Appendix I (Non-mandatory) Yield Limit Equations for Connections

I.1 Yield Modes

The yield limit equations specified in 11.3.1 for dowel-type fasteners such as bolts, lag screws, wood screws, nails and spikes represent four primary connection yield modes (see Figure I1). Modes I_m and I_s represent bearing-dominated yield of the wood fibers in contact with the fastener in either the main or side member(s), respectively. Mode II represents pivoting of the fastener at the shear plane of a single shear connection with localized crushing of wood fibers near the faces of the wood member(s). Modes III_m and III_s represent fastener yield in bending at one plastic hinge point per shear plane, and bearing-dominated yield of wood fibers in contact with the fastener in either the main or side member(s), respectively. Mode IV represents fastener yield in bending at two plastic hinge points per shear plane, with limited localized crushing of wood fibers near the shear plane(s).

I.2 Dowel Bearing Strength for Steel Members

Dowel bearing strength, F_e, for steel members shall be based on accepted steel design practices (see References 39, 40 and 41). Design values in Tables 11B, 11D, 11G, 11I, 11J, 11M and 11N are for 1/4" ASTM A36 steel plate or 3 gage and thinner ASTM A653, Grade 33 steel plate with dowel bearing strength proportional to ultimate tensile strength. Bearing strengths used to calculate connection yield load represent nominal bearing strengths of 2.4 F_u and 2.2 F_u, respectively (based on design provisions in References 39, 40 and 41 for bearing strength of steel members at connections). To allow proper application of the load duration factor for these connections, the bearing strengths have been divided by 1.6.

I.3 Dowel Bearing Strength for Wood Members

Dowel bearing strength, F_e, for wood members may be determined in accordance with ASTM D5764.

I.4 Fastener Bending Yield Strength, F_{yb}

In the absence of published standards which specify fastener strength properties, the designer should contact fastener manufacturers to determine fastener bending yield strength for connection design.

ASTM F1575 provides a standard method for testing bending yield strength of nails.

Fastener bending yield strength (F_{yb}) shall be determined by the 5% diameter (0.05D) offset method of analyzing load-displacement curves developed from fastener bending tests. However, for short, large diameter fasteners for which direct bending tests are impractical, test data from tension tests such as those specified in ASTM F606 shall be evaluated to estimate F_{yb}.

