Timber connections with mixed properties in single and double shear : a simple design method for bolts and lag screws under service conditions.

In practice provided there is adequate embedment only one equation is required to determine the basic shear load which an element in a shear connection can sustain.

Consider the shearing action between two similar wooden members connected by a dowel as shown in Figure 1.

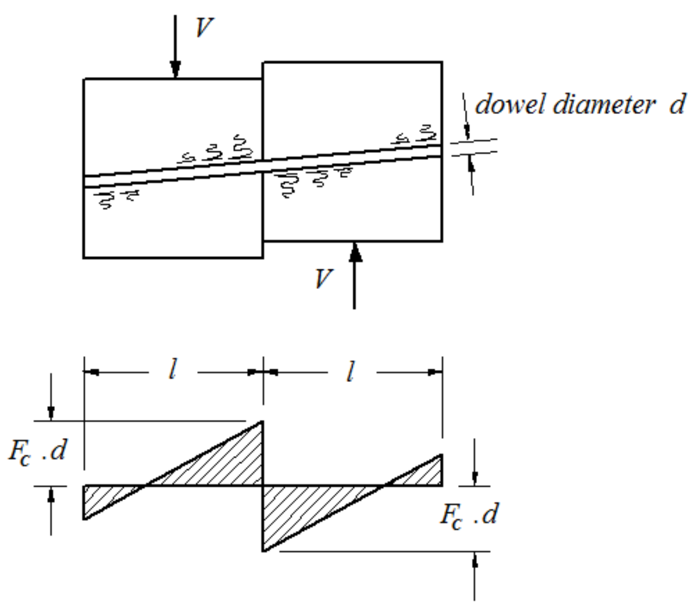

Figure 1

From beam theory the shear $V = \frac{F_c \times d \times l}{4}$

And the maximum bending moment in the dowel $M = \frac{F_c \times d \times l^2}{27}$

If M is equated to the ultimate flexural yield moment of the dowel $\frac{d^3}{6} \times F_y$

the critical embedment length $l = 2.12\sqrt{\frac{F_y}{F_c}} \times d$, and substituting for l

the ultimate shear $V_{ult} = .53\sqrt{F_y \times F_c} \times d^2$.

Then allowing a factor of safety of *3.3* , the basic shear

$$V_{basic} = \frac{.53\sqrt{F_y \times F_c} \times d^2}{3.3}$$

$$= .16\sqrt{F_y \times F_c} \times d^2 \quad \text{under service conditions}$$

In which : d = dowel diameter

F_y = dowel yield stress

F_c = wood crushing strength

Embedments less than critical will reduce the ultimate shear load in direct proportion to the embedment length while embedments more than critical cannot increase the ultimate shear beyond that determined at critical embedment. In the following examples the yield stress in the dowels and the crushing strength of the wood are taken from the Appendix. To adjust for embedment length less than critical a reduction factor "r" is applied.

EXAMPLE 1

A Bolt in single shear between similar members.

Actual embedment length L = 3.5 inches.

Species S-P-F (spruce- pine- fir), parallel to grain F_c = 6.2 Ksi

Bolt : Yield stress $F_y = 45$ *Ksi*, *diameter*	*½"*	*¾"*	*1"*	
$V_{basic} = .16\sqrt{45 \times 6.2} \times d^2 \times 10^3$	*670*	*1500*	*2670*	*lbs*
$l = 2.12\sqrt{\frac{45}{6.2}} \times d$	*2.86*	*4.28*	*5.71*	*inches*
$r = L/l \quad = 3.5/l$	*1.0*	*.82*	*.61*	
$V = V_{basic} \times r$	*670*	*1230*	*1630*	*lbs.*

EXAMPLE 2

A typical wood/wood connection is not symmetrical. Tests and analysis show that the basic shear capacity of a side element may be reduced by a factor equal to the square root of the ratio of the actual embedment to the critical embedment length of the side member.

$$\text{ie. } r = \sqrt{L/l}$$

EXAMPLE 2 (continued)

A bolt in single shear between members with differing values of F_c

Bolt : F_y = 45 Ksi	*diameter*	*½”*	*¾”*	*1”*

Main member : S-P-F, perpendicular to grain, L = 5.5”, F_c = 1.9 Ksi

$V_{basic} = .16\sqrt{45 \times 1.9} \times d^2 \times 10^3$	*370*	*833*	*1480 lbs*
$l = 2.12\sqrt{\frac{45}{1.9}} \times d$	*5.15*	*7.73*	*10.3 inches*
$r = L/l \quad = 5.5/l$	*1.0*	*.71*	*.53*
$V = V_{basic} \times r$	*370*	*591*	*784 lbs.*

Side member : S-P-F, parallel to grain, L = 1.5”, F_c = 6.2 Ksi

$V_{basic} = .16\sqrt{45 \times 6.2} \times d^2 \times 10^3$	*670*	*1500*	*2670 lbs*
$l = 2.12\sqrt{\frac{45}{6.2}} \times d$	*2.86*	*4.28*	*5.71 inches*
$r = \sqrt{L/l} \quad = \sqrt{1.5/l}$	*.72*	*.59*	*.51*
$V = V_{basic} \times r$	*482*	*888*	*1368 lbs*

Main member is the governing element.

EXAMPLE 3.

Tests on a series of double shear connections proved that the basic load for center members can be increased by a factor of 2.0.

A side member in a double shear connection is treated as it would be in single shear.

