CONNECTION DESIGN

- Connections must be designed at the strength limit state
  - Average of the factored force effect at the connection and the force effect in the member at the same point
  - At least 75% of the force effect in the member

- End connections for diaphragms, cross-frames, lateral bracing for straight flexural members - designed for factored member loads

- Connections should be symmetrical about member axis
  - At least two bolts or equivalent weld per connection
  - Members connected so that their gravity axes intersect at a point
  - Eccentric connections should be avoided

- End connections for floorbeams and girders
  - Two angles with thickness $\geq$ 0.375 in.
  - Made with high strength bolts
  - If welded account for bending moment in design

BOLTED CONNECTIONS

- Slip-critical and bearing type bolted connections.
- Connections should be designed to be slip-critical where:
  - stress reversal, heavy impact loads, severe vibration
  - joint slippage would be detrimental to the serviceability of the structure
- Joints that must be designed to be slip-critical include
  - Joints subject to fatigue loading or significant load reversal.
  - Joints with oversized holes or slotted holes
  - Joints where welds and bolts sharing in transmitting load
  - Joints in axial tension or combined axial tension and shear
- Bearing-type bolted connections can be designed for joints subjected to compression or joints for bracing members

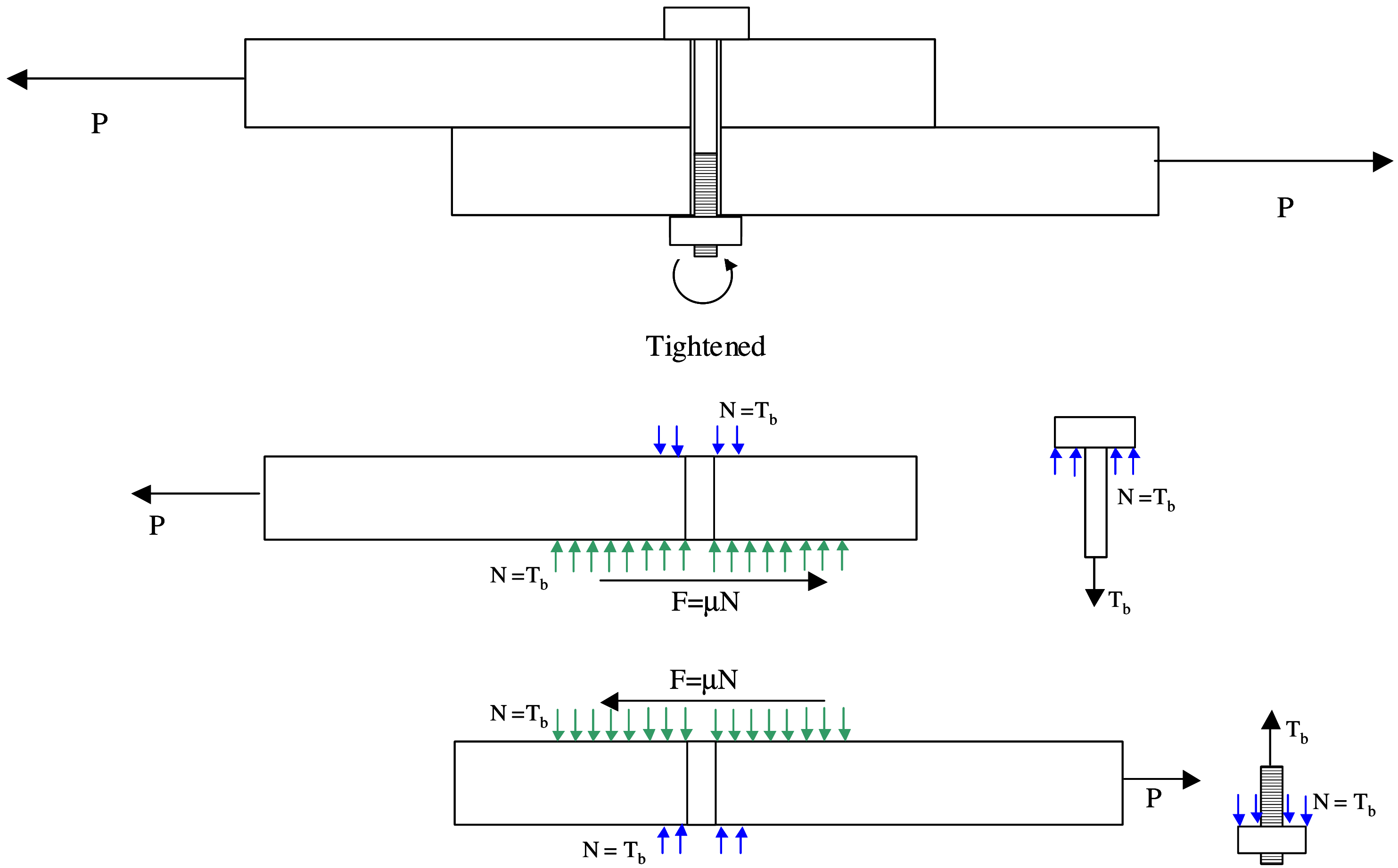
SLIP-CRITICAL BOLTED CONNECTION

- Slip-critical bolted connections can fail in two ways: (a) slip at the connection; (b) bearing failure of the connection
