WOOD CONNECTIONS

- Variables that affect the design of wood connections
  - Load carrying capacity of the connector itself
    - Nails and screws = light loads
    - Timber connectors = large loads
  - Species of wood
  - Type of load
  - Condition of wood
  - Whether fire retardant or not
  - Angle of load to the grain

Species of Wood
- Species and density affect the holding power of connectors
  - Species are classified into four groups
  - Four groups for timber connectors
    - Groups A, B, C and D
  - Groups for other connectors
    - Groups I, II, III and IV

Type of Load
- Design values for connectors can be adjusted for the duration of loading just as wood members can be b/c wood can carry greater max loads for short duration than for long durations
- Allowable connector loads are for normal **duration** of 10 years
- Other conditions, the allowable values are multiplied by:
  - .90 for permanent loading over 10 years
  - 1.15 for 2 months duration (snow loading)
  - 1.25 for 7 day duration
  - 1.60 for wind or earthquake
  - 2.0 for impact loads

Condition of Wood
- **Tabulated design values:** in building codes are for fastenings in wood seasoned to a moisture content of 19% or less
- Partially seasoned or wet wood at time of fabrication or in service reduces the holding power of the connector

Service Conditions
- The environment in which the wood joint will be used; dry, wet, exposed to weathering or subject to wetting and drying
- Any service condition other than dry or continuously wet reduce the holding power

Fire Retardant Treatment
- Treated does not hold connectors as well as those not treated

Angle of Load
- One of the most important values affecting allowable loads is angle of load to the grain
- If load is other than parallel or perpendicular to grain, it must be calculated by **Hankinson formula**
  - Gives the unit compressive stress at angle \( \theta \)
    \[
    F_n = \frac{F_g F_c}{F_g \sin^2 \theta + F_c \cos^2 \theta}
    \]
- **Example 7.1:** a 2x6 truss member bears on a 4x6 member at an angle of 40°. Both pieces of lumber are select structural Douglas fir \( F_g = 1400\text{psi} \) and \( F_c = 625\text{psi} \). What is the allowable unit compressive stress for the connection
Using the Hankinson formula

\[ F_n = \frac{(1400)(625)}{[(1400\sin^240) + (625\cos^240)]} \]
\[ F_n = 875000/[(1400)(.413) + (625)(.587)] \]
\[ F_n = 926\text{psi} \]

Critical Net Section
- **Critical net section**: section where the most wood has been removed
  - Check for load carrying capacity at this section

Connector Spacing
- The distance between centers
- Min spacing for various types of connectors given in building codes & National Design Specification for Wood Construction published by Nat'l forest Products Assoc

End and Edge Distances to Connectors
- **End distance**: distance measured parallel to the grain from the center of connector to square cut end of member
- **Edge distance**: distance from edge of member to center of connector closest to & measured perpendicular to the edge
- Loading perpendicular to the grain
  - **Loaded edge**: edge toward which the fastener load acts
  - **Unloaded edge**: edge opposite this
  - **Min values given** in tables

Nails
- Weakest connector & the most common
- **Types**:
  - **Box nail range**: 6d to 40d (smallest diameters)
  - **Wire nails range**: six penny (6d) to sixty penny (60d) (medium diameters)
  - **Common wire spike range**: 10d (3") to 8 1/2" & 3/8"dia (largest diameters)
- For engineering applications where each nailed joint is specifically designed there are tables of values giving the allowable withdrawal resistance & lateral load (shear)
- **Preferable orientation**: fastener loaded laterally in side grain where the holding power is greatest
  - If one piece is metal, allowable values increase by 25%
- For nails the design values for shear are the same regardless of the angle of load to grain
- Fasteners may also be driven or screwed so there is withdrawal from side grain
  - Fasteners loaded in withdrawal from end grain are not allowed by code
Screws
- Like nails, best used laterally loaded in side grain rather than in withdrawal from side grain
  - Withdrawal from end grain is not permitted
- Design values given in tables are for penetration into the main member of approximately 7 diameters
  - In no case should the penetration be less than 4 diameters
  - Like nails, design values increase by 25% if a metal side plate is used
- Lead holes are drilled for proper insertion of wood screws
  - Recommended size depends on species & if screw is in lateral resistance or withdrawal resistance

Lag Screws
- Threaded with pointed end but has head like a bolt
- Lead holes and screwing fastener into wood with wrench
- Also called lag bolts
- Sizes:
  - **Diameters**: 1/4” to 1 1/4”
    - Diameters are measured at the non-threaded shank
  - **Lengths**: 1” – 12”
- Design values for lateral loading and withdrawal resistance depends on
  - Species
  - Angle of load
  - Diameter of lag
  - Thickness of side member
  - Length of screw
- Unlike nails & spikes, if load is other than 0° or 90°, the design value must be determined by Hankinson formula
- Spacing end distances and edge distance for lag screw joints are same as for bolts of the same diameter as the shank of lag screw

