Governing Yield Modes for Common Bolted and Nailed Wood Connections

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GOVERNING YIELD MODES FOR COMMON BOLTED AND NAILED WOOD CONNECTIONS

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ABSTRACT: Connections in wood structures are important when designing for ductility. The 1997 Uniform Building Code has taken this into consideration when designating wind and earthquake load duration factors for connections. Factors of 1.6 or 1.33 may be applied to the connection strength, depending on the type of yield mode exhibited by the connection, which may be determined from the yield limit equations supplied in the *National Design Specification for Wood Construction* (NDS). The NDS provides the designer with multiple tables containing capacities for various common connections. Unfortunately, yield modes are not published along with tabulated capacities. Therefore, the designer must carry out potentially cumbersome calculations using the NDS yield limit equations simply to determine the governing yield mode before an appropriate Uniform Building Code load duration factor can be applied. In this paper, several NDS tables are extended to include capacity *and* yield mode, smaller side member thickness configurations are added to the existing nail/spike tables, and a useful toe-nail table is provided. The overall purpose of these tables is to accelerate the design process by eliminating time-consuming calculations.

INTRODUCTION

Due to the need for ductile performance of a structure, connections may be one of the most important engineered aspects of light-frame wood construction. Connection ductility is essential for maintaining structural integrity during dynamic loading events such as wind and earthquakes.

Capacity of a given connection may be obtained from yield limit equations, which are presented in the *National Design Specification for Wood Construction* (NDS) (''ANSI/AF&PA'' 1997). Yield mode equations for the capacity of bolted connections and nail/spike connections are included in NDS chapters 8 and 12, respectively. Bolted connection equations are separated into two categories: single shear and double shear. One set of equations is required for nail/spike connections since they are typically only used in single shear configurations. The nominal design value of the connection, *Z*, is determined by taking the least value calculated from the appropriate set of yield mode equations. The mode corresponding to the least value is referred to as the yield mode of the connection (for example, I_m, I_s, II, III_m, III_s, IV). The various yield modes are illustrated in Appendix I of the NDS and duplicated here in Fig. 1. Yield modes I_m and I_s are the result of wood fibers crushing in the main and side members, respectively. Yield mode II is the result of wood fiber crushing in both members, which allows the fastener to rotate. This is often due to oversized bolt holes. Mode II is not applicable to bolted double shear or nail/spike connections. Yield modes III_m and III_s are the result of fastener yielding, wherein a plastic hinge is formed at the shear plane, along with wood fiber crushing primarily in the main member or side member, respectively. Mode IV is also a result of fastener yielding, in which multiple plastic hinges are formed.

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The strength of wood connections depends not only on material properties (such as wood bearing strength and fastener bending yield strength) and connection geometry (such as member dimensions and fastener diameter), but also on the duration of the load applied to the connection. Wood has the property of exhibiting greater strength for shorter duration loads than for longer, sustained loads. The NDS addresses this time-dependent behavior of wood by applying a load duration factor, C_D, to the capacity of the connection. For load combinations, including short-duration loads such as wind or earthquake, the NDS prescribes a load duration factor of 1.6 to be applied to the capacity of all connections. However, the *Uniform Building Code* (UBC) (1997) prescribes load duration factors that differ slightly from the NDS with regard to these loading conditions. The UBC permits a load duration factor of 1.6 to be used for connections exhibiting yield modes III_m, III_s, or IV when the loading is due to wind or earthquake. A lower load duration factor of 1.33 must be used when yield modes I_m, I_s, or II are exhibited. The primary reason for this discrepancy is the difference in the amount of cyclic test data available for each yield mode. Recent laboratory tests of modes III and IV connections have revealed sufficient ductility under cyclic loading (Dolan et al. 1995, 1996). This is the result of inelastic fastener deformation and yielding, which lead to energy dissipation in the connection. The lack of data for modes I and II under cyclic loading conditions has led to concerns about the ductility of these connections and about the UBC-imposed limitation on the load duration factor.

The NDS contains several bolt and nail/spike connection design tables with yield capacities for multiple configurations. Unfortunately, these tables do not indicate the governing yield mode. A designer could use the NDS yield limit equations to determine the mode of connection yield or, more conservatively, always use a load duration factor of 1.33 when designing to resist wind or seismic loads, according to the UBC. However, from an economic standpoint, there is a need to know which yield mode governs the connection behavior.

In addition to yield modes, the NDS tables of connection design values do not address some common connection configurations. For example, the tables for nail/spike connection values in chapter 12 of the NDS do not address side member thickness values below 12.7 mm (0.5 in.). These connection capacities and yield modes would be useful for shear wall and diaphragm design where thin sheathing is used. Toe-nail connections are commonly used in light-frame construction; however, design tables for these connections are not included in

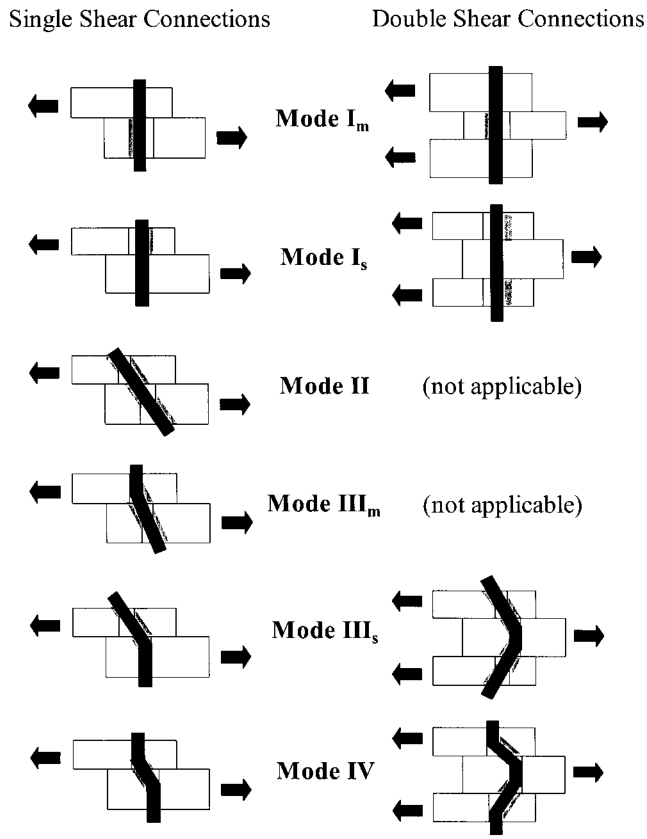

FIG. 1. Connection Yield Modes (Adapted from American Forest and Paper Association 1997)

the NDS. This paper addresses these limitations in the NDS connection tables.

SCOPE

The purpose of this paper is to evaluate governing yield modes for bolted and nailed connections commonly used in wood construction. NDS tables are extended, providing both the capacity *and* the governing yield mode. Additional nailed connection values and yield modes are tabulated for smaller side member thicknesses. Tables are also created presenting the design strength for toe-nailed connections as a useful addition to the existing NDS design tables.

DESIGN TABLES AND EXAMPLES

Tables provided herein present a limited number of species and member sizes. A more comprehensive set of tables is available from the authors.

Bolted Connections

Various governing yield modes are applicable throughout the NDS bolted connection design tables and are not necessarily intuitive. This state of affairs presents a need for bolted connection yield mode tables for efficient structural design. Otherwise, to accurately use the UBC load duration factors, a designer must calculate the yield mode using the NDS bolted connection equations simply to determine the mode. The NDS yield mode equations are provided in the appendix to this paper.

Not all yield modes are applicable in all bolted connection configurations. For example, modes II and III_m do not pertain to double shear bolted connections. In addition, mode I_s does not pertain to bolted connections with steel side plates. The applicable modes for different bolted connection configurations are summarized in Table 1. Slightly over 50% of the bolted connection configurations in the NDS tables exhibit yield modes of either I_m, I_s, or II. Therefore, a slight majority of the connections are considered by the UBC to be ''nonductile,'' requiring a designer to use the lesser load duration factor of 1.33. The percentages of each applicable yield mode in the NDS bolt tables are summarized in Table 1. Tables 2–7 provide tabulated design values and modes for various bolted connection configurations.