- Slip-critical connection must be designed to: (a) resist slip at load Service *II;* and (b) resist bearing / shear at strength limit states

SLIP-CRITICAL BOLTED CONNECTION

- Slip-critical bolted connections can be installed with such a degree of tightness → large tensile forces in the bolt → clamp the connected plates together

- Applied Shear force resisted by friction



SLIP-CRITICAL BOLTED CONNECTION

- *Slip-critical connections* can resist the shear force using friction.
  - If the applied shear force is less than the friction that develops between the two surfaces, then no slip will occur between them

- Nominal slip resistance of a bolt in a slip-critical connection
  - $R_n = K_h K_s N_s P_t$
  - Where, P_t = minimum required bolt tension specified in Table 1

    K_h = hole factor specified in Table 1

    K_s = surface condition factor specified in Table 3

SLIP-CRITICAL BOLTED CONNECTION

Values of P_t

Bolt diameter (in.)	Required Tension (kips) A325	Required Tension (kips) A490
5/8	19	24
3/4	28	35
7/8	39	49
1	51	64
1-1/8	56	80
1-1/4	71	102
1-3/8	85	121
1-1/2	103	148

Values of K_h

For standard holes	1.0
For oversize and short-slotted holes	0.85
For long slotted holes with the slot Perpendicular to the force direction	0.70
For long-slotted holes with the slot Parallel to the force direction	0.60

Values of K_s

For Class A surface conditions	0.33
For Class B surface conditions	0.50
For Class C surface conditions	0.33

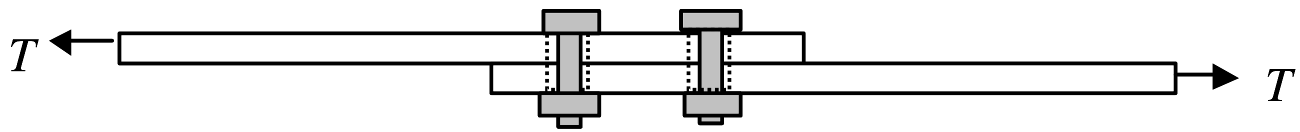
- Faying surfaces
  - Unpainted clean mill scale, and blast-cleaned surfaces with *Class A* coating
  - Unpainted blast-cleaned surfaces with *Class B* coating
  - Hot-dip galvanized surfaces roughened by wire brushing – *Class C*