Bolts
- Moderate to heavy loading
- Variables such as thickness of main side member, ratio of bolt length in main member to bolt diameter and number of members joined affect allowable design values & spacing
- Typical conditions: single shear & double shear
- If values in charts given only in double shear joints, single shear joints of members of equal widths are taken as one half the value for double shear joints
- When 1/4" steel plates are used for side members the design values are found in tables like
  - Values must be reduced by 60% if separate side plates are not used for each row of bolts parallel to the grain or if wood will not be dry at fabrication
  - Adjustment to tabulated design values required if adequate bolt spacing is not provided or if multiple bolts are placed in a line parallel to the load
- If loading is at an angle to the grain, use **Hankinson formula**
Example 7.2: A nominal 4x6 southern pine beam is to be supported by two 2x6 members acting as a spaced column as shown in the illustration below. The minimum spacing and edge distances for 1/2" bolts are shown. Assume that all normal conditions apply to the beam. How many 1/2" bolts will be required to safely carry a load of 1500lbf?

- This is a double shear connection and table 7.1(b) is appropriate. Look under the column labeled “main member”
- Since the length of bolt in main member is 3 1/2” use that row and the portion of the row labeled 1 1/2” in the side members and 1/2” in bolt dia.
- Select the lower of the values under southern pine for $Z_i = 1320$ lbf and $Z_m = 940$ lbf.
  - This value is $940$ lbf
- Two bolts will allow for a load of (940)(2) or 1880 lbf which is above the 1500 lbf required
- Using the spacing and edge distances given in the illustration there must be a spacing of 2”, a top distance of 2” and a bottom distance of 3/4” for a total of 4 3/4” within the total actual depth of 5 1/2” of a 4x6

Timber Connectors

- **Split ring connectors**: 2 1/4” or 4” dia and are cut in the circumference to form a tongue and slot
  - Ring is beveled from the central portion towards the edges
  - Grooves are cut in each piece so half the ring is in each section & held together with a bolt
- **Shear plates**: 2 5/8” or 4” dia and are flat plates with a flange extending from the face of the plate with a hole in the middle thru which a 3/4” or 7/8” bolt is place to hold two members together
  - Suited for construction that must be disassembled
  - Plates are inserted in precut grooves so plate is flush
  - This configuration can hold either two pieces of wood or one piece of wood & a steel plate
- These connectors transfer larger loads than bolts or screws alone and are often used in connecting truss members
**STEEL CONNECTIONS**

**Bolts**

- **Bearing type connections**: resist shear loads on bolt thru friction between surfaces but may also produce direct bearing between steel being fastened and the sides of the bolts b/c bolt holes are slightly larger than bolt and under load, the pieces connected may shift until they are bearing against the bolt
- **Slip Critical connections**: where any slippage would be detrimental to serviceability of the structure
  - **Examples**:
    - Joints subject to fatigue loading
    - Joints with oversized holes
    - Entire load is carried by friction
    - Nuts are tightened to develop high tensile stress in bolt thus causing the connected members to develop a high friction between them that resists the shear
    - Bolts are further classified as to whether threads are included or excluded from the shear plane

- This affects strength b/c there is less area to resist load thru the threaded portion
- Bolts may be in single or double shear
- Bolt types designated by ASTM
  - **ASTM A307 unfinished bolts**: lowest load carrying capacity & are used only for bearing type connections
  - **A325 & A490 high strength bolts**: may be used in bearing type but must be used in slip critical connections
- **Diameter**: 5/8” to 1 1/2” in 1/8” increments (3/4” & 7/8” are most typical)
- **ASTM designations**
  - **SC**: slip critical
  - **N**: bearing type connection with threads included in shear plane
  - **X**: bearing type connection with threads excluded from shear plane
  - **S**: bolts in single shear
  - **D**: bolts in double shear

- AISC manual of steel construction gives allowable loads for various connectors in both shear and bearing. For bearing connections different values are given based on minimum tensile strength of base material of the connected part
  - A36 steel the value is 58ksi
- Maximum allowable bearing stress between bolt and the side of the hole is given by:

\[ F_p = 1.2F_u \]

