Defining Bolt Preload

How to apply preload to bolts?

Preloaded Bolted Joints

Modeling the Bolt and Preload

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Outline

1. Why is Bolt Preload Necessary?
2. Using Torque to Calculate Bolt Preload
3. Defining Bolt Preload in Finite Element Simulations

Why is Bolt Preload Necessary?

- Bolt preload ensures that the mating parts stay connected during the operation of the machine.
- Insufficient bolt preload may cause the bolts to become loose, leading to failure of the machine assembly or separation and lateral movement of the mating parts.
- Since tightening of bolts produces tensile loads in the bolt, the bolt preload is also known as bolt pretension.

Calculating the Bolt Preload

- One way to select a bolt of an appropriate size is to assume a worst-case scenario where the entire external load F is sustained by the bolt alone.
- Calculate bolt stress as

$$\sigma_B = \frac{F}{A_t}$$

where A_t is the tensile stress area of the bolt.

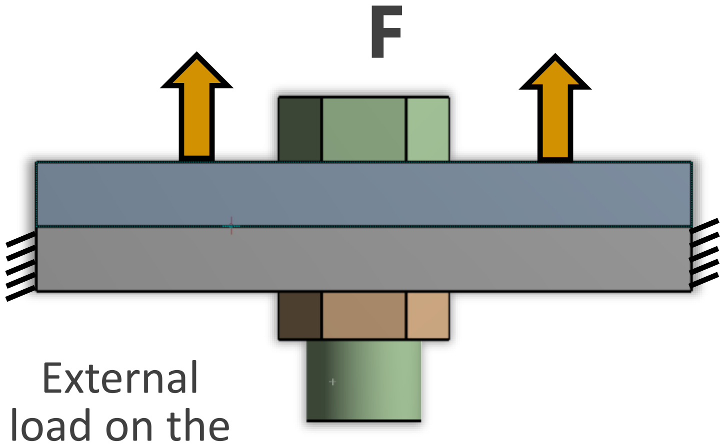
- The selected bolt should satisfy the condition

$$\sigma_B < \text{Proof Strength of bolt material}$$

Values for A_t for standard bolts and Proof Strength for various good quality bolt materials can be obtained from published data in design guides.

- If data for proof strength for a bolt material is not available, we can approximate it as

$$\text{Proof Strength} = 0.85 \times \text{Yield Strength}^1$$



[1] Budynas, Richard Gordon, and J. Keith Nisbett. *Shigley's Mechanical Engineering Design*. Vol. 9. New York: McGraw-Hill, 2011.

Calculating the Bolt Preload

- Calculate the proof load as

$$\text{Proof Load} = \text{Proof Strength} \times {A_t}^{1}$$

- Calculate bolt preload as

$$P = \text{Factor} \times \text{Proof Load}^{1}$$

where

P is the bolt preload,

$0.75 < \text{Factor} < 0.9^{1}$

- In case of fatigue loading, we need to ensure

$$P \leq (1 - C) \times S_{ut} \times {A_t}^{1}$$

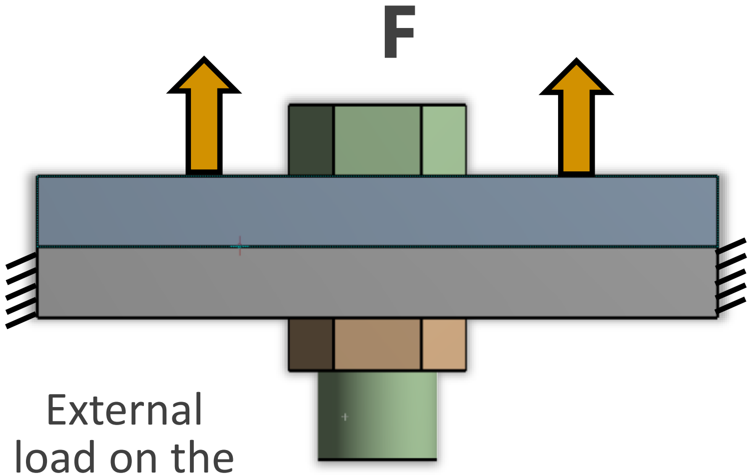
where

$C = \frac{1}{\left(1 + {}^{K_M}/_{K_B}\right)}$ and ${}^{K_M}/_{K_B}$ is the ratio of member stiffness to bolt stiffness

S_{ut} is the ultimate strength of the bolt material

A_t is the tensile stress area of the bolt

If the calculated bolt preload P does not satisfy this condition, then additional bolts and/or a different size bolt may be called for.



[1] Budynas, Richard Gordon, and J. Keith Nisbett. *Shigley's Mechanical Engineering Design*. Vol. 9. New York: McGraw-Hill, 2011.