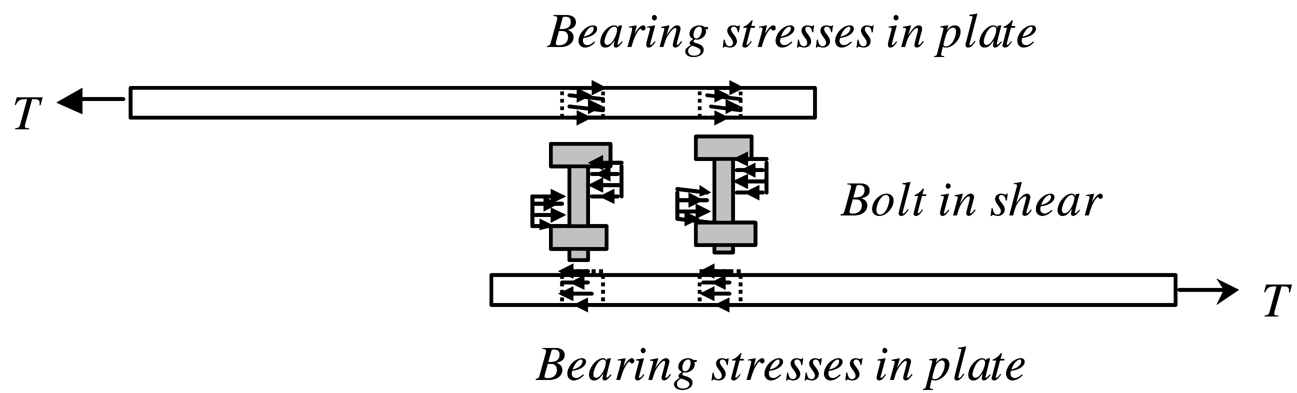
SLIP-CRITICAL CONNECTION

- Connection subjected to tensile force (T_u), which reduces clamping
  - Nominal slip resistance should be reduced by ($1 - T_u/P_t$)
- Slip is not a catastrophic failure limit-state because slip-critical bolted connections behave as bearing type connections after slip.
- Slip-critical bolted connections are further designed as bearing-type bolted connection for the applicable factored strength limit state.

BEARING CONNECTION

- In a bearing-type connection, *bolts are subjected to shear* and the connecting / connected plates are subjected to bearing stresses :





BEARING CONNECTION

- Bearing type connection can fail in several failure modes
  a) Shear failure of the bolts
  b) Excessive bearing deformation at the bolt holes in the connected parts
  c) Edge tearing or fracture of the connected plate
  d) Tearing or fracture of the connected plate between two bolt holes
  e) Failure of member being connected due to fracture or block shear or ...

BEARING CONNECTION

- Nominal shear resistance of a bolt
  - Threads excluded: $R_n = 0.48\ A_b\ F_{ub}\ N_s$
  - Threads included: $R_n = 0.38\ A_b\ F_{ub}\ N_s$

  Where, A_b = area of the bolt corresponding to the nominal diameter

  F_{ub} = 120 ksi for A325 bolts with diameters 0.5 through 1.0 in.

  F_{ub} = 105 ksi for A325 bolts with diameters 1.125 through 1.5 in.

  F_{ub} = 150 ksi for A490 bolts.

  N_s = number of shear planes

- Resistance factor for bolts in shear = $\phi_s = 0.80$
- Equations above - valid for joints with length < less than 50.0 in.
  - If the length is greater than 50 in., then the values from the equations have to be multiplied by 0.8

BEARING CONNECTION

- Effective bearing area of a bolt = the bolt diameter multiplied by the thickness of the connected material on which it bears
- Bearing resistance for standard, oversize, or short-slotted holes in any direction, and long-slotted holes parallel to the bearing force:
  - For bolts spaced with clear distance between holes greater than or equal to 3.0 d and for bolts with a clear end distance greater than or equal to 2.0 d

$$\mathbf{R_n = 2.4\ d\ t\ F_u}$$

  - For bolts spaced with clear distance between holes less than 3.0 d and for bolts with clear end distances less than 2.0 d

$$\mathbf{R_n = 1.2\ L_c\ t\ F_u}$$

Where, d = nominal bolt diameter

L_c= clear distance between holes or between the hole and the end of the member in the direction of applied bearing force

F_u = tensile strength of the connected material

- <u>The resistance factor ϕ_{bb} for material in bearing due to bolts = 0.80</u>