**F_p** = allowable bearing in stress
**F_u** = min tensile strength of steel

- **Standard round holes**: 1/16” larger than diameter of bolt
- Other kinds of holes may be used with high strength bolts having 5/8” dia & larger
- **Oversized holes**: nominal diameters up to 3/16” larger than bolts 7/8” and less in dia, 1/4” larger than 1” bolts and 5/16” larger than bolts 1 1/8” and greater
- **Short slotted holes**: 1/16” wider than bolt dia and have a length that does not exceed the oversized hole dimension by more than 1/16”
  - Used in either bearing or slip critical
  - Bearing: slot must be perpendicular to the load
• **Long slotted holes:** 1/16" wider than bolt dia and has a length not exceeding 2 1/2 X the bolt dia
  - May be used in slip critical connections without regard to direction of load
  - Must be perpendicular to load in bearing connections
  - Can only be used in one of the connected parts of a joint. Other part must use standard round holes or welded

• Slotted holes are used where some adjustment is needed
• The effect of reducing the cross sectional area of the members must be checked. This area is called the **net area**
  - Tendency for the web of the beam to tear where the area of the web has been reduced by bolt

• **Failure:**
  - **Shear:** parallel to the load
  - **Tension:** perpendicular to the load

AISC specifications limit the allowable stress on the **net tension area** by:

\[
F_t = 0.5F_u
\]

- \(F_t\) = allowable tensile stress
- \(F_u\) = min tensile strength of steel

- Allowable stress on the **net shear area** is limited by:

\[
F_v = 0.30F_u
\]

- \(F_v\) = Allowable shear stress
- For A36 steel, \(F_u = 58\text{ksi}\) and \(F_y = 36\text{ksi}\)
- Total tearing force is the sum required to cause both forms of failure.
- Stress on the net tension area must be compared w/ the allowable stress on the gross section which is:

\[
F_t = 0.60F_y
\]

- \(F_t\) = allowable tensile stress
- \(F_y\) = specified minimum yield stress of steel

• **Example 7.3:** A 3/8" A36 steel plate is suspended from a 1/2" plate with three 3/4" A325 bolts in standard holes spaced as shown. The threads are excluded from the shear plane and the connection is a bearing type. What is the maximum load carrying capacity of the 3/8" plate?
- **Step one:** check the shear capacity of the bolts
  - From Table 7.2, one bolt can carry a load of 13.3 kips. ∴ three bolts can carry **39.9 kips**

- **Step two:** check the bearing capacity.
  - Thinner material governs so use the 3/8" row in table 7.3 & read under the 3/4" dia column (with Fu = 58) which shows the load is 19.6 kips.
  - Three bolts will then carry 3 x 19.6 = **58 kips**

- **Step three:** determine the max stress on the net section thru the holes
  - The thinner material is the most critical component so the allowable unit stress is
    
    \[
    F_t = 0.50F_u \\
    F_t = (0.50)(58) \\
    F_t = 29 kips
    \]

  - The diameter of each hole is 1/16" larger than the bolts (13/16" or .8125") so the net width of the 3/8" plate is
    
    \[
    9 - (3)(.8125) = 6.56" \]

  - The allowable load on the net section is
    
    \[
    P = [(6.56)(.375)]2 = 71.34 kips
    \]

  - The allowable stress on the gross section is
    
    \[
    P = (0.6)(36)(9)(.375) \\
    P = 72.9 kips
    \]

  - *** * * From these four loads, the minimum governs which is the shear capacity of the bolts at **39.9 kips**

- Welding is more suitable for moment connections
- For tubes and round columns, a single plate can be welded to the column and connected with beams
  - With heavy loads, engineers prefer to slot the column and run the shear plate thru & welding it at front and back
- Connecting with angles and bolts is such a common method of steel framing, AISC manual gives allowable loads for various types and diameters of bolts and lengths and thicknesses of angles
Important consideration in bolted steel is the spacing of bolts and the edge distance from the last bolt to the edge
- AISC specifies minimum dimensions
- Absolute minimum spacing is 2 2/3 times the diameter of the bolt with 3 times being the preferred
- Often 3” is used for all size bolts up to 1” dia
- The required distance varies with diameter of the bolt used
- At the edges of plates, shapes or bars the dimension is 1” for a 3/4” bolt and 1/25” for a 1” bolt
  - To simplify detailing and tabulated values a dimension of 1.25” is often used for all bolts having a diameter up to 1”

Example 7.4: A W24x104 girder supports a W18x55 beam with two 3 1/2” x 3 1/2 x 5/16 x 14 1/2” long angles. The connection is made with 7/8” A325 bolts in a slip critical connection. What is the max allowable load that can be supported?
- In Table 7.5 in the A325-SC bolt type column & since 7/8” bolts are being used, read down that sub-column to find the row corresponding to the angle length of 14 1/2 in
  - Allowable load is 102kips

Welds
- Used in lieu of bolts for several reasons:
  - Gross cross section of members can be used instead of net section
  - Construction is more efficient b/c no angles, bolts, washer to deal with and no clearance problems with wrenches
  - More practical for moment connections
- Since members must be held in place until welding is complete, it is often used in combination with bolting