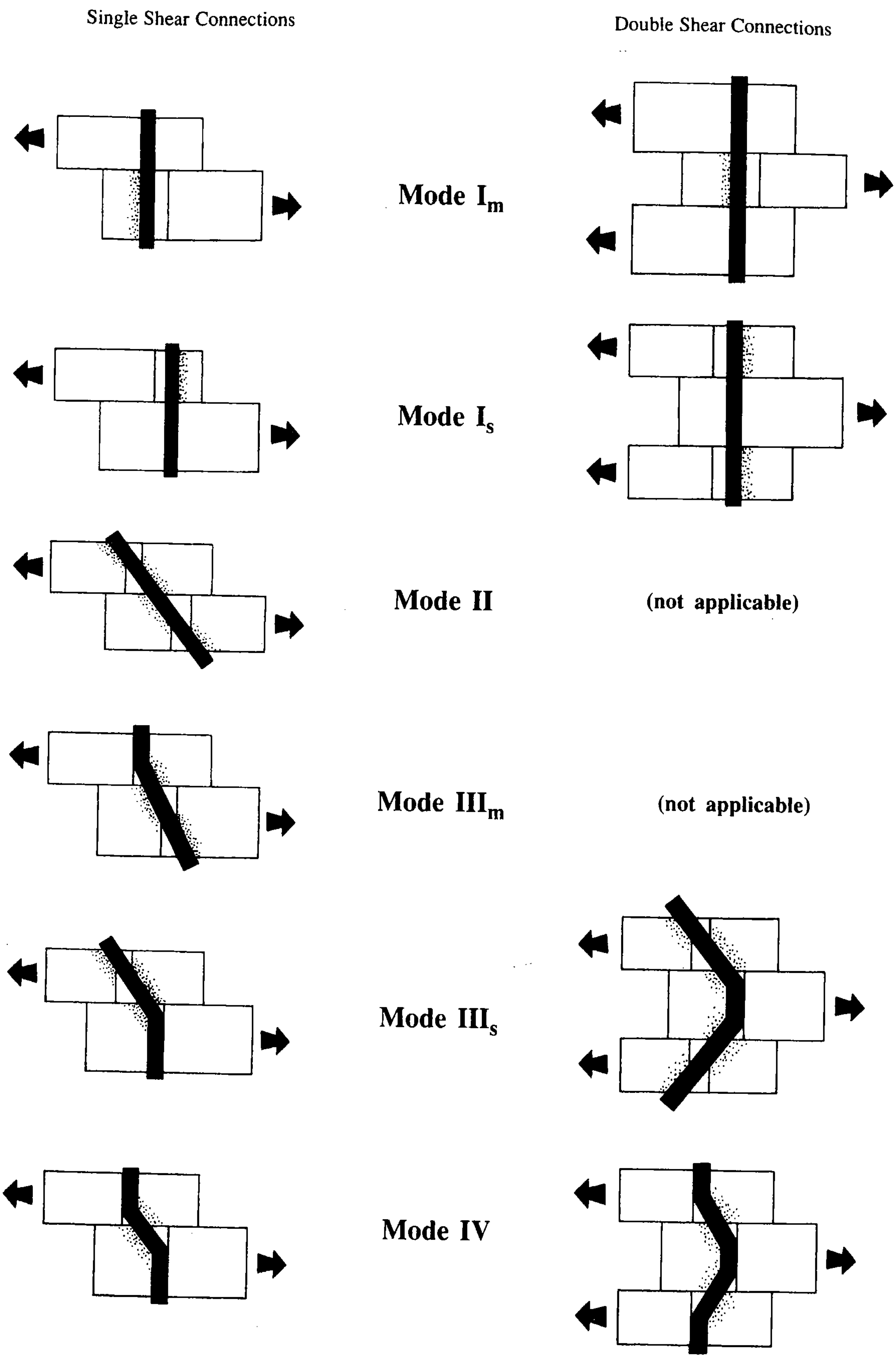
Research indicates that F_{yb} for bolts is approximately equivalent to the average of bolt tensile yield strength and bolt tensile ultimate strength, $F_{yb} = F_y/2 + F_u/2$. Based on this approximation, 48,000 psi $\leq F_{yb} \leq$ 140,000 psi for various grades of SAE J429 bolts. Thus, the aforementioned research indicates that F_{yb} = 45,000 psi is reasonable for many commonly available bolts. Tests of limited samples of lag screws indicate that F_{yb} = 45,000 psi is also reasonable for many commonly available lag screws with D ≥ 3/8".

Tests of a limited sample of box nails and common wire nails from twelve U.S. nail manufacturers indicate that F_{yb} increases with decreasing nail diameter, and may exceed 100,000 psi for very small diameter nails. These tests indicate that the F_{yb} values used in Tables 11N-R are reasonable for many commonly available box nails and small diameter common wire nails (D < 0.2"). Design values for large diameter common wire nails (D > 0.2") are based on extrapolated estimates of F_{yb} from the aforementioned limited study. For hardened-steel nails, F_{yb} is assumed to be approximately 30% higher than for the same diameter common wire nails. Design values in Tables 11J-M for wood screws and small diameter lag screws (D < 3/8") are based on estimates of F_{yb} for common wire nails of the same diameter. Table I1 provides values of F_{yb} based on fastener type and diameter.

I.5 Threaded Fasteners

The reduced moment resistance in the threaded portion of dowel-type fasteners can be accounted for by use of root diameter, D_r, in calculation of nominal lateral design values. Use of diameter, D, is permitted when the threaded portion of the fastener is sufficiently far away from the connection shear plane(s). For example, diameter, D, may be used when the length of thread bearing in the main member of a two member connection does not

Figure I1 (Non-mandatory) Connection Yield Modes



exceed 1/4 of the total bearing length in the main member (member holding the threads). For a connection with three or more members, diameter, D, may be used when the length of thread bearing in the outermost member does not exceed 1/4 of the total bearing length in the outermost member (member holding the threads). Use of diameter, D, is permitted when bolts defined in 11.1.2 are used since thread bearing lengths are typically small in the member holding the threads. For thread lengths greater than 1/4 of the total bearing length in the member holding the threads, the effect of reduced moment resistance of bolts defined in 11.1.2 is small when evaluated with a more detailed analysis.