BEARING CONNECTION

- SPACING REQUIREMENTS
  - Minimum spacing between centers of bolts in standard holes shall not be less than three times the diameter of the bolt
  - For sealing against penetration of moisture in joints, the spacing on a single line adjacent to the free edge shall satisfy $s \leq (4.0 + 4.0\ t) \leq 7.0$
  - Minimum edge distances

Bolt diameter (in.)	Sheared edge	Rolled or Gas Cut edge
5/8	1-1/8	7/8
3/4	1-1/4	1
7/8	1-1/2	1-1/8
1	1-3/4	1-1/4
1-1/8	2	1-1/2
1-1/4	2-1/4	1-5/8
1-3/8	2-3/8	1-3/4

BOLTED CONNECTION

- **Example 1** Design a slip-critical splice for a tension member. For the Service II load combination, the member is subjected to a tension load of 200 kips. For the strength limit state, the member is subjected to a maximum tension load of 300 kips.
  - The tension member is a *W8 x 28* section made from M270-Gr. 50 steel. Use A325 bolts to design the slip-critical splice.

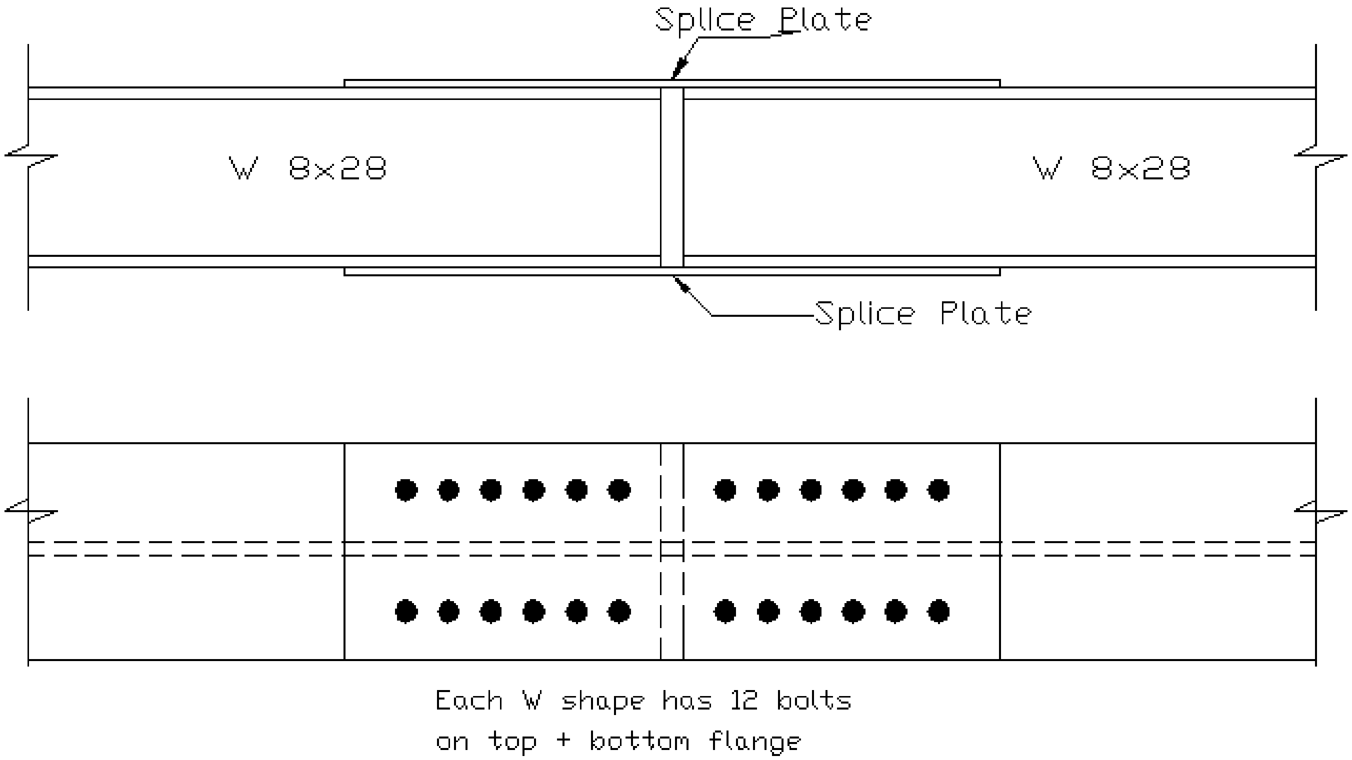
- **Step I.** <u>Service and factored loads</u>
  - Service Load = 200 kips.
  - Factored design load = 300 kips
  - Tension member is *W8 x 28* section made from M270 Gr.50. The tension splice must be slip critical (i.e., it must not slip) at service loads.