Using Torque to Calculate Bolt Preload

- Calculate the torque corresponding the bolt preload as

$$T = K \times D \times P$$

where;

T is the torque applied to tighten the bolt,

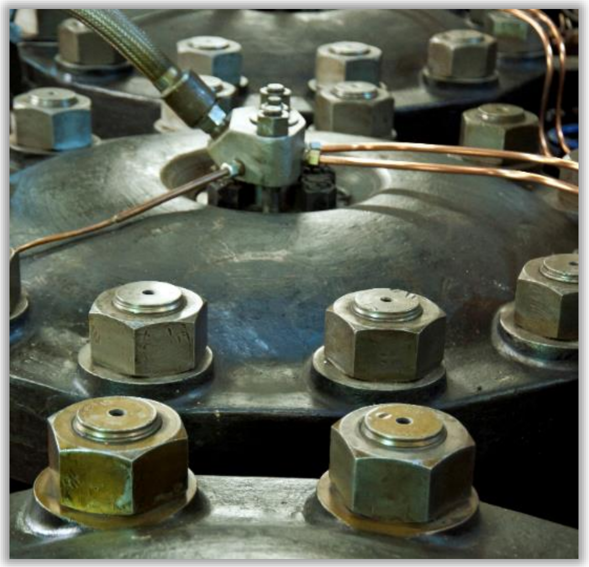
D is the major diameter of the bolt,

P is the bolt preload,

K is the nut-factor or the tightening factor

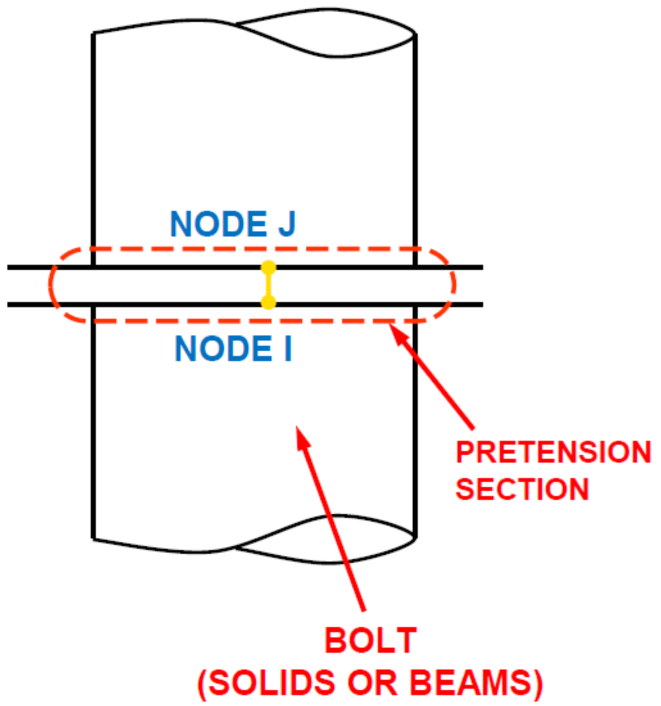
- Representative values of K for a few cases are listed below:

K	Type of bolt
0.2	Steel bolts (with no plating)
0.15	Steel bolts with cadmium plating
0.28	Steel bolts with zinc plating
0.18	Steel bolts with lubrication



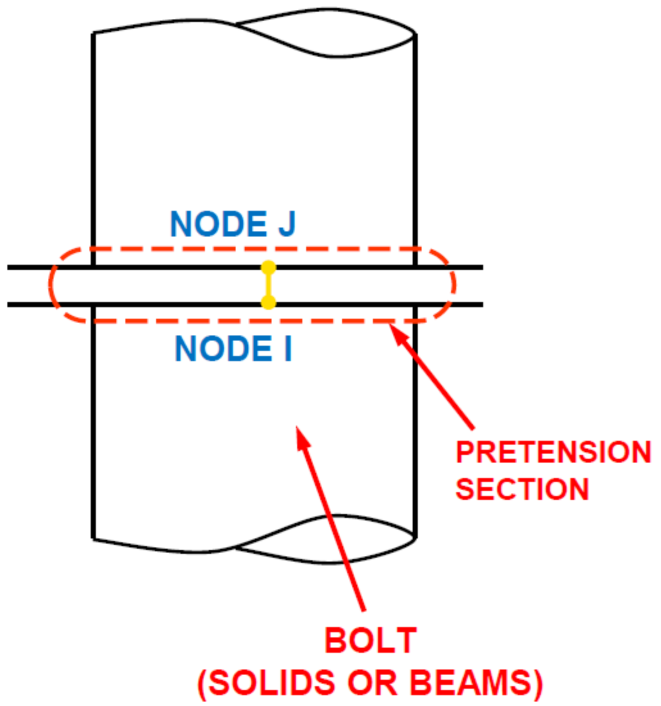
Defining Bolt Preload in Finite Element Simulations