Tabulated lateral design values for reduced body diameter lag screw and rolled thread wood screw connections are based on root diameter, D_r to account for the reduced diameter of these fasteners. These values may also be applicable for full-body diameter lag screws and cut thread wood screws since the length of threads for these fasteners is generally not known and/or the thread bearing length based on typical dimensions exceeds 1/4 the total bearing length in the member holding the threads. For bolted connections, tabulated lateral design values are based on diameter, D.

One alternate method of accounting for the moment and bearing resistance of the threaded portion of the fastener and moment acting along the length of the fastener is provided in AF&PA's *Technical Report 12 - General Dowel Equations for Calculating Lateral Connection Values* (see Reference 51). A general set of equations permits use of different fastener diameters for bearing resistance and moment resistance in each member.

Table I1 Fastener Bending Yield Strengths, F_{yb}

Fastener Type	F_{yb} (psi)
Bolt, lag screw (with D ≥ 3/8"), drift pin (SAE J429 Grade 1- F_y = 36,000 psi and F_u = 60,000 psi)	45,000
Common, box, or sinker nail, spike, lag screw, wood screw (low to medium carbon steel)	
0.099" ≤ D ≤ 0.142"	100,000
0.142" < D ≤ 0.177"	90,000
0.177" < D ≤ 0.236"	80,000
0.236" < D ≤ 0.273"	70,000
0.273" < D ≤ 0.344"	60,000
0.344" < D ≤ 0.375"	45,000
Hardened steel nail (medium carbon steel)	
0.120" ≤ D ≤ 0.142"	130,000
0.142" < D ≤ 0.192"	115,000
0.192" < D ≤ 0.207"	100,000

Appendix J (Non-mandatory) Solution of Hankinson Formula

J.1

When members are loaded in bearing at an angle to grain between 0° and 90°, or when split ring or shear plate connectors, bolts, or lag screws are loaded at an angle to grain between 0° and 90°, design values at an angle to grain shall be determined using the Hankinson formula.

J.2

The Hankinson formula is for the condition where the loaded surface is perpendicular to the direction of the applied load.

J.3

When the resultant force is not perpendicular to the surface under consideration, the angle θ is the angle between the direction of grain and the direction of the force component which is perpendicular to the surface.

J.4

The bearing surface for a split ring or shear plate connector, bolt or lag screw is assumed perpendicular to the applied lateral load.

J.5

The bearing strength of wood depends upon the direction of grain with respect to the direction of the applied load. Wood is stronger in compression parallel to grain than in compression perpendicular to grain. The variation in strength at various angles to grain between 0° and 90° shall be determined by the Hankinson formula as follows:

$$F_\theta' = \frac{F_c^* F_{c\perp}'}{F_c^* \sin^2\theta + F_{c\perp}' \cos^2\theta} \qquad \text{(J-1)}$$

where:

F_c^* = allowable compression design value parallel to grain multiplied by all applicable adjustment factors except the column stability factor

$F_{c\perp}'$ = allowable compression design value perpendicular to grain

F_θ' = allowable bearing design value at an angle to grain

θ = angle between direction of load and direction of grain (longitudinal axis of member)

When determining dowel bearing design values at an angle to grain for bolt or lag screw connections, the Hankinson formula takes the following form:

$$F_{e\theta} = \frac{F_{e\parallel} F_{e\perp}}{F_{e\parallel} \sin^2\theta + F_{e\perp} \cos^2\theta} \qquad \text{(J-2)}$$

where:

$F_{e\parallel}$ = dowel bearing strength parallel to grain

$F_{e\perp}$ = dowel bearing strength perpendicular to grain

$F_{e\theta}$ = dowel bearing strength at an angle to grain

When determining design values for bolt or lag screw wood-to-metal connections or wood-to-wood connections with the main or side member(s) loaded parallel to grain, the following form of the Hankinson formula provides an alternate solution:

$$Z_\theta' = \frac{Z_\parallel' Z_\perp'}{Z_\parallel' \sin^2\theta + Z_\perp' \cos^2\theta}$$

For wood-to-wood connections with side member(s) loaded parallel to grain,

$Z_\parallel'$ = allowable lateral design value for a single bolt or lag screw connection with the main and side wood members loaded parallel to grain, $Z_\parallel$

