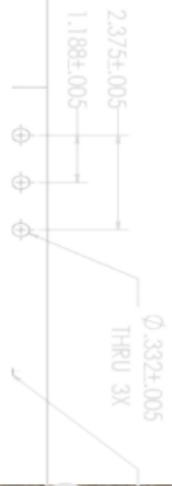


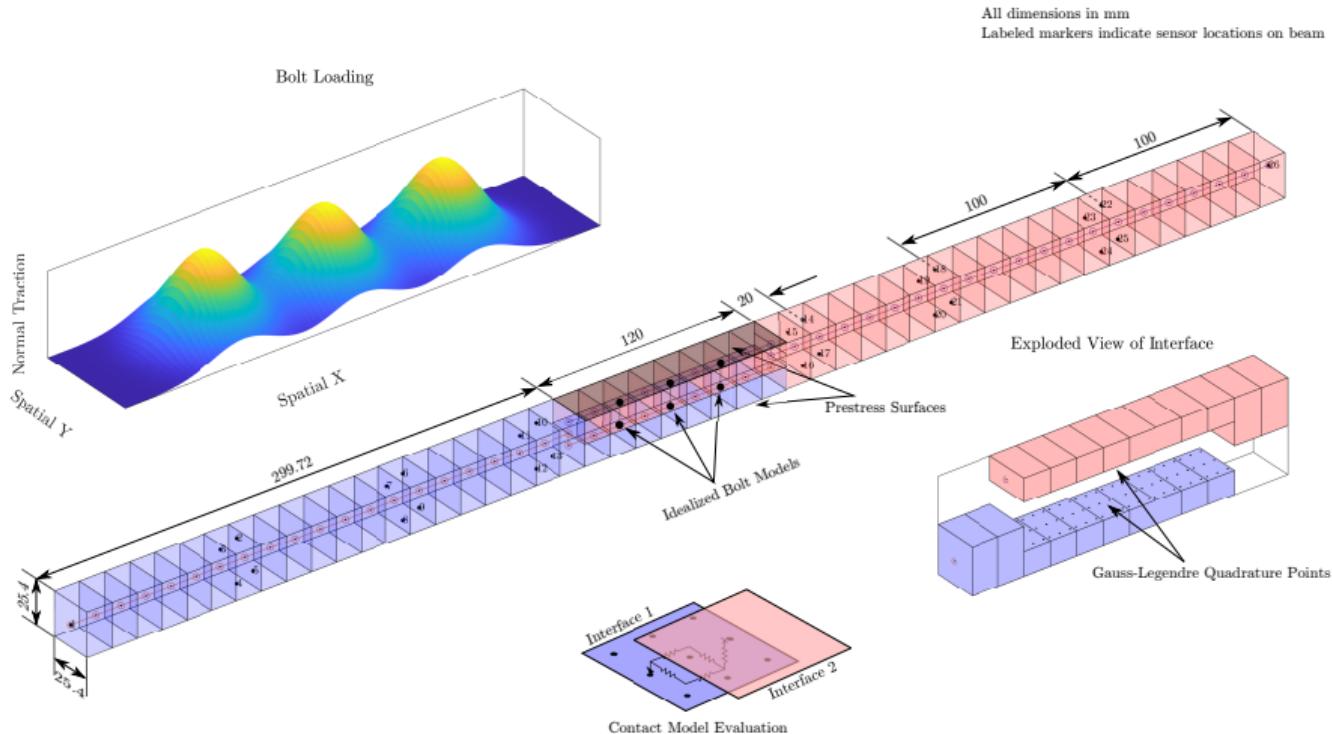
Description of Timoshenko Model of a Bolted System

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Overview



Numerical Description

Beam Models

- ▶ The model is a 3D Timoshenko finite element model discretized using C^0 shear elements (corrected for locking)
- ▶ See previous slide for the figure and dimensions
- ▶ The elastic properties are assumed to be:

Young's Modulus $E = 2 \times 10^{11} \text{ Pa}$

Density $\rho = 7800 \text{ Kgm}^{-3}$

Poisson's Ratio $\nu = 0.3$

Shear correction factor $\kappa = \frac{10(1+\nu)}{12+11\nu}$ (from Cowper (1966) for rectangular sections)

- ▶ The model is constructed with 8 elements in the "interface" region and 20 elements in the "far-field" region



Numerical Description

Bolt Idealization

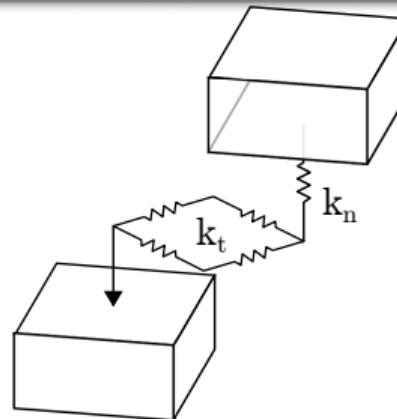
- ▶ Each bolt is