TABLE 1. Percentages of Applicable Yield Modes for NDS Bolted Connection Tables

Yield mode	Single Shear		Double Shear	
	Wood-to-wood	Wood-to-metal	Wood-to-wood	Wood-to-metal
(1)	(2)	(3)	(4)	(5)
I_m	0	0	27.14	51.62
I_s	17.6	—	16.8	—
II	42.81	55	—	—
III_m	1.79	0	—	—
III_s	28.01	45	42.24	48.38
IV	9.8	0	13.81	0

Bolted connection tables were created for some common connection configurations, including single and double shear connections with wood and steel side members. As an example of table usage, consider the following connection configuration, illustrated in Fig. 2:

- Double shear connection
- Load applied parallel to main member and perpendicular to side members
- All members are spruce-pine-fir
- 38.1 mm (1-1/2 in.) side member thickness
- 88.9 mm (3-1/2 in.) main member thickness
- 15.9 mm (5/8 in.) diameter ASTM A307 bolt
- Seismic loading conditions

TABLE 2. Bolt Design Values (*Z*) and Yield Modes for Single Shear (Two Member) Connections for Sawn Lumber with Both Members of Identical Species

Thickness: Main Member	Thickness: Side Member	Bolt Diameter	G=0.55 Southern Pine								G=0.50 Douglas-Fir-Larch							
t_m in.	t_s in.	D in.	$Z_{\parallel}$ lbs.	Yield Mode	$Z_{s\perp}$ lbs.	Yield Mode	$Z_{m\perp}$ lbs.	Yield Mode	$Z_{\perp}$ lbs.	Yield Mode	$Z_{\parallel}$ lbs.	Yield Mode	$Z_{s\perp}$ lbs.	Yield Mode	$Z_{m\perp}$ lbs.	Yield Mode	$Z_{\perp}$ lbs.	Yield Mode
1-1/2	1-1/2	1/2	530	II	330	II	330	II	250	II	480	II	300	II	300	II	220	II
		5/8	660	II	400	II	400	II	280	II	600	II	360	II	360	II	240	II
		3/4	800	II	460	II	460	II	310	II	720	II	420	II	420	II	270	II
		7/8	930	II	520	II	520	II	330	II	850	II	470	II	470	II	290	II
		1	1060	II	580	II	580	II	350	II	970	II	530	II	530	II	310	II
2-1/2	1-1/2	1/2	660	IIIs	400	IIIs	420	II	350	II	610	IIIs	370	IIIs	370	II	310	II
		5/8	930	II	560	IIIs	490	II	390	II	850	II	520	IIIs	430	II	340	II
		3/4	1120	II	660	Is	560	II	430	II	1020	II	590	Is	500	II	380	II
		7/8	1300	II	720	Is	620	II	470	II	1190	II	630	Is	550	II	410	II
		1	1490	II	770	Is	680	II	490	II	1360	II	680	Is	610	II	440	II
3	1-1/2	1/2	660	IIIs	400	IIIs	470	IIIs	360	IIIs	610	IIIs	370	IIIs	420	II	330	IIIs
		5/8	940	IIIs	560	IIIs	550	II	460	II	880	IIIs	520	IIIs	480	II	400	II
		3/4	1270	IIIs	660	Is	620	II	500	II	1190	II	590	Is	550	II	440	II
		7/8	1520	II	720	Is	690	II	540	II	1390	II	630	Is	610	II	480	II
		1	1740	II	770	Is	750	II	580	II	1590	II	680	Is	670	II	510	II
3-1/2	1-1/2	1/2	660	IIIs	400	IIIs	470	IIIs	360	IIIs	610	IIIs	370	IIIs	430	IIIs	330	IIIs
		5/8	940	IIIs	560	IIIs	620	II	500	IIIs	880	IIIs	520	IIIs	540	II	460	II
		3/4	1270	IIIs	660	Is	690	II	580	II	1200	IIIs	590	Is	610	II	510	II
		7/8	1680	IIIs	720	Is	770	II	630	II	1590	IIIs	630	Is	680	II	550	II
		1	2010	II	770	Is	830	II	670	II	1830	II	680	Is	740	II	590	II
	3-1/2	1/2	750	IV	520	IV	520	IV	460	IV	720	IV	490	IV	490	IV	430	IV
		5/8	1170	IV	780	IV	780	IV	650	II	1120	IV	700	IIIs	700	IIIm	560	II
		3/4	1690	IV	960	IIIs	960	IIIm	710	II	1610	IV	870	IIIs	870	IIIm	630	II
		7/8	2170	II	1160	IIIs	1160	IIIm	780	II	1970	II	1060	IIIs	1060	IIIm	680	II
		1	2480	II	1360	II	1360	II	820	II	2260	II	1230	II	1230	II	720	II

TABLE 3. Bolt Design Values (*Z*) and Yield Modes for Single Shear (Two Member) Connections for Sawn Lumber with Both Members of Identical Species

Thickness: Main Member	Thickness: Side Member	Bolt Diameter	G=0.43 Hem-Fir								G=0.42 Spruce-Pine-Fir							
t_m in.	t_s in.	D in.	$Z_{\parallel}$ lbs.	Yield Mode	$Z_{s\perp}$ lbs.	Yield Mode	$Z_{m\perp}$ lbs.	Yield Mode	$Z_{\perp}$ lbs.	Yield Mode	$Z_{\parallel}$ lbs.	Yield Mode	$Z_{s\perp}$ lbs.	Yield Mode	$Z_{m\perp}$ lbs.	Yield Mode	$Z_{\perp}$ lbs.	Yield Mode
1-1/2	1-1/2	1/2	410	II	250	II	250	II	180	II	410	II	240	II	240	II	170	II
		5/8	520	II	300	II	300	II	190	II	510	II	290	II	290	II	190	II
		3/4	620	II	350	II	350	II	210	II	610	II	340	II	340	II	210	II
		7/8	720	II	390	II	390	II	230	II	710	II	380	II	380	II	220	II
		1	830	II	440	II	440	II	250	II	810	II	430	II	430	II	240	II
2-1/2	1-1/2	1/2	550	IIIs	320	IIIs	310	II	250	II	540	IIIs	320	IIIs	300	II	240	II
		5/8	730	II	420	Is	360	II	270	II	710	II	410	Is	350	II	270	II
		3/4	870	II	460	Is	410	II	300	II	850	II	450	Is	400	II	290	II
		7/8	1020	II	500	Is	450	II	320	II	1000	II	490	Is	440	II	310	II
		1	1160	II	540	Is	500	II	350	II	1140	II	530	Is	490	II	340	II
3	1-1/2	1/2	550	IIIs	320	IIIs	350	II	290	II	540	IIIs	320	IIIs	330	II	280	II
		5/8	790	IIIs	420	Is	400	II	320	II	780	IIIs	410	Is	390	II	310	II
		3/4	1020	II	460	Is	450	II	350	II	1000	II	450	Is	440	II	340	II
		7/8	1190	II	500	Is	500	II	380	II	1160	II	490	Is	490	II	370	II
		1	1360	II	540	Is	550	II	410	II	1330	II	530	Is	540	II	400	II
3-1/2	1-1/2	1/2	550	IIIs	320	IIIs	380	IIIs	290	IIIs	540	IIIs	320	IIIs	370	IIIs	280	IIIs
		5/8	790	IIIs	420	Is	440	II	370	II	780	IIIs	410	Is	430	II	360	II
		3/4	1100	IIIs	460	Is	500	II	400	II	1080	IIIs	450	Is	480	II	390	II
		7/8	1370	II	500	Is	550	II	430	II	1340	II	490	Is	540	II	420	II
		1	1570	II	540	Is	600	II	470	II	1530	II	530	Is	590	II	460	II
	3-1/2	1/2	660	IV	440	IV	440	IV	390	IV	660	IV	430	IV	430	IV	380	IV
		5/8	1040	IV	600	IIIs	600	IIIm	450	II	1020	IV	590	IIIs	590	IIIm	440	II
		3/4	1450	II	740	IIIs	740	IIIm	500	II	1420	II	730	IIIs	730	IIIm	480	II
		7/8	1690	II	910	II	910	II	540	II	1660	II	890	II	890	II	520	II
		1	1930	II	1030	II	1030	II	580	II	1890	II	1000	II	1000	II	560	II