$Z_\perp'$ = allowable lateral design value for a single bolt or lag screw connection with the side member(s) loaded parallel to grain and main member loaded perpendicular to grain, $Z_{m\perp}$

For wood-to-wood connections with the main member loaded parallel to grain,

$Z_\parallel'$ = allowable lateral design value for a single bolt or lag screw connection with the main and side wood members loaded parallel to grain, $Z_\parallel$

$Z_\perp'$ = allowable lateral design value for a single bolt or lag screw connection with the main member loaded parallel to grain and side member(s) loaded perpendicular to grain, $Z_{s\perp}$

For wood-to-metal connections,

$Z_{\parallel}'$ = allowable lateral design value for a single bolt or lag screw connection with the wood member loaded parallel to grain, $Z_{\parallel}$

$Z_{\perp}'$ = allowable lateral design value for a single bolt or lag screw connection with the wood member loaded perpendicular to grain, $Z_{\perp}$

When determining design values for split ring or shear plate connectors or timber rivets, the Hankinson formula takes the following form:

$$N' = \frac{P'Q'}{P' \sin^2 \theta + Q' \cos^2 \theta} \qquad \text{(J-3)}$$

where:

P' = allowable lateral design value parallel to grain for a single split ring connector unit or shear plate connector unit

Q' = allowable lateral design value perpendicular to grain for a single split ring connector unit or shear plate connector unit

N' = allowable lateral design value at an angle to grain for a single split ring connector unit or shear plate connector unit

The nomographs presented in Figure J1 provide a graphical solution of the Hankinson formula.

