the Grain. The strength of a laterally loaded wood connection with small diameter dowel fasteners — nails, spikes, staples, and screws — is independent of the direction of fastener bearing in relation to the grain of the members. The stength of a laterally loaded wood connection with large diameter dowel fasteners — bolts, lag screws, drift bolts and pins — as well as split ring and shear plate connectors depends on the direction of fastener bearing in relation to the grain of the members. Loads acting at some angle to the grain direction are computed by the Hankinson forumula.

$$N' = \frac{P'Q'}{P'\sin^2\theta + Q'\cos^2\theta} \tag{1}$$

TABLE 1.3.9 Penetration Depth Factor C_d.

			Penetration of Lag Screw into Member Receiving Point (Number of Shank Diameters)				
			Fastener Species Group				
Connector Size and Type	Side Plate	Penetration[1]	A	B	C	D	C_d
2-1/2 inch split ring 4 inch split ring 4 inch shear plate	Wood or metal	Standard	7	8	10	11	1.00
		Minimum	3	3-1/2	4	4-1/2	.75
2-5/8 inch shear plate	Wood	Standard	4	5	7	8	1.00
		Minimum	3	3-1/2	4	4-1/2	.75
2-5/8 inch shear plate	Metal	Standard and Minimum	3	3-1/2	4	4-1/2	1.00

[1] Use straight line interpolation for intermediate values.

where: N' = allowable dowel bearing strength or connector design value at an angle to grain;

P' = allowable dowel bearing strength or connector design value for the fasteners parallel to grain;

Q' = allowable dowel bearing strength or connector design value for fasteners perpendicular to grain;

θ = angle between the direction of load and the direction of grain.

The NDS applies the Harnkinson formula to the allowable dowel bearing strength for large diameter dowel fasteners and applies the formula to the design value for split ring and shear plate connectors.

1.3.3.2 Member Capacity. The strength of a wood connection depends not only on the strength of the fastener but also on the structural capacity of the individual members. Discussions to this point have focused primarily on the strength of fasteners; however, fastener capacity is irrelevant unless the connected members are capable of transmitting the required loads. As a part of the design process the capacity of all members must be verified to insure adequate strength.

connection-related factors that may affect capacity include net area and eccentric loading.

Net Area

The net area of a member is the cross-sectional area remaining after subtracting the area of material removed for fastener placement. Depending on the type of loading and size and placement of fasteners, this reduction in area can significantly reduce member capacity. Requirements for determining net area vary for different fasteners and are discussed in more detail in subsequent chapters.

Eccentricity

Eccentric loading is produced at connections when the resultant member forces are offset at the connection. Eccentricity in connections induces tension perpendicular to grain which can severely reduce the capacity of the members. The strength of eccentric connections is difficult to evaluate and connections of this type must be avoided unless tests are employed in design to insure members can safely carry applied loads.

1.4 CONNECTION DETAILS

This manual emphasizes design procedures. However, problems and failures have been observed, because of poor detailing and fabrication practices. The detailing problems are usually associated with shrink/swell and decay.

1.4.1 Shrink/Swell Problems

Wood is dimensionally stable as long as its moisture content is above the fiber saturation point. (Fiber saturation is when wood cell walls are completely saturated but no water exists in cell cavities.) The moisture content at the fiber saturation point is about 30 percent for commonly used wood species. Wood shrinks as it dries below the fiber saturation point. Since wood is anisotropic it does not shrink equally in all directions.

It shrinks most in the direction of the annual growth rings (tangentially), about one-half that amount across the growth rings (radially), and almost negligibly along the grain (longitudinally) (U.S. Department of Agriculture, 1987).

Typical shrinkage values for softwoods drying from the fiber saturation point to an oven dry condition are six to eight percent tangentially and three to four percent radially. The direction of the lumber as-it is cut from a log (fig. 1.4.1) will determine how shrinkage affects a board. A rule of thumb is that a member's cross sectional dimensions change approximately one percent for a four percent change in moisture content. Thus, a commercially available 36-inch deep glulam beam with an initial 12 percent moisture content will shrink about 3/8 inch in depth when it eventually dries to eight percent moisture content.