Welding process:
- Electric arc process: most common where one electrode from the power source is attached to the steel member being joined. The other electrode is the welding rod. Intense heat generated by the electric arc formed when the welding rod is brought close to the members causes some of the base metal and the end of the electrode to melt into the joint so the materials fuse together
- Penetration: refers to the depth from the surface of the base metal to the point where fusion stops

Types of electrodes
- E60: allowable shear stress is 18kips per square inch
- E70: allowable shear stress is 21ksi
• **Types of welds:** which one to use depends on the configuration of the joint, magnitude and direction of the load, cost of preparing the joint and what the erection process will be
  - Three most common types are
    - Lap
    - Butt
    - Tee
  - Plug or slot welds are where holes are cut or punched in one of the members and the area is filled with the weld

• **Throat:** the perpendicular distance from the 90° corner to the hypotenuse of the triangle
  - B/c angles are 45° the dimension of the throat is \(0.707\) times the leg dimension
  - For a butt joint the throat dimension is the thickness of the material if both pieces are the same thickness or the size of the thinner of the two materials

• Type of weld is indicated with standard symbols and placed below the line if the weld is on the side near the arrow and above the line if it is on the side away from the arrow
  - Repeated above and below the line if welded on both sides
  - The perpendicular legs of the fillet, bevel, J and flare bevel welds must be at the left

• Designing a weld joint requires knowledge of the load to be resisted and allowable stressing the weld
  - For fillet welds the stress is considered as shear on the throat regardless of the direction of load
  - For butt welds the allowable stress is the same as for the base metal
  - For any size fillet weld it is possible to multiply the size by \(0.707\) and by the allowable stress to get allowable working strength per linear inch of weld but these values have been tabulated by AISC

• In addition to knowing allowable stresses, the following AISC code provisions apply to weld design
  - Max size of a fillet weld is 1/16" less than the nominal thickness of the material being joined if it is 1/4"t or more. If material is less than 1/4"t the max size is the same as the material
  - Minimum size of fillet welds is shown in table 7.7 (below)
  - Minimum length of fillet welds must not be less than 4x the weld size plus 1/4" for starting and stopping the arc
  - For two or more welds parallel, the length must be at least equal to the perpendicular distance between them
  - Intermittent welds length must be at least 1 1/2"

<table>
<thead>
<tr>
<th>Minimum Size of Fillet Welds</th>
<th>material thickness of the thicker part joined</th>
<th>minimum size of fillet weld</th>
</tr>
</thead>
<tbody>
<tr>
<td>(in)</td>
<td>(in)</td>
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<tr>
<td>over 1/4&quot; inclusive</td>
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<td>over 1/4&quot; to 1/8&quot;</td>
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<tr>
<td>over 1/8&quot; to 1/16&quot;</td>
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<tr>
<td>over 1/16&quot;</td>
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</tbody>
</table>
• **Example 7.5:** An A36 steel bar 3/8" x 4" is welded to a tube section with E70 electrodes as shown. What is the maximum load carrying capacity if the maximum size of weld is used?

![Diagram of Example 7.5](image)

Since the maximum weld size is 1/16" less than the member being joined, a weld of 5/16" will be used. From table 7.6 the allowable load is 4.6kips/in. the total load is therefore

\[(2)(3)(4.6) = 27.6\text{kips}\]

• **Example 7.6:** A 3 x 3 x 1/4 angle (area of 1.44in²) is to be welded to a gusset plate to serve as a tension member as shown. If A36 steel and E60 electrodes are used what are the required size and length of weld on both sides of the angle if the full load carrying capacity of the angle is to be developed?

![Diagram of Example 7.6](image)

- **Step one:** max allowable capacity of the angle must be determined.
  - The allowable unit stress is .60 x min yield pint of steel (Fₜ = .60Fₚ)
  - The total maximum capacity = unit stress x area of the angle

\[(.60)(36)(1.44) = 31.1\text{kips}\]

- **Step two:** For an angle the maximum size of weld is 3/16" which from Table 7.6 has a load carrying capacity of 2.4kips/in with E60 electrodes.
  - The total length of weld is

\[31.1/2.4 = 12.96\text{in}\]

- Round up to 13” & since the welding will be on both sides of the angle, each weld should be at least 6 1/2” long

**CONCRETE CONNECTIONS**

Rebars and Keyed Sections
- **Dowels:** reinforcing is only for the purpose of typing two pours of concrete together rather than transmit large loads

Shear Connectors
- Tie steel and concrete together in composite sections so forces are transmitted from one to the other
  - Connectors welded to top of beams
- Concrete is poured around connectors where enlarged head of connector is provided to give extra bearing surface
  - Studs are called **head anchor studs (HAS)**