BOLTED CONNECTION

S**tep II.** <u>Slip-critical splice connection</u>

- Slip resistance of one fully-tensioned slip-critical bolt = $R_n = K_h\ K_s\ N_s\ P_t$
  - ϕ = 1.0 for slip-critical resistance evaluation
  - Assume bolt diameter = d = ¾ in. Therefore P_t = 28 kips from Table 1
  - Assume standard holes. Therefore K_h = 1.0
  - Assume Class A surface condition. Therefore K_s = 0.33
  - Therefore, ϕR_n = 1.0 x 0.33 x 1 x 28 = 9.24 kips
- Therefore, number of ¾ in. diameter bolts required for splice to be slip-critical at service loads = 200 / 9.24 = 21.64.
- Therefore, number of bolts required $\geq$ 22

BOLTED CONNECTION



Step III: Layout of flange-plate splice connection

- To be symmetric about centerline, need the number of bolts = multiple of 8.
- Therefore, choose 24 fully tensioned 3/4 in. A325 bolts with layout above.
  – Slip-critical strength of the connection = 24 x 9.24 kips = 221.7 kips
- Minimum edge distance (L_e) = 1 in. from Table 4.
  – Design edge distance L_e = 1.25 in.
- Minimum spacing = s = 3 x bolt diameter = 3 x ¾ = 2.25 in.
  – Design spacing = 2.5 in.

BOLTED CONNECTION

Step IV: Connection strength at factored loads

- The connection should be designed as a normal shear/bearing connection beyond this point for the factored load of 300 kips

- Shear strength of high strength bolt = ϕ R_n = $\underline{0.80}$ x 0.38 x A_b x F_{ub} N_s
  - Equation given earlier for threads included in shear plane.
  - A_b = 3.14 x 0.75^2 / 4 = 0.442 in^2
  - F_{ub} = 120 ksi for A325 bolts with d < 1-1/8 in.
  - N_s= 1
  - Therefore, ϕR_n = 16.1 kips

- The shear strength of 24 bolts = 16.1 kips/bolt x 24 = 386.9 kips

BOLTED CONNECTION

- Bearing strength of 3/4 in. bolts at edge holes (L_e = 1.25 in.)
  - ϕ_{bb} R_n = <u>0.80</u> x 1.2 L_c t F_u

    Because the clear edge distance = 1.25 – (3/4 + 1/16)/2 = 0.84375 in. < 2 d
  - ϕ_{bb} R_n = 0.80 x 1.2 x 0.84375 x 65 kips x t = 52.65 kips / in. thickness

- Bearing strength of of 3/4 in. bolts at non-edge holes (s = 2.5)
  - ϕ_{bb} R_n = <u>0.80</u> x 2.4 d t F_u

    Because the clear distance between holes = 2.5 – (3/4 + 1/16) = 1.6875 in. > 2d
  - ϕ_{bb} R_n = 0.80 x 2.4 x 0.75 x 65 kips x t = 93.6 kips / in. thickness

- Bearing strength of bolt holes in flanges of wide flange section *W8 x 28* (t = 0.465 in.)
  - 8 x 52.65 x <u>0.465</u> +16 x 93.6 x <u>0.465</u> = 892 kips

CONNECTION STRENGTH

Connection Strength
Slip-critical strength = 221.7 kips
Shear strength of bolts = 386.9 kips
Bearing strength (plate) = 892 kips

- Connection strength (ϕR_n) > applied factored loads (γQ).
  - Therefore ok