- In the real world, bolts are tightened by applying torque.
- In real-life, tightening a bolt reduces its grip-length and produces tensile preload.
- Applying torque and rotating the nut in a simulation is computationally expensive and does not add any value or accuracy to the results.
- Instead, the shortening of the grip-length (which induces tensile preload) is mimicked in simulations by slicing the bolt into two parts and applying preload to both ends.
- The finite element mesh overlaps in the cut region, but it is a convenient way of representing shortening of grip-length.



Defining Bolt Preload in Finite Element Simulations

- Assuming that the bolt is represented by a cylinder, the cylinder is split into two halves.
- Two nodes are picked on each half, say nodes I and J. The two nodes are generally, physically coincident.
- Constraint equations are created to tie together the relative motion of nodes I and J.
- By specifying the relative displacement between nodes I and J, or by specifying the force applied on the preload force acting between nodes I and J, we introduce a tensile load in the two halves of the cylinder.
- Similar procedure can be used to split a line into two halves.

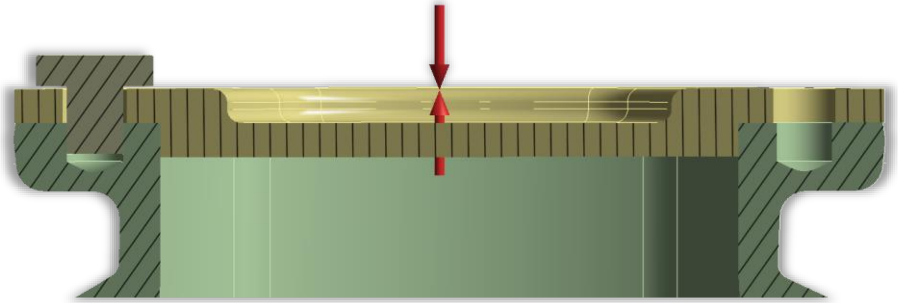


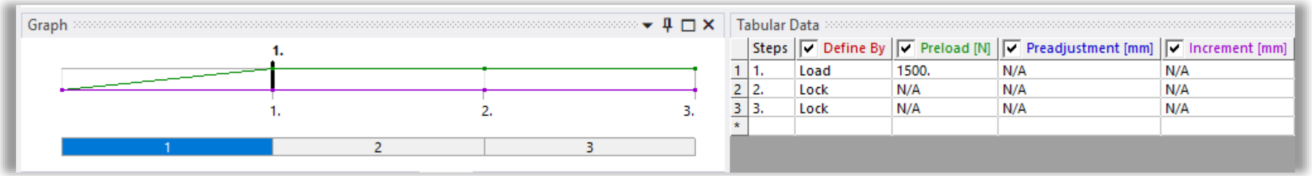
Defining Bolt Preload in Finite Element Simulations

- In real-life, a machine is first assembled, and then operational loads are applied on the machine. Simulations mimic real-life scenarios.
- Two important steps to define bolt preload in simulations: load and lock.
  - Load: Specify the tensile force developed in the bolt during its tightening.
  - Lock: Simulates complete tightening of the bolt before applying any external loads on the assembly.

Why is locking the bolts important?

- Once bolt pretension is applied to model tightening of bolts, the bolts need to be locked in all the subsequent steps in which the assembly is being loaded.
- In a real-world scenario, bolts in a machine assembly are always tightened completely before any external load is applied.
- If the bolts are not locked (and instead still set to load) prior to applying external loads the tensile force in the bolt will stay the same, and not change with applied loads, as it should.





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General observations about simulations with bolted joints

- Analysis consisting of preloaded bolted joints generally consist of multiple steps since we mimic the assembly first.
- Typically, we “load” the bolt in step 1, then “lock” the bolt in the subsequent steps. Applying bolt preload and operational loads in the same step will result in incorrect results.
- Simulations involving bolted joints often are treated as nonlinear simulations. There may be path-dependent effects, such as friction or metal plasticity, and the order of the loads may affect the final result. Thus, the Newton-Raphson method is often used for solving such nonlinear problems (see separate course “Methods of Solving Problems”).
- Usually, preloading all the bolts at once vs. applying preload to bolts in sequence are the same, but it’s possible to simulate the latter. In such cases, just apply a small (10% of final) preload to the untightened bolts in Step 1 so that the bolts do not separate from the rest of the structure.

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