The moisture content of wood used in timber structures varies considerably. Dimension lumber may not be dried in some geographical areas.

If dried, dimension lumber and glulam is usually dried to 12 to 19 percent moisture content. Larger structural timbers (greater than 4 x 4 in.) may not be dried. Many timber structures built during World War II used green timber because of the emergency situation at the time.

Wood used in a dry environment will dry after use to five to ten percent moisture content. Shrinkage of wood after it is used in a structure causes several problems. The first problem is most frequent in connection details. If two points in a member are restrained from movement (as by a bolted metal side plate) and the member tries to shrink, then the wood will split. A second problem is drying checks developing in the wood. Checks can serve as conduits for future moisture to cause decay.

Because lumber dries more rapidly through the ends than through the sides, more serious splitting or checking occurs at the ends where connections are located. This can loosen and eventually fail joints by splitting between fasteners for dowel-type connections.

Design details, such as connections, are affected by changes in dimension (shrink/swell) because of change in moisture content. A common failure occurs in drying members, such as glulam beam, when the wood shrinkage is restrained by metal side plates and bolts (fig. 1.4.2 left) resulting in horizontal splits. The same situation occurs if the wood shrinkage is restrained by a concrete or masonry wall (fig. 1.4.2 middle), or by a cantilever saddle system (fig. 1.4.2 right) with bolts in a single line (as the supporting beam shrinks, the saddle wants to move downward but is restrained by the bolt). The solution to prevent the horizontal splitting is to allow the wood to shrink. This can be done by using separate metal plates top and bottom (fig. 1.4.2 left); by eliminating the top clip angle connection or by using slotted holes (fig. 1.4.2 middle); and by moving the tension tie bolt to the top of the supporting beam (fig. 1.4.2 right). These examples are representative of typical problems; the horizontal splits can reduce the shear capacity of the member as well as reducing the effectiveness of the fasteners. A further discussion can be found in the reference, American Society of Civil Engineers, 1982.

Bolts and split ring connectors may lose their effectiveness because of a loose fit resulting from wood shrinkage. Good construction practice is to retighten bolts after a structure has been in service for a year or so but unfortunately this is rarely done.

1.4.2 Decay Problems

Decay in wood is caused by fungi which break down and utilize wood cell wall material as food. Oxygen, favorable temperature, food, and water are necessary for fungus growth. Of these, water is the only parameter the designer has control over in untreated wood; the food source can be

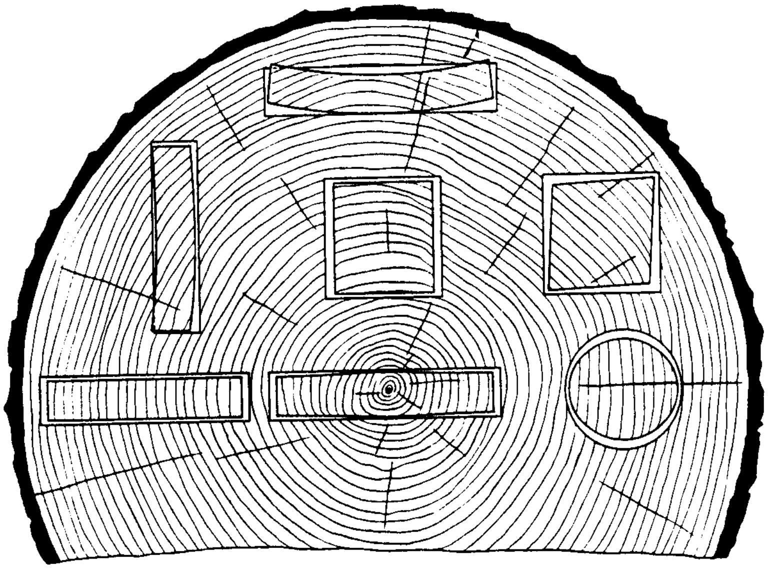

Figure 1.4.1—Shrinkage Distortion, Checks, and Splits Depend on where Lumber-is Cut from a Tree.

controlled by treating the wood. The other parameters will exist in all usual timber structures. The fungus requires the presence of water in the wood cell cavities; thus decay is not likely to occur in wood at moisture contents below the fiber saturation point and will not occur below about 20 percent moisture content. Humid air is not likely to raise the moisture content above about 15 percent moisture content; only wetting of wood by free water will provide the high moisture contents necessary for decay.

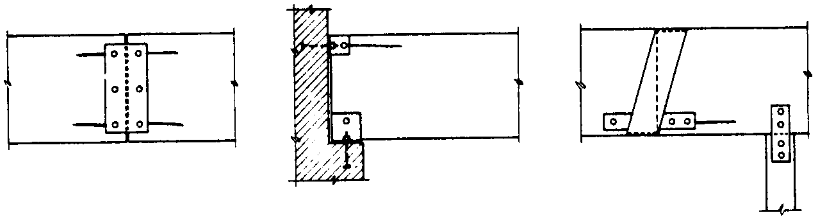

Figure 1.4.2—Avoid Excess Shrinkage Across Beam Depth Restrained by (Left) Bolted Side Plates; (Middle) Masonry or Concrete Wall, and (Right) Cantilever Beam Hanger with Tension Tie Bolts Aligned.

Dry wood members that cannot be maintained dry because of external exposure, soil contact, condensation, leaks, etc., must be protected by a preservative that is toxic to the fungi. Preservative treatments are outside the scope of this manual but some precautions related to design details will be discussed later.

Several references (Eslyn and Clark, 1979; Scheffer and Verrall, 1979) are recommended for a more detailed discussion of decay.

Critical points for moisture absorption and decay are connections, exposed end-grain surfaces, and splits and checks. Connections such as column bases encased in concrete (fig. 1.4.3 left) or supported on slab or grade; arch or column base enclosed in box (fig. 1.4.3 right); and sill plates not separated from the soil will absorb moisture and decay. To prevent these problems, column bases should be set on a pedestal above the floor slab; arch or column bases enclosed in boxes should have drip holes, flashing or gutters; and sill plates should be at least eight inches above ground line.

Exposed end grain is susceptible to water penetration making exposed ends of timber beams particularly vulnerable. The problem can be alleviated by sloping or capping the end-grain surfaces (fig. 1.4.4). Some care must be taken when capping end-grain surfaces. For example, often a sheet metal cap is fastened to a vertical member by driving a fastener through the cap (fig. 1.4.5). This creates a funnel for water to enter the end grain of the material. Additionally, a ventilation space should be provided between the cap and the member.

If it is impossible to keep a timber member dry, then the member must be protected. Some natural protection is obtained by using the heartwood of decay-resistant species, such as western redcedar or redwood. Wood preservatives, however, are the usual choice for protection. Wood preser-

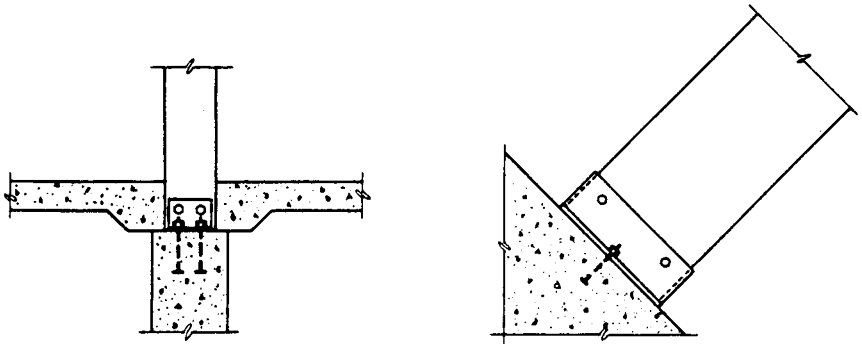

Figure 1.4.3—Avoid Critical Points for Water Collection at (Left) Column Encased in Concrete; (Right) Arch or Column Base in Box.

vatives are poisons designed to inhibit fungus attack. A discussion of the available types of preservatives is beyond the scope of this manual. Additionally, there are increasing environmental limitations on the use of preservatives. Even when preservatives are used, good design details should shed as much water as possible and should provide for air circulation for faster drying. Details such as overhangs, sloped surfaces, flashing, and spaced members lessen the duration of conditions favorable for decay.

The American Wood-Preservers Association (1991) has standards on preservatives, treatments, application methods, quality control, and inspection. The method of application is important. Preservatives are applied as liquids. The least effective application is brushing, next is dipping or immersion processes, and the most effective is a pressure or vacuum application. The objective of these processes is to get the maximum penetration possible into the wood; but the success is dependent on the wood species, whether the wood surface is scarred, and the method of applica-

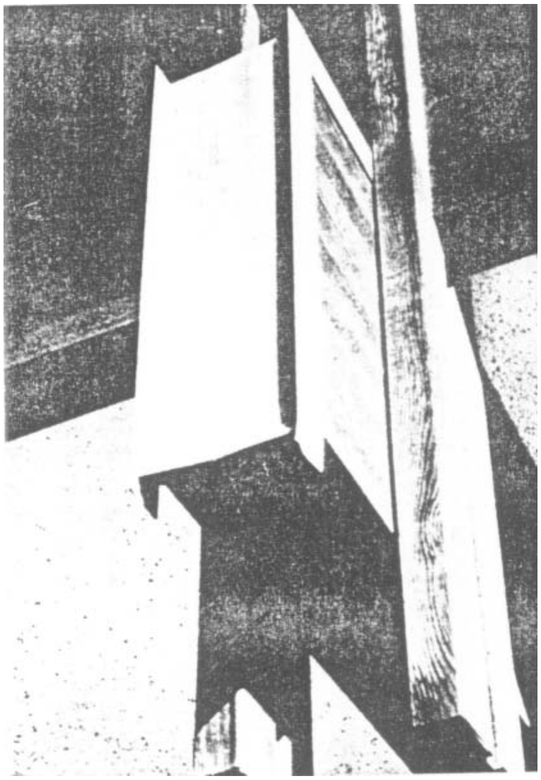

Figure 1.4.4—Capping the Exposed End-Grain of a Timber beam.

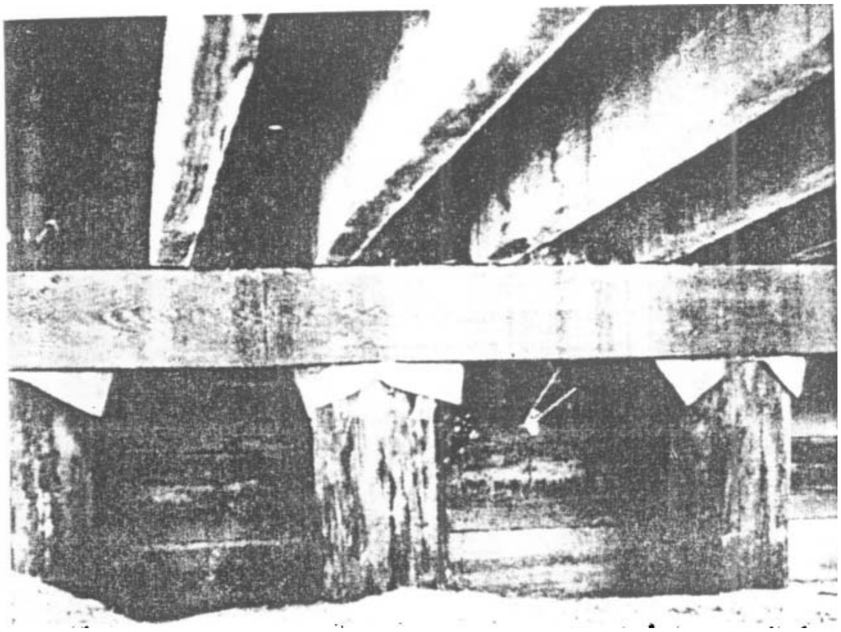

Figure 1.4.5—Bad Example of Capping Bridge Piling. The Fastener Connecting the Sill Beam to the Piling is Driven Through the Cap Providing a Water Funnel.