Figure J1 Solution of Hankinson Formula

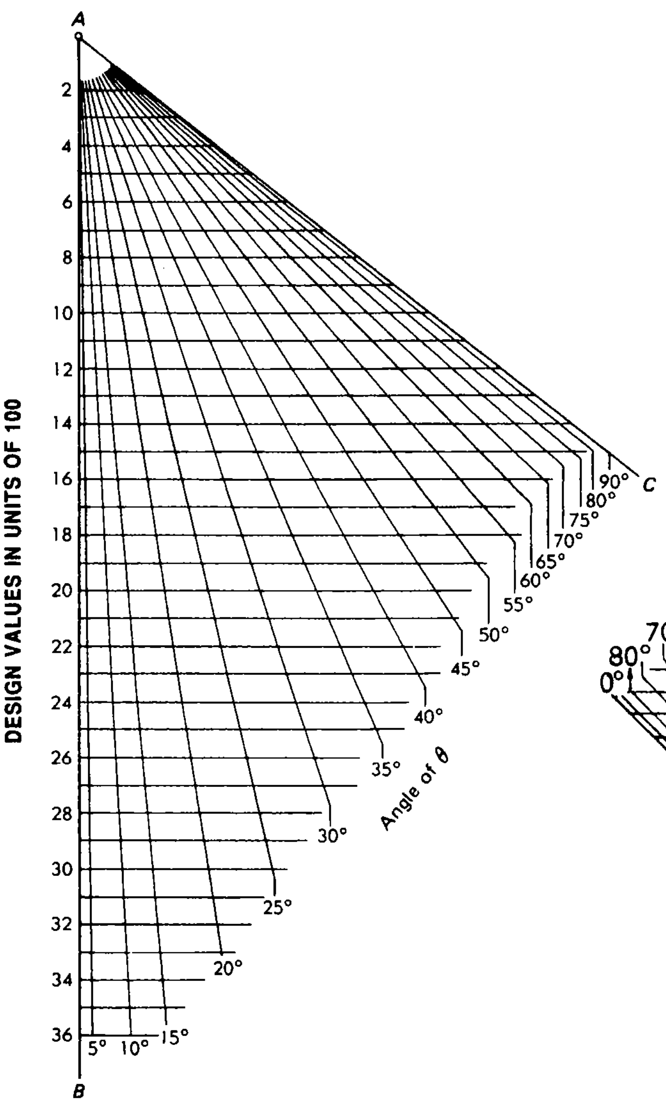
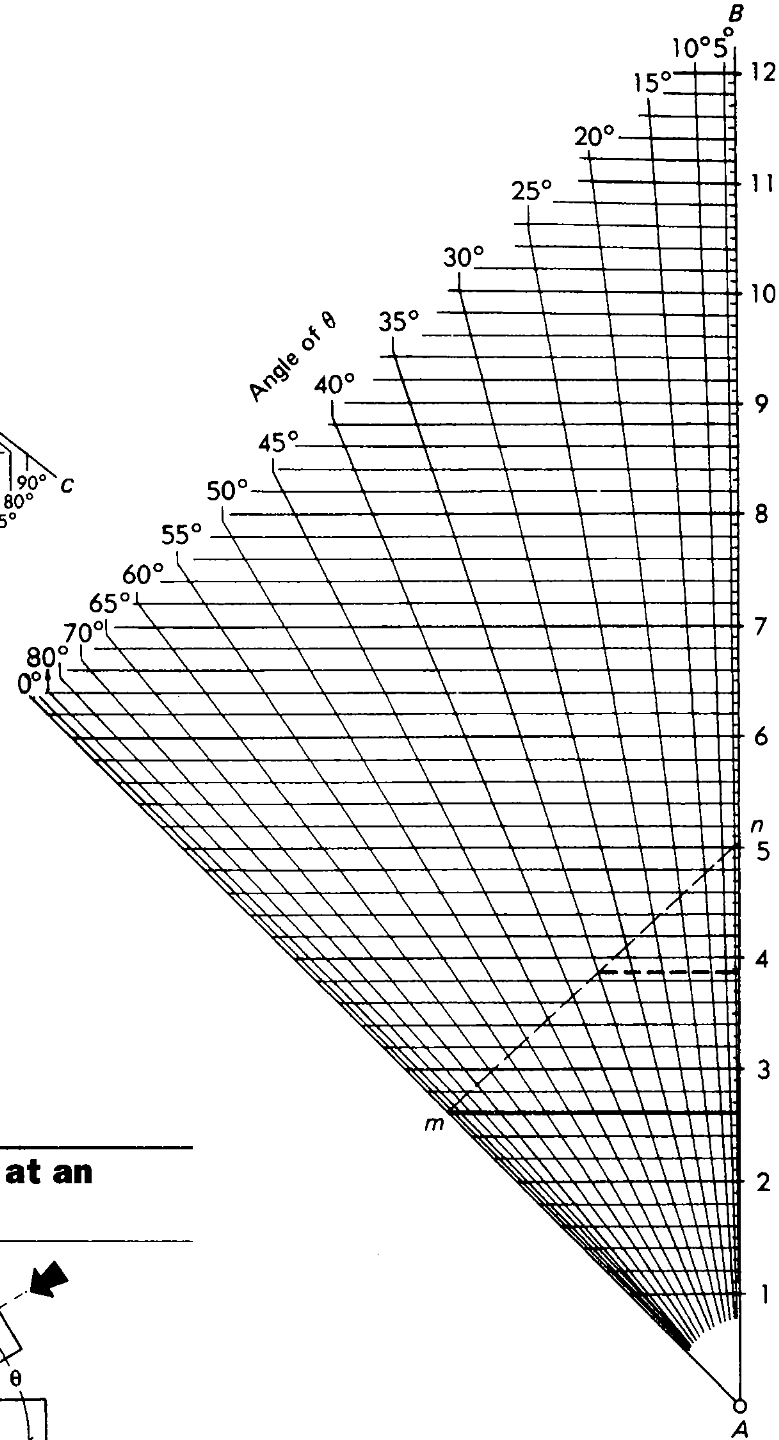
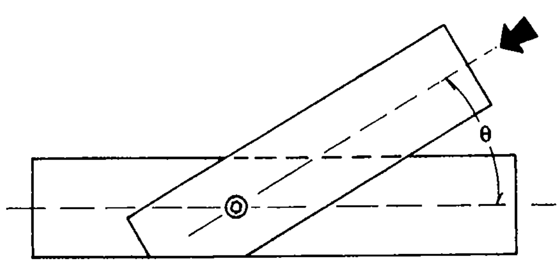



Figure J2 Connection Loaded at an Angle to Grain



Sample Solution for Split Ring or Shear Plate Connection: Assume that P' = 5030 lbs., Q' = 2620 lbs., and θ = 35° in Figure J2. On line A-B in Figure J1, locate 5030 lbs. at point n. On the same line A-B, locate 2620 lbs. and project to point m on line A-C. Where line m-n intersects the radial line for 35°, project to line A-B and read the allowable design value, N' = 3870 lbs.