At ultimate conditions if the center member is not split or the dowel torn out primary hinges will form at the center line. In the example the reduction factors for the side members would indicate that secondary hinges will form in the half inch bolt but not in the ¾ or1 inch bolt.

The procedure can be applied only to mortise and tenon joints in weak woods otherwise the joint is governed by compression perpendicular to grain on the peg.

EXAMPLE 3 (continued)

A bolt in double shear between members with differing values for F_c

Bolt : F_y = 45 Ksi, diameter	*½”*	*¾”*	*1”*

Center member : D – fir, parallel to grain, L = 2.5 inches , F_c = 8.4 Ksi

$V_{basic} = .16\sqrt{45 \times 8.4} \times d^2 \times 10^3$	778	1750	3111 lbs
$l = 2.12\sqrt{\frac{45}{8.4}} \times d$	2.46	3.68	4.91 inches
$r = L/l \quad = 2.5/l$	1.0	.68	.51
$V = 2.0 \times V_{basic} \times r$	1556	2380	3173 lbs.

Side members : D – fir , perpendicular to grain , L = 4.5” each side, F_c = 2.77 Ksi

$V_{basic} = .16\sqrt{45 \times 2.77} \times d^2 \times 10^3$	447	1005	1786 lbs
$l = 2.12\sqrt{\frac{45}{2.77}} \times d$	4.27	6.41	8.54 inches
$r = \sqrt{L/l} \quad = \sqrt{4.5/l}$	1.0	.84	.73
$V = 2.0 \times V_{basic} \times r$	894	1688	2608 lbs.

Side members govern.

EXAMPLE 4.

Note. The diameter of the root of a lag-screw is less than that of the shank.

Main member . D – fir, perpendicular to grain $F_c = 2.77$ *Ksi ,* $L = 6.5''$

Lag screw $F_y = 45$ *Ksi diameter (nominal)*	*½"*	*¾"*	*1"*
Diameter (root)	*0.37"*	*0.58"*	*0.78"*
$V_{basic} = .16\sqrt{45 \times 2.77} \times d^2 \times 10^3$	*244*	*601*	*1087 lbs*
$l = 2.12\sqrt{\frac{45}{2.77}} \times d$	*3.15*	*4.95*	*6.66 in.*
$r = L/l = 6.5/l$	*1.0*	*1.0*	*.98*
$V = V_{basic} \times r$	*244*	*601*	*1061 lbs*

Side member. S-P-F , perpendicular to grain $F_c = 1.90$ *Ksi ,* $L = 1.5$ *inches*

Diameter (shank)	*½"*	*¾"*	*1"*
$V_{basic} = .16\sqrt{45 \times 1.90} \times d^2 \times 10^3$	*370*	*833*	*1480 lbs*
$l = 2.12\sqrt{\frac{45}{1.90}} \times d$	*5.15*	*7.73*	*10.3 inches*
$r = \sqrt{L/l} = \sqrt{1.5/l}$	*.54*	*.44*	*.38*
$V = V_{basic} \times r$	*200*	*367*	*565 lbs.*

The side member is the governing element.

Note : A bearing washer would double the shear capacity of the side member.

Conclusions

Discussion of resistance and load factors has been avoided as it is felt the test load and service load are more relevant. The former because it is useful and the latter because it represents traditional construction practice . Manipulation of load factors and resistance factors is trumped by more important considerations such as load duration, service conditions, group effects and brittle placement factors.

The factor of safety of 3.3 gives results for bolts similar to those published values in the Uniform Building Code but should be adjusted for nails and other types of fastenings.

The published values in the Uniform Building Code are close to the basic shears under service conditions but note that the method in this paper calls for greater embedment lengths.

A factor of 2.2 applied to the so-called “bedding stress” gives the crushing strength.

Appendix

WOOD PARAMETERS

Crushing Stress for Wood F_c

Species	Douglas fir		Spruce-Pine-Fir	
Specific Gravity	.49		.42	
Parallel to grain	Ksi	MPa	Ksi	MPa
	8.4	58	6.2	43
Perpendicular to grain	Ksi	MPa	Ksi	MPa
	2.77	19	1.9	13

DOWEL PARAMETERS

		Ksi	MPa
Yield stress for wooden fasteners F_y		Ksi	MPa
White Oak Pegs		15	103
Yield stress for steel fasteners F_y		Ksi	MPa
Bolts		45	310
Common nails : diameter	.11” - .13”	100	690
	.15” - .16”	90	621
	.19” - .21”	80	552
	.24” - .26”	70	483

Hardened steel nails			Ksi	MPa
	diameter	.12" - .14"	130	897
		.15" - .18"	115	793
		.21"	100	690

Lag screws :	diameter			
	nominal	root (inches)		
	¼"	.17	70	482
	5/16"	.23	60	413
	3/8"	.26	50	310
	½"	.37	50	310
	¾"	.58	50	310
	1"	.78	50	310

Carbon steel self tapping screws (STS)- Full thread

6 mm	.15	82	570
8 mm	.20	86	598
10 mm	.24	80	554
12 mm	.28	98	674

Withdrawal strength (lbs/ inch) * installation angle (degrees)

	Douglas fir			Spruce- Pine-Fir		
	90	45	30	90	45	30 *
6 mm	381	327	304	289	238	232
8 mm	507	435	406	387	330	311
10 mm	634	542	508	482	416	387
12 mm	761	653	609	580	498	463

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return to home page