TABLE 4. Bolt Design Values (*Z*) and Yield Modes for Single Shear (Two Member) Connections for Sawn Lumber with 1/4″ ASTM A36 Steel Side Plate

Thickness: Main Member t_m in.	Thickness: Side Member t_s in.	Bolt Diameter D in.	G=0.55 Southern Pine $Z_{\parallel}$ lbs.	Yield Mode	$Z_{\perp}$ lbs.	Yield Mode	G=0.50 Douglas-Fir-Larch $Z_{\parallel}$ lbs.	Yield Mode	$Z_{\perp}$ lbs.	Yield Mode	G=0.43 Hem-Fir $Z_{\parallel}$ lbs.	Yield Mode	$Z_{\perp}$ lbs.	Yield Mode	G=0.42 Spruce-Pine-Fir $Z_{\parallel}$ lbs.	Yield Mode	$Z_{\perp}$ lbs.	Yield Mode
1-1/2	1/4	1/2	570	II	310	II	530	II	270	II	470	II	240	II	460	II	230	II
		5/8	710	II	350	II	660	II	320	II	590	II	270	II	580	II	270	II
		3/4	860	II	390	II	800	II	360	II	700	II	310	II	690	II	300	II
		7/8	1000	II	440	II	930	II	400	II	820	II	340	II	810	II	340	II
		1	1140	II	480	II	1060	II	440	II	940	II	380	II	920	II	370	II
2-1/2	1/4	1/2	780	IIIs	440	II	750	IIIs	390	II	700	II	320	II	690	II	310	II
		5/8	1100	II	500	II	1010	II	440	II	880	II	370	II	860	II	360	II
		3/4	1320	II	550	II	1210	II	490	II	1050	II	410	II	1030	II	400	II
		7/8	1540	II	610	II	1410	II	540	II	1230	II	450	II	1210	II	440	II
		1	1760	II	650	II	1620	II	590	II	1410	II	490	II	1380	II	480	II
3	1/4	1/2	780	IIIs	500	IIIs	750	IIIs	450	II	710	IIIs	370	II	700	IIIs	360	II
		5/8	1170	IIIs	580	II	1130	IIIs	510	II	1040	II	420	II	1020	II	410	II
		3/4	1560	II	640	II	1430	II	570	II	1240	II	470	II	1220	II	460	II
		7/8	1830	II	700	II	1670	II	620	II	1450	II	510	II	1420	II	500	II
		1	2090	II	750	II	1910	II	670	II	1660	II	560	II	1630	II	540	II
3-1/2	1/4	1/2	780	IIIs	500	IIIs	750	IIIs	470	IIIs	710	IIIs	430	II	700	IIIs	410	II
		5/8	1170	IIIs	670	II	1130	IIIs	580	II	1050	IIIs	480	II	1040	IIIs	470	II
		3/4	1650	IIIs	730	II	1580	IIIs	650	II	1440	II	530	II	1410	II	520	II
		7/8	2120	II	800	II	1940	II	710	II	1680	II	570	II	1640	II	560	II
		1	2420	II	850	II	2210	II	760	II	1910	II	630	II	1880	II	610	II

TABLE 5. Bolt Design Values (*Z*) and Yield Modes for Double Shear (Three Member) Connections for Sawn Lumber with Both Members of Identical Species

Thickness: Main Member t_m in.	Thickness: Side Member t_s in.	Bolt Diameter D in.	G=0.55 Southern Pine $Z_{\parallel}$ lbs.	Yield Mode	$Z_{s\perp}$ lbs.	Yield Mode	$Z_{m\perp}$ lbs.	Yield Mode	G=0.50 Douglas-Fir-Larch $Z_{\parallel}$ lbs.	Yield Mode	$Z_{s\perp}$ lbs.	Yield Mode	$Z_{m\perp}$ lbs.	Yield Mode
1-1/2	1-1/2	1/2	1150	Im	800	IIIs	550	Im	1050	Im	730	IIIs	470	Im
		5/8	1440	Im	1130	IIIs	610	Im	1310	Im	1040	IIIs	530	Im
		3/4	1730	Im	1330	Is	660	Im	1580	Im	1170	Is	590	Im
		7/8	2020	Im	1440	Is	720	Im	1840	Im	1260	Is	630	Im
		1	2310	Im	1530	Is	770	Im	2100	Im	1350	Is	680	Im
2-1/2	1-1/2	1/2	1320	IIIs	800	IIIs	910	Im	1230	IIIs	730	IIIs	790	Im
		5/8	1870	IIIs	1130	IIIs	1020	Im	1760	IIIs	1040	IIIs	880	Im
		3/4	2550	IIIs	1330	Is	1110	Im	2400	IIIs	1170	Is	980	Im
		7/8	3360	IIIs	1440	Is	1200	Im	3060	Im	1260	Is	1050	Im
		1	3840	Im	1530	Is	1280	Im	3500	Im	1350	Is	1130	Im
3	1-1/2	1/2	1320	IIIs	800	IIIs	940	IIIs	1230	IIIs	730	IIIs	860	IIIs
		5/8	1870	IIIs	1130	IIIs	1220	Im	1760	IIIs	1040	IIIs	1050	Im
		3/4	2550	IIIs	1330	Is	1330	Im	2400	IIIs	1170	Is	1170	Im
		7/8	3360	IIIs	1440	Is	1440	Im	3180	IIIs	1260	Is	1260	Im
		1	4310	IIIs	1530	Is	1530	Im	4090	IIIs	1350	Is	1350	Im
3-1/2	1-1/2	1/2	1320	IIIs	800	IIIs	940	IIIs	1230	IIIs	730	IIIs	860	IIIs
		5/8	1870	IIIs	1130	IIIs	1290	IIIs	1760	IIIs	1040	IIIs	1190	IIIs
		3/4	2550	IIIs	1330	Is	1550	Im	2400	IIIs	1170	Is	1370	Im
		7/8	3360	IIIs	1440	Is	1680	Im	3180	IIIs	1260	Is	1470	Im
		1	4310	IIIs	1530	Is	1790	Im	4090	IIIs	1350	Is	1580	Im
	3-1/2	1/2	1500	IV	1040	IV	1040	IV	1430	IV	970	IV	970	IV
		5/8	2340	IV	1560	IV	1420	Im	2240	IV	1410	IIIs	1230	Im
		3/4	3380	IV	1910	IIIs	1550	Im	3220	IV	1750	IIIs	1370	Im
		7/8	4600	IV	2330	IIIs	1680	Im	4290	Im	2130	IIIs	1470	Im
		1	5380	Im	2780	IIIs	1790	Im	4900	Im	2580	IIIs	1580	Im

TABLE 6. Bolt Design Values (*Z*) and Yield Modes for Double Shear (Three Member) Connections for Sawn Lumber with Both Members of Identical Species

Thickness: Main Member t_m in.	Thickness: Side Member t_s in.	Bolt Diameter D in.	G=0.43 Hem-Fir $Z_{\parallel}$ lbs.	Yield Mode	$Z_{s\perp}$ lbs.	Yield Mode	$Z_{m\perp}$ lbs.	Yield Mode	G=0.42 Spruce-Pine-Fir $Z_{\parallel}$ lbs.	Yield Mode	$Z_{s\perp}$ lbs.	Yield Mode	$Z_{m\perp}$ lbs.	Yield Mode
1-1/2	1-1/2	1/2	900	Im	650	IIIs	380	Im	880	Im	640	IIIs	370	Im
		5/8	1130	Im	840	Is	420	Im	1100	Im	830	Is	410	Im
		3/4	1350	Im	920	Is	460	Im	1320	Im	900	Is	450	Im
		7/8	1580	Im	1000	Is	500	Im	1540	Im	970	Is	490	Im
		1	1800	Im	1080	Is	540	Im	1760	Im	1050	Is	530	Im
2-1/2	1-1/2	1/2	1100	IIIs	650	IIIs	640	Im	1080	IIIs	640	IIIs	610	Im
		5/8	1590	IIIs	840	Is	700	Im	1570	IIIs	830	Is	690	Im
		3/4	2190	IIIs	920	Is	770	Im	2160	IIIs	900	Is	750	Im
		7/8	2630	Im	1000	Is	830	Im	2570	Im	970	Is	810	Im
		1	3000	Im	1080	Is	900	Im	2940	Im	1050	Is	880	Im
3	1-1/2	1/2	1100	IIIs	650	IIIs	760	IIIs	1080	IIIs	640	IIIs	740	Im
		5/8	1590	IIIs	840	Is	840	Im	1570	IIIs	830	Is	830	Im
		3/4	2190	IIIs	920	Is	920	Im	2160	IIIs	900	Is	900	Im
		7/8	2920	IIIs	1000	Is	1000	Im	2880	IIIs	970	Is	970	Im
		1	3600	Im	1080	Is	1080	Im	3530	Im	1050	Is	1050	Im
3-1/2	1-1/2	1/2	1100	IIIs	650	IIIs	760	IIIs	1080	IIIs	640	IIIs	740	IIIs
		5/8	1590	IIIs	840	Is	980	Im	1570	IIIs	830	Is	960	Im
		3/4	2190	IIIs	920	Is	1080	Im	2160	IIIs	900	Is	1050	Im
		7/8	2920	IIIs	1000	Is	1160	Im	2880	IIIs	970	Is	1130	Im
		1	3600	Is	1080	Is	1260	Im	3530	Is	1050	Is	1230	Im
	3-1/2	1/2	1330	IV	880	IV	880	IV	1310	IV	870	IV	860	Im
		5/8	2070	IV	1190	IIIs	980	Im	2050	IV	1170	IIIs	960	Im
		3/4	2980	IV	1490	IIIs	1080	Im	2950	IV	1460	IIIs	1050	Im
		7/8	3680	Im	1840	IIIs	1160	Im	3600	Im	1810	IIIs	1130	Im
		1	4200	Im	2280	IIIs	1260	Im	4110	Im	2240	IIIs	1230	Im

TABLE 7. Bolt Design Values (*Z*) and Yield Modes for Double Shear (Three Member) Connections for Sawn Lumber with 1/4″ ASTM A36 Steel Side Plate

Thickness: Main Member t_m in.	Thickness: Side Member t_s in.	Bolt Diameter D in.	G=0.55 Southern Pine $Z_{\parallel}$ lbs.	Yield Mode	$Z_{\perp}$ lbs.	Yield Mode	G=0.50 Douglas-Fir-Larch $Z_{\parallel}$ lbs.	Yield Mode	$Z_{\perp}$ lbs.	Yield Mode	G=0.43 Hem-Fir $Z_{\parallel}$ lbs.	Yield Mode	$Z_{\perp}$ lbs.	Yield Mode	G=0.42 Spruce-Pine-Fir $Z_{\parallel}$ lbs.	Yield Mode	$Z_{\perp}$ lbs.	Yield Mode
1-1/2	1/4	1/2	1150	Im	550	Im	1050	Im	470	Im	900	Im	380	Im	880	Im	370	Im
		5/8	1440	Im	610	Im	1310	Im	530	Im	1130	Im	420	Im	1100	Im	410	Im
		3/4	1730	Im	660	Im	1580	Im	590	Im	1350	Im	460	Im	1320	Im	450	Im
		7/8	2020	Im	720	Im	1840	Im	630	Im	1580	Im	500	Im	1540	Im	490	Im
		1	2310	Im	770	Im	2100	Im	680	Im	1800	Im	540	Im	1760	Im	530	Im
2-1/2	1/4	1/2	1570	IIIs	910	Im	1510	IIIs	790	Im	1410	IIIs	640	Im	1400	IIIs	610	Im
		5/8	2350	IIIs	1020	Im	2190	Im	880	Im	1880	Im	700	Im	1840	Im	690	Im
		3/4	2880	Im	1110	Im	2630	Im	980	Im	2250	Im	770	Im	2200	Im	750	Im
		7/8	3360	Im	1200	Im	3060	Im	1050	Im	2630	Im	830	Im	2570	Im	810	Im
		1	3840	Im	1280	Im	3500	Im	1130	Im	3000	Im	900	Im	2940	Im	880	Im
3	1/4	1/2	1570	IIIs	1000	IIIs	1510	IIIs	940	IIIs	1410	IIIs	770	Im	1400	IIIs	740	Im
		5/8	2350	IIIs	1220	Im	2250	IIIs	1050	Im	2110	IIIs	840	Im	2090	IIIs	830	Im
		3/4	3300	IIIs	1330	Im	3150	Im	1170	Im	2700	Im	920	Im	2640	Im	900	Im
		7/8	4040	Im	1440	Im	3680	Im	1260	Im	3150	Im	1000	Im	3080	Im	970	Im
		1	4610	Im	1530	Im	4200	Im	1350	Im	3600	Im	1080	Im	3530	Im	1050	Im
3-1/2	1/4	1/2	1570	IIIs	1000	IIIs	1510	IIIs	940	IIIs	1410	IIIs	860	IIIs	1400	IIIs	840	IIIs
		5/8	2350	IIIs	1420	IIIs	2250	IIIs	1230	Im	2110	IIIs	980	Im	2090	IIIs	960	Im
		3/4	3300	IIIs	1550	Im	3170	IIIs	1370	Im	2960	IIIs	1080	Im	2940	IIIs	1050	Im
		7/8	4440	IIIs	1680	Im	4260	IIIs	1470	Im	3680	Im	1160	Im	3600	Im	1130	Im
		1	5380	Im	1790	Im	4900	Im	1580	Im	4200	Im	1260	Im	4110	Im	1230	Im

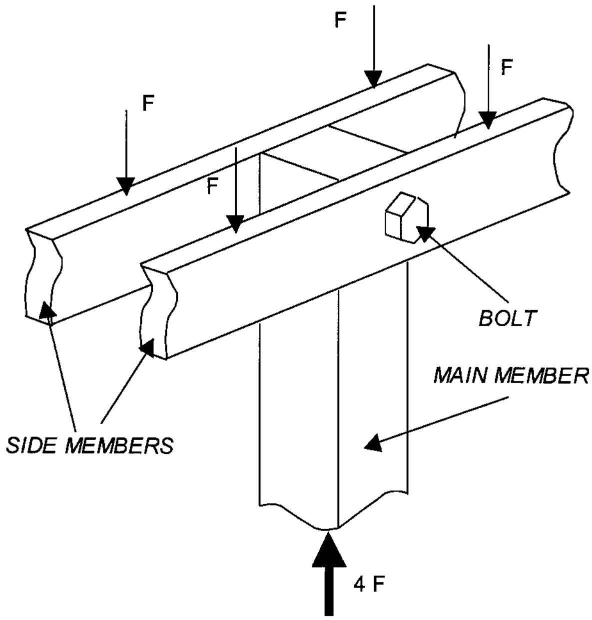

FIG. 2. Bolted Double Shear Connection

Using Table 6, entitled ''Bolt Design Values (Z) and Yield Modes for Double Shear (Three Member) Connections,'' for sawn lumber with both members of identical species, the connection yield capacity, $Z_{s\perp}$, and yield mode are found to be 3.69 kN (830 lb) and I_s, respectively. According to the UBC, for a mode I_s connection, a load duration factor, C_D, of 1.33 may be used to obtain the tabulated connection capacity for seismic loading. The factored design capacity, Z', is the resulting product, as follows:

$$Z' = Z_{s\perp}C_D = (3.69)(1.33) = 4.91 \text{ kN}$$

$$[Z' = Z_{s\perp}C_D = (830)(1.33) = 1{,}104 \text{ lb}]$$

For comparison of UBC and NDS design procedures, the allowable connection capacity for seismic loading, according to the NDS, is as follows:

$$Z' = Z_{s\perp}C_D = (3.69)(1.6) = 5.90 \text{ kN}$$

$$[Z' = Z_{s\perp}C_D = (830)(1.6) = 1{,}328 \text{ lb}]$$

If a 12.7 mm (1/2 in.) diameter ASTM A307 bolt is used instead of the 15.9 mm (5/8 in.) diameter bolt, a connection yield capacity and yield mode of 2.85 kN (640 lb) and III_s, respectively, are obtained again from Table 6. For this yield mode, the 1.6 load duration factor may be applied to the design capacity of the connection for both UBC and NDS design procedures. The result is as follows:

$$Z' = Z_{s\perp}C_D = (285)(1.6) = 4.55 \text{ kN}$$

$$[Z' = Z_{s\perp}C_D = (640)(1.6) = 1{,}024 \text{ lb}]$$

This demonstrates that a smaller bolt diameter does not necessarily result in a significantly lower design capacity due to the UBC use of the 1.33 load duration factor, instead of the 1.6 factor, for ''nonductile'' connections.

Nailed Connections

Tables 8–10 were created with yield capacities and yield modes for common wire nails, box nails, and threaded hardened-steel nails for connections with both members of the same species. The existing NDS nail/spike tables were expanded to include smaller side member thickness configurations. All NDS tabulated nail/spike configurations with metal side plates exhibit mode III yielding; therefore, they were not replicated here. For weak species with small side member thicknesses, yield mode I_s was more prominent when compared with larger side member thickness configurations. For example, common wire nail connections consisting of spruce-pine-fir members with a 7.94 mm (5/16 in.) side member thickness primarily exhibit mode I_s yielding, as presented in Table 9. This pattern is very obvious for common wire spike connections; and this information may be valuable for shear wall design. For example, consider the shear wall connection illustrated in Fig. 3.

- 10d common nail
- 7.94 mm (5/16 in.) plywood
- 51 mm by 102 mm (2 by 4) stud
- Both members are spruce-pine-fir (to demonstrate changes in yield mode)

For wall diaphragm design, the diaphragm factor (C_{di} = 1.1) may be used. By referring to Table 9, entitled ''Common Wire Nail Design Values (Z) for Single Shear (two member) Connections,'' the design capacity and yield mode for the connection are 311 N (70 lb) and I_s, respectively. The allowable connection capacity can then be calculated according to the UBC as follows:

$$Z' = ZC_DC_{di} = (311)(1.33)(1.1) = 455 \text{ N}$$

$$[Z' = ZC_DC_{di} = (70)(1.33)(1.1) = 102.4 \text{ lb}]$$

If a thicker side member is used, such as 9.53 mm (3/8 in.) plywood, the design capacity and yield mode are 316 N (71 lb) and III_s, respectively. The allowable design capacity is then calculated as follows:

$$Z' = ZC_DC_{di} = (316)(1.6)(1.1) = 556 \text{ N}$$

$$[Z' = ZC_DC_{di} = (71)(1.6)(1.1) = 123.2 \text{ lb}]$$

By using a thicker side member, yielding of the connection is governed by mode III_s instead of mode I_s, which allows the higher load duration factor of 1.6 to be used, according to UBC design procedures.

Toe-Nailed Connections

Toe-nail connection values are not dependent upon actual side member thickness, but instead on the fastener length in each member. For the toe-nail design table, the toe-nail factor, C_{tn}, of 0.83 was applied to the nominal design capacity, as well as the penetration depth factor C_d. All toe-nailed connections presented in Table 11 exhibit a yield mode of III_s or IV. Therefore, a load duration factor of 1.6 may be applied, using either NDS or UBC design procedures. Consider a wall stud (side member) to bottom plate (main member) toe-nail connection, as illustrated in Fig. 4 with an additional nail inserted on the opposite side of the wall stud:

- Wall stud to bottom plate connection
- All members are southern pine
- Two 10d common nails

The nominal design capacity, Z*, and yield mode are found in Table 11 to be 427 N (96 lb) and IV, respectively. Nominal design capacity is the result of the connection capacity multiplied by the toe-nail factor and the penetration depth factor, as follows:

TABLE 8. Box Nail Design Values (*Z*) and Yield Modes for Single Shear (Two Member) Connections with Both Members of Identical Species

Side Member Thickness	Nail Length	Nail Diameter	Penny Weight	G=0.55 Southern Pine		G=0.50 Douglas-Fir-Larch		G=0.43 Hem-Fir		G=0.42 Spruce-Pine-Fir	
ts inches	L inches	D inches		Z lbs.	Yield Mode	Z lbs.	Yield Mode	Z lbs.	Yield Mode	Z lbs.	Yield Mode
5/16	2	0.099	6d	46	IIIs	41	IIIs	35	IIIs	34	IIIs
	2.5	0.113	8d	58	IIIs	52	IIIs	45	IIIs	44	IIIs
	3	0.128	10d	73	IIIs	66	IIIs	57	IIIs	56	IIIs
	3.25	0.128	12d	73	IIIs	66	IIIs	57	IIIs	56	IIIs
	3.5	0.135	16d	81	IIIs	73	IIIs	63	IIIs	62	IIIs
	4	0.148	20d	92	IIIs	83	IIIs	72	IIIs	70	Is
	4.5	0.148	30d	92	IIIs	83	IIIs	72	IIIs	70	Is
	5	0.162	40d	109	IIIs	100	IIIs	81	Is	77	Is
3/8	2	0.099	6d	48	IIIs	43	IIIs	36	IIIs	35	IIIs
	2.5	0.113	8d	60	IIIs	54	IIIs	46	IIIs	45	IIIs
	3	0.128	10d	75	IIIs	68	IIIs	58	IIIs	56	IIIs
	3.25	0.128	12d	75	IIIs	68	IIIs	58	IIIs	56	IIIs
	3.5	0.135	16d	83	IIIs	75	IIIs	64	IIIs	62	IIIs
	4	0.148	20d	94	IIIs	85	IIIs	73	IIIs	71	IIIs
	4.5	0.148	30d	94	IIIs	85	IIIs	73	IIIs	71	IIIs
	5	0.162	40d	111	IIIs	101	IIIs	87	IIIs	85	IIIs
1/2	2	0.099	6d	55	IIIs	48	IIIs	39	IIIs	38	IIIs
	2.5	0.113	8d	67	IIIs	59	IIIs	49	IIIs	47	IIIs
	3	0.128	10d	82	IIIs	73	IIIs	61	IIIs	59	IIIs
	3.25	0.128	12d	82	IIIs	73	IIIs	61	IIIs	59	IIIs
	3.5	0.135	16d	89	IIIs	79	IIIs	66	IIIs	65	IIIs
	4	0.148	20d	101	IIIs	90	IIIs	75	IIIs	73	IIIs
	4.5	0.148	30d	101	IIIs	90	IIIs	75	IIIs	73	IIIs
	5	0.162	40d	117	IIIs	105	IIIs	89	IIIs	87	IIIs
5/8	2	0.099	6d	61	IV	55	IIIs	44	IIIs	42	IIIs
	2.5	0.113	8d	76	IIIs	66	IIIs	53	IIIs	52	IIIs
	3	0.128	10d	91	IIIs	79	IIIs	65	IIIs	63	IIIs
	3.25	0.128	12d	91	IIIs	79	IIIs	65	IIIs	63	IIIs
	3.5	0.135	16d	98	IIIs	86	IIIs	71	IIIs	69	IIIs
	4	0.148	20d	110	IIIs	97	IIIs	80	IIIs	77	IIIs
	4.5	0.148	30d	110	IIIs	97	IIIs	80	IIIs	77	IIIs
	5	0.162	40d	126	IIIs	112	IIIs	93	IIIs	90	IIIs
3/4	2	0.099	6d	61	IV	55	IV	48	IV	47	IIIs
	2.5	0.113	8d	79	IV	72	IV	58	IIIs	57	IIIs
	3	0.128	10d	101	IIIs	87	IIIs	70	IIIs	68	IIIs
	3.25	0.128	12d	101	IIIs	87	IIIs	70	IIIs	68	IIIs
	3.5	0.135	16d	108	IIIs	94	IIIs	76	IIIs	74	IIIs
	4	0.148	20d	121	IIIs	105	IIIs	85	IIIs	83	IIIs
	4.5	0.148	30d	121	IIIs	105	IIIs	85	IIIs	83	IIIs
	5	0.162	40d	138	IIIs	121	IIIs	99	IIIs	96	IIIs
1-1/2	3.25	0.128	12d	101	IV	93	IV	80	IV	79	IV
	3.5	0.135	16d	113	IV	103	IV	89	IV	88	IV
	4	0.148	20d	128	IV	118	IV	102	IV	100	IV
	4.5	0.148	30d	128	IV	118	IV	102	IV	100	IV
	5	0.162	40d	154	IV	141	IV	122	IV	120	IV

TABLE 9. Common Wire Nail Design Values (*Z*) and Yield Modes for Single Shear (Two Member) Connections with Both Members of Identical Species

Side Member Thickness t_s inches	Nail Length L inches	Nail Diameter D inches	Penny Weight	G=0.55 Southern Pine Z lbs.	G=0.55 Southern Pine Yield Mode	G=0.50 Douglas-Fir-Larch Z lbs.	G=0.50 Douglas-Fir-Larch Yield Mode	G=0.43 Hem-Fir Z lbs.	G=0.43 Hem-Fir Yield Mode	G=0.42 Spruce-Pine-Fir Z lbs.	G=0.42 Spruce-Pine-Fir Yield Mode
5/16	2	0.113	6d	58	IIIs	52	IIIs	45	IIIs	44	IIIs
	2.5	0.131	8d	76	IIIs	69	IIIs	60	IIIs	58	IIIs
	3	0.148	10d	92	IIIs	83	IIIs	72	IIIs	70	Is
	3.25	0.148	12d	92	IIIs	83	IIIs	72	IIIs	70	Is
	3.5	0.162	16d	109	IIIs	100	IIIs	81	Is	77	Is
	4	0.192	20d	131	IIIs	115	Is	87	Is	83	Is
	4.5	0.207	30d	140	Is	117	Is	88	Is	84	Is
	5	0.225	40d	142	Is	119	Is	89	Is	86	Is
	5.5	0.244	50d	144	Is	121	Is	91	Is	87	Is
	6	0.263	60d	152	Is	127	Is	96	Is	92	Is
3/8	2	0.113	6d	60	IIIs	54	IIIs	46	IIIs	45	IIIs
	2.5	0.131	8d	78	IIIs	71	IIIs	60	IIIs	59	IIIs
	3	0.148	10d	94	IIIs	85	IIIs	73	IIIs	71	IIIs
	3.25	0.148	12d	94	IIIs	85	IIIs	73	IIIs	71	IIIs
	3.5	0.162	16d	111	IIIs	101	IIIs	87	IIIs	85	IIIs
	4	0.192	20d	132	IIIs	120	IIIs	104	IIIs	100	Is
	4.5	0.207	30d	144	IIIs	131	IIIs	106	Is	101	Is
	5	0.225	40d	158	IIIs	143	Is	107	Is	103	Is
	5.5	0.244	50d	163	IIIs	145	Is	109	Is	104	Is
	6	0.263	60d	182	Is	153	Is	115	Is	110	Is
1/2	2	0.113	6d	67	IIIs	59	IIIs	49	IIIs	47	IIIs
	2.5	0.131	8d	85	IIIs	76	IIIs	63	IIIs	61	IIIs
	3	0.148	10d	101	IIIs	90	IIIs	75	IIIs	73	IIIs
	3.25	0.148	12d	101	IIIs	90	IIIs	75	IIIs	73	IIIs
	3.5	0.162	16d	117	IIIs	105	IIIs	89	IIIs	87	IIIs
	4	0.192	20d	137	IIIs	124	IIIs	105	IIIs	103	IIIs
	4.5	0.207	30d	148	IIIs	134	IIIs	115	IIIs	112	IIIs
	5	0.225	40d	162	IIIs	147	IIIs	126	IIIs	123	IIIs
	5.5	0.244	50d	166	IIIs	151	IIIs	130	IIIs	127	IIIs
	6	0.263	60d	188	IIIs	171	IIIs	147	IIIs	144	IIIs
5/8	2	0.113	6d	76	IIIs	66	IIIs	53	IIIs	52	IIIs
	2.5	0.131	8d	94	IIIs	82	IIIs	67	IIIs	65	IIIs
	3	0.148	10d	110	IIIs	97	IIIs	80	IIIs	77	IIIs
	3.25	0.148	12d	110	IIIs	97	IIIs	80	IIIs	77	IIIs
	3.5	0.162	16d	126	IIIs	112	IIIs	93	IIIs	90	IIIs
	4	0.192	20d	146	IIIs	130	IIIs	109	IIIs	106	IIIs
	4.5	0.207	30d	156	IIIs	140	IIIs	118	IIIs	115	IIIs
	5	0.225	40d	169	IIIs	151	IIIs	128	IIIs	125	IIIs
	5.5	0.244	50d	173	IIIs	155	IIIs	132	IIIs	129	IIIs
	6	0.263	60d	194	IIIs	175	IIIs	149	IIIs	145	IIIs
3/4	2.5	0.131	8d	104	IIIs	90	IIIs	73	IIIs	70	IIIs
	3	0.148	10d	121	IIIs	105	IIIs	85	IIIs	83	IIIs
	3.25	0.148	12d	121	IIIs	105	IIIs	85	IIIs	83	IIIs
	3.5	0.162	16d	138	IIIs	121	IIIs	99	IIIs	96	IIIs
	4	0.192	20d	157	IIIs	138	IIIs	114	IIIs	111	IIIs
	4.5	0.207	30d	166	IIIs	147	IIIs	122	IIIs	119	IIIs
	5	0.225	40d	178	IIIs	158	IIIs	132	IIIs	129	IIIs
	5.5	0.244	50d	182	IIIs	162	IIIs	136	IIIs	132	IIIs
	6	0.263	60d	203	IIIs	181	IIIs	152	IIIs	149	IIIs
1-1/2	3.5	0.162	16d	154	IV	141	IV	122	IV	120	IV
	4	0.192	20d	185	IV	170	IV	147	IV	144	IV
	4.5	0.207	30d	203	IV	186	IV	161	IV	158	IV
	5	0.225	40d	224	IV	205	IV	178	IV	172	IIIs
	5.5	0.244	50d	230	IV	211	IV	181	IIIs	175	IIIs
	6	0.263	60d	262	IV	240	IV	197	IIIs	191	IIIs

TABLE 10. Threaded Hardened-Steel Nail Design Values (*Z*) and Yield Modes for Single Shear (Two Member) Connections with Both Members of Identical Species

Side Member Thickness	Nail Length	Nail Diameter	Penny Weight	G=0.55 Southern Pine		G=0.50 Douglas-Fir-Larch		G=0.43 Hem-Fir		G=0.42 Spruce-Pine-Fir	
t_s inches	L inches	D inches		Z lbs.	Yield Mode	Z lbs.	Yield Mode	Z lbs.	Yield Mode	Z lbs.	Yield Mode
5/16	2	0.12	6d	73	IIIs	66	IIIs	57	IIIs	56	IIIs
	2.5	0.12	8d	73	IIIs	66	IIIs	57	IIIs	56	IIIs
	3	0.135	10d	91	IIIs	83	IIIs	67	Is	64	Is
	3.25	0.135	12d	91	IIIs	83	IIIs	67	Is	64	Is
	3.5	0.148	16d	103	IIIs	94	IIIs	74	Is	70	Is
	4	0.177	20d	135	Is	113	Is	85	Is	82	Is
3/8	2	0.12	6d	74	IIIs	67	IIIs	57	IIIs	56	IIIs
	2.5	0.12	8d	74	IIIs	67	IIIs	57	IIIs	56	IIIs
	3	0.135	10d	93	IIIs	84	IIIs	72	IIIs	71	IIIs
	3.25	0.135	12d	93	IIIs	84	IIIs	72	IIIs	71	IIIs
	3.5	0.148	16d	104	IIIs	95	IIIs	82	IIIs	80	IIIs
	4	0.177	20d	143	IIIs	130	IIIs	102	Is	98	Is
1/2	2	0.12	6d	80	IIIs	71	IIIs	60	IIIs	58	IIIs
	2.5	0.12	8d	80	IIIs	71	IIIs	60	IIIs	58	IIIs
	3	0.135	10d	98	IIIs	88	IIIs	74	IIIs	72	IIIs
	3.25	0.135	12d	98	IIIs	88	IIIs	74	IIIs	72	IIIs
	3.5	0.148	16d	110	IIIs	98	IIIs	83	IIIs	81	IIIs
	4	0.177	20d	147	IIIs	133	IIIs	114	IIIs	111	IIIs
	4.5	0.177	30d	147	IIIs	133	IIIs	114	IIIs	111	IIIs
	5	0.177	40d	147	IIIs	133	IIIs	114	IIIs	111	IIIs
	5.5	0.177	50d	147	IIIs	133	IIIs	114	IIIs	111	IIIs
	6	0.177	60d	147	IIIs	133	IIIs	114	IIIs	111	IIIs
5/8	2.5	0.12	8d	88	IIIs	77	IIIs	63	IIIs	62	IIIs
	3	0.135	10d	106	IIIs	93	IIIs	78	IIIs	75	IIIs
	3.25	0.135	12d	106	IIIs	93	IIIs	78	IIIs	75	IIIs
	3.5	0.148	16d	118	IIIs	104	IIIs	87	IIIs	85	IIIs
	4	0.177	20d	154	IIIs	138	IIIs	116	IIIs	113	IIIs
	4.5	0.177	30d	154	IIIs	138	IIIs	116	IIIs	113	IIIs
	5	0.177	40d	154	IIIs	138	IIIs	116	IIIs	113	IIIs
	5.5	0.177	50d	154	IIIs	138	IIIs	116	IIIs	113	IIIs
	6	0.177	60d	154	IIIs	138	IIIs	116	IIIs	113	IIIs
3/4	2.5	0.12	8d	97	IIIs	84	IIIs	68	IIIs	66	IIIs
	3	0.135	10d	115	IIIs	101	IIIs	82	IIIs	80	IIIs
	3.25	0.135	12d	115	IIIs	101	IIIs	82	IIIs	80	IIIs
	3.5	0.148	16d	128	IIIs	112	IIIs	92	IIIs	89	IIIs
	4	0.177	20d	164	IIIs	145	IIIs	121	IIIs	117	IIIs
	4.5	0.177	30d	164	IIIs	145	IIIs	121	IIIs	117	IIIs
	5	0.177	40d	164	IIIs	145	IIIs	121	IIIs	117	IIIs
	5.5	0.177	50d	164	IIIs	145	IIIs	121	IIIs	117	IIIs
	6	0.177	60d	164	IIIs	145	IIIs	121	IIIs	117	IIIs
	7	0.207	70d	178	IIIs	159	IIIs	133	IIIs	130	IIIs
	8	0.207	80d	178	IIIs	159	IIIs	133	IIIs	130	IIIs
	9	0.207	90d	178	IIIs	159	IIIs	133	IIIs	130	IIIs
1-1/2	3.25	0.135	12d	128	IV	118	IV	102	IV	100	IV
	3.5	0.148	16d	145	IV	133	IV	115	IV	113	IV
	4	0.177	20d	201	IV	184	IV	160	IV	156	IV
	4.5	0.177	30d	201	IV	184	IV	160	IV	156	IV
	5	0.177	40d	201	IV	184	IV	160	IV	156	IV
	5.5	0.177	50d	201	IV	184	IV	160	IV	156	IV
	6	0.177	60d	201	IV	184	IV	160	IV	156	IV
	7	0.207	70d	227	IV	208	IV	177	IIIs	171	IIIs
	8	0.207	80d	227	IV	208	IV	177	IIIs	171	IIIs
	9	0.207	90d	227	IV	208	IV	177	IIIs	171	IIIs

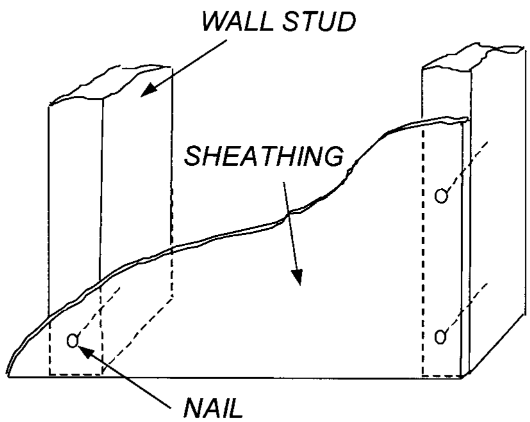

FIG. 3. Sheathing to Stud Wall Connection

$$Z^* = ZC_{tn}C_d = (427)(0.83)(0.9) = 319 \text{ N}$$

$$[Z^* = ZC_{tn}C_d = (128)(0.83)(0.9) = 96 \text{ lb}]$$

Since the connection exhibits a mode IV yielding, a load duration factor of 1.6 may be multiplied by the nominal design capacity, Z^*, to obtain the allowable design capacity, Z' as follows:

$$Z' = Z^*C_D = (319)(1.6) = 510 \text{ N}$$

$$[Z' = Z^*C_D = (96)(1.6) = 154 \text{ lb}]$$

Thus, for two 10d common nails, the capacity would be 1.02 kN (308 lb).

For toe-nails and slant nailing subjected to seismic loading, the Structural Engineers Association of California (SEAOC)

TABLE 11. Design Values (*Z) and Yield Modes for Laterally Loaded, Toe-Nailed Connections[a,b] with Both Members of Identical Species**

Nail Length L inches	Nail Diameter D inches	Penny Weight	Side Member Thickness t_s inches	Penetration Depth Factor C_d	G=0.55 Southern Pine Z* lbs.	G=0.55 Southern Pine Yield Mode	G=0.50 Douglas-Fir-Larch Z* lbs.	G=0.50 Douglas-Fir-Larch Yield Mode	G=0.43 Hem-Fir Z* lbs.	G=0.43 Hem-Fir Yield Mode	G=0.42 Spruce-Pine-Fir Z* lbs.	G=0.42 Spruce-Pine-Fir Yield Mode
Box Nail												
2	0.099	6d	0.667	0.897	45	IV	41	IV	34	IIIs	33	IIIs
2.5	0.113	8d	0.833	0.982	64	IV	59	IV	51	IIIs	49	IIIs
3	0.128	10d	1.000	1.000	84	IV	77	IV	67	IV	65	IV
3.25	0.128	12d	1.083	1.000	84	IV	77	IV	67	IV	65	IV
3.5	0.135	16d	1.167	1.000	94	IV	86	IV	74	IV	73	IV
4	0.148	20d	1.333	1.000	107	IV	98	IV	85	IV	83	IV
4.5	0.148	30d	1.500	1.000	107	IV	98	IV	85	IV	83	IV
Common Wire Nail												
2	0.113	6d	0.667	0.786	51	IIIs	45	IIIs	36	IIIs	35	IIIs
2.5	0.131	8d	0.833	0.847	75	IV	68	IIIs	54	IIIs	52	IIIs
3	0.148	10d	1.000	0.900	96	IV	88	IV	74	IIIs	72	IIIs
3.25	0.148	12d	1.083	0.975	104	IV	95	IV	83	IV	81	IV
3.5	0.162	16d	1.167	0.959	123	IV	112	IV	97	IV	95	IIIs
4	0.192	20d	1.333	0.925	142	IV	130	IV	113	IV	111	IV
4.5	0.207	30d	1.500	0.965	162	IV	149	IV	129	IV	126	IV
5	0.225	40d	1.667	0.986	183	IV	168	IV	146	IV	142	IV
5.5	0.244	50d	1.833	1.000	191	IV	175	IV	152	IV	149	IV
6	0.263	60d	2.000	1.000	218	IV	199	IV	173	IV	169	IV
Threaded Hardened-Steel Nail												
2	0.12	6d	0.667	0.740	56	IIIs	49	IIIs	40	IIIs	39	IIIs
2.5	0.12	8d	0.833	0.925	78	IV	69	IIIs	55	IIIs	53	IIIs
3	0.135	10d	1.000	0.986	105	IV	96	IV	77	IIIs	74	IIIs
3.25	0.135	12d	1.083	1.000	107	IV	98	IV	82	IIIs	79	IIIs
3.5	0.148	16d	1.167	1.000	121	IV	110	IV	95	IIIs	92	IIIs
4	0.177	20d	1.333	1.000	167	IV	153	IV	128	IIIs	124	IIIs
4.5	0.177	30d	1.500	1.000	167	IV	153	IV	133	IV	130	IV
5	0.177	40d	1.667	1.000	167	IV	153	IV	133	IV	130	IV
5.5	0.177	50d	1.833	1.000	167	IV	153	IV	133	IV	130	IV
6	0.177	60d	2.000	1.000	167	IV	153	IV	133	IV	130	IV
7	0.207	70d	2.333	1.000	188	IV	172	IV	149	IV	146	IV
8	0.207	80d	2.667	1.000	188	IV	172	IV	149	IV	146	IV
9	0.207	90d	3.000	1.000	188	IV	172	IV	149	IV	146	IV

1. Tabulated values (Z*) have been multiplied by the penetration depth factor (C_d) and the toe-nail factor (C_{tn}=0.83).
2. Tabulated values (Z*) are for toe-nailed connections fabricated according to Figure 4.

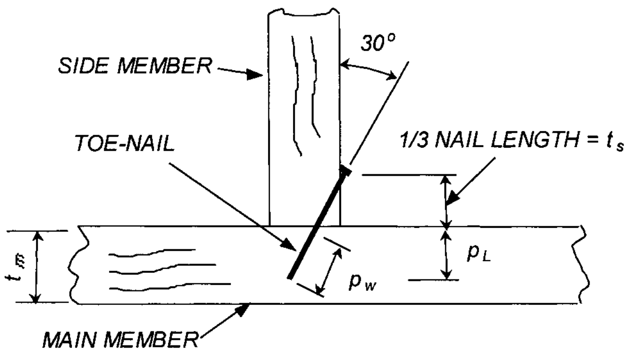

FIG. 4. Toe-Nail Diagram (Adapted from Breyer et al. 1999)

recommends limiting the design capacity of toe-nailed connections to 2.189 kN/m (150 lb/ft). This limitation applies to forces being transferred from diaphragms to shear walls, drag struts (collectors), or other elements, or from shear walls to other elements (*Recommended* 1996). The rationale behind this recommendation is based on shrinkage of blocking or close nail spacing, which might cause a weakened plane for wood splitting. This recommendation is also appropriate due to the difficulty of toe-nail installation and inspection.

SUMMARY

NDS bolted connection tables were modified to include the governing yield mode for the tabulated connection capacity. The NDS tables were also expanded to include additional side member thicknesses as well as the yield modes for each tabulated connection capacity. Toe-nail tables were created that present the nominal connection capacity and the yield mode. The nominal capacity is the result of multiplying the calculated connection capacity by the toe-nail factor and the penetration depth factor, when applicable. Using these tables alleviates the need for lengthy capacity and yield mode calculations. This allows the designer to quickly determine whether the connection behaves in a ductile or nonductile manner, according to the 1997 NDS. The appropriate load duration factor for wind and earthquake loading of 1.6 or 1.33 may then be applied to the strength of the connection in accordance with the 1997 UBC provisions. The following are general trends to be remembered when designing ductile connections:

- A decrease in fastener diameter, D, moves from brittle to ductile modes.
- An increase in side member thickness, t_s, or main member thickness, t_m, moves from brittle to ductile modes.
- An increase in wood dowel bearing strength, F_e, moves from brittle to ductile modes.

Even in the absence of a quantitative advantage associated with ductile connections (for example, 1997 UBC C_D = 1.6 versus 1.33), it is recommended that designers in regions of high seismic activity specify ductile connection yield modes rather than brittle yield modes since this can facilitate greater structural deformations without catastrophic failure in overload scenarios. From a practical standpoint, this may involve designing with a larger number of small diameter fasteners, in lieu of a few large diameter fasteners.

A more comprehensive set of bolt and nail/spike tables is available from the authors. These include more of the species, thicknesses, and connectors listed in the NDS tables.

APPENDIX I.

Bolted Connection Yield Mode Equations

Single shear	Yield mode	Double shear
$Z = \frac{D t_m F_{em}}{4 K_\theta}$	I_m	$Z = \frac{D t_m F_{em}}{4 K_\theta}$
$Z = \frac{D t_s F_{es}}{4 K_\theta}$	I_s	$Z = \frac{D t_s F_{es}}{2 K_\theta}$
$Z = \frac{k_1 D t_s F_{es}}{3.6 K_\theta}$	II	-
$Z = \frac{k_2 D t_m F_{em}}{3.2(1+2R_e)K_\theta}$	III_m	-
$Z = \frac{k_3 D t_s F_{em}}{3.2(2+R_e)K_\theta}$	III_s	$Z = \frac{k_3 D t_s F_{em}}{1.6(2+R_e)K_\theta}$
$Z = \frac{D^2}{3.2 K_\theta}\sqrt{\frac{2 F_{em} F_{yb}}{3(1+R_e)}}$	IV	$Z = \frac{D^2}{1.6 K_\theta}\sqrt{\frac{2 F_{em} F_{yb}}{3(1+R_e)}}$

Note: Mode I_s does not apply to steel side plate connections.

Where

$$k_1 = \frac{\sqrt{R_e + 2R_e^2\left(1 + R_t + R_t^2\right) + R_t^2 R_e^3} - R_e\left(1 + R_t\right)}{\left(1 + R_e\right)}$$

$$k_2 = -1 + \sqrt{2\left(1 + R_e\right) + \frac{2 F_{yb}\left(1 + 2R_e\right)D^2}{3 F_{em} t_m^2}}$$

$$k_3 = -1 + \sqrt{\frac{2\left(1 + R_e\right)}{R_e} + \frac{2 F_{yb}\left(2 + R_e\right)D^2}{3 F_{em} t_s^2}}$$

$R_e = F_{em} / F_{es}$

$R_t = t_m / t_s$

t_m = thickness of main (thicker) member, inches

t_s = thickness of side (thinner) member, inches

F_{em} = dowel bearing strength of main (thicker) member, psi

Nailed Connection Yield Mode Equations	
	Yield mode
$Z = \frac{D t_s F_{es}}{K_D}$	I_m
$Z = \frac{k_1 D p F_{em}}{K_D (1 + 2 R_e)}$	III_m
$Z = \frac{k_2 D t_s F_{em}}{K_D (2 + R_e)}$	III_s
$Z = \frac{D^2}{K_D} \sqrt{\frac{2 F_{em} F_{yb}}{3(1 + R_e)}}$	IV

Note: Mode I_s does not apply to steel side plate connections.

Where:

$$k_1 = -1 + \sqrt{2(1 + R_e) + \frac{2 F_{yb} (1 + 2 R_e) D^2}{3 F_{em} p^2}}$$

$$k_2 = -1 + \sqrt{\frac{2(1 + R_e)}{R_e} + \frac{2 F_{yb} (2 + R_e) D^2}{3 F_{em} t_s^2}}$$

$R_e = F_{em} / F_{es}$

p = penetration of nail or spike in main member (member holding point), inches

t_s = thickness of side member or $L/3$ for toe-nailed connections, inches

F_{em} = dowel bearing strength of main member (member holding point), psi

F_{es} = dowel bearing strength of side member, psi

F_{yb} = bending yield strength of nail or spike, psi

$F_e = 16600\, G^{1.84}$

D = nail or spike diameter, inches (When annularly threaded nail are used with threads at the shear plane, D = root diameter of threaded portion of nail, inches)

$K_D = 2.2$ for $D \leq 0.17$"

$K_D = 10\, D + 0.5$ for 0.17" $< D <$ 0.25"

$K_D = 3.0$ for $D \geq 0.25$"

F_{es} = dowel bearing strength of side (thinner) member, psi

$F_{e\parallel} = 11200\, G$

$$F_{e\perp} = \frac{6100\, G^{1.45}}{\sqrt{D}}$$

F_{yb} = bending yield strength of bolt, psi

D = nominal bolt diameter, inches

$K_\theta = 1 + (\theta_{max} / 360°)$

θ_{max} = maximum angle of load to grain ($0° \leq \theta \leq 90°$)

APPENDIX II. REFERENCES

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