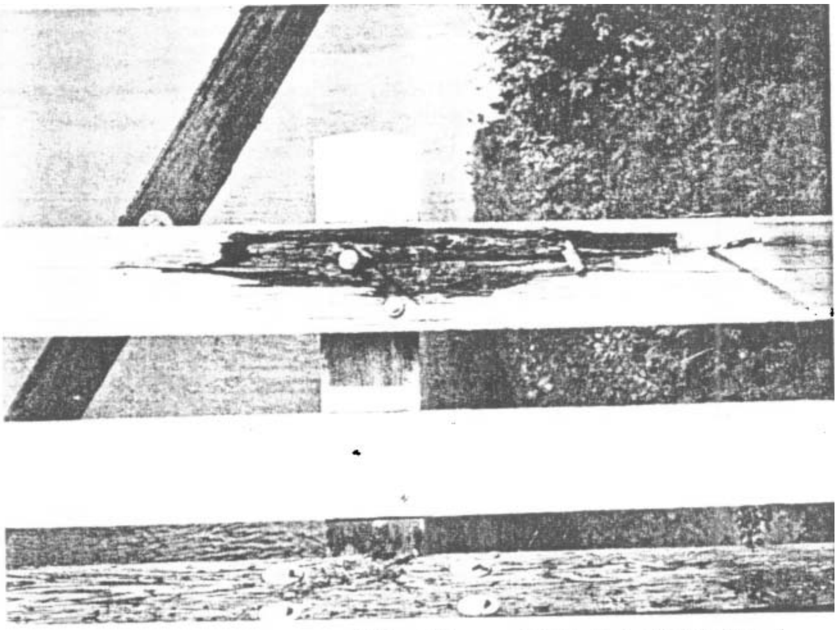

Figure 1.4.6—Decay in Treated Wood Began at Bolt Holes Providing A Funnel to the Untreated Wood.

tion. Often only the surface is treated and penetrations through the surface such as bolt holes, or checks and splits will funnel water to untreated wood. Figure 1.4.6 shows decay beginning at bolt holes. Treating after fabrication often consists of a brush treatment which is not as effective as pressure treatment.

1.4.3 Fabrication Tolerances

The bearing strength of wood in lateral connections is affected considerably by fabrication tolerances. For example, in multi-bolted connections an oversize hole for one bolt may mean that this bolt does not transfer loads that need to be redistributed to the other bolts. There are no standardized specifications for fabrication tolerances; however, tabulated values for various fastener types are usually based on specific fabrication tolerances. They are discussed in the following chapters.

1.5 FOREIGN PRACTICE

Specific design requirements in various foreign codes for each type of mechanical fastener are discussed in their respective chapters. In general, Canadian, European, Australian, and New Zealand codes have lateral, withdrawal, spacing, multiple connected, etc., requirements similar to the NDS.

1.6 GENERAL REFERENCES

The majority of the timber design requirements in various building or bridge codes (American Association of State Highway and Transportation Officials, 1983) are based on past editions of&e National Design Specification for Wood Construction. NDS is the most widely recognized general specification for timber design and is updated periodically by the American Forest and Paper Association. The NDS is also approved as the consensus Standard through the American National Standards Institute (ANSI). The specification includes design requirements and tabulated design stresses for structural lumber, glued laminated timber, timber piling, and connections.

In addition to the NDS, glued laminated timber design requirements are based on standards and details in the Timber Construction Manual (TCM) (American Institute of Timber Construction, 1994). AITC is a national trade association of the glued laminated timber industry and is responsible for numerous specifications and technical publications for fabrication, design, and construction of glulam. AITC also publishes AITC 117-Design Standard Specifications for Structural Glued Laminated Timber of Softwood Species (American Institute of Timber Construction, 1993), which is the source of tabulated stresses for glued laminated timber.

Plywood design requirements are specified by the Plywood Design Specification (American Plywood Association, 1986). Trade associations, such as the Truss Plate Institute, and manufacturers of proprietary products such as toothed metal connector plates, hangers and anchors, trusses, and I-beams publish design recommendations. These recommendations are often incorporated into model or local building codes.

Specific end use specifications, such as the bridge requirements of the American Association of State Highway and Transportation Officials, either refer to or have similar requirements as the NDS and TCM.

Several textbooks are available to provide design examples (Breyer, 1993; Faherty and Williamson, 1989; Gurfinkel, 1981; Hoyle and Woeste, 1989; Stalnacker and Harris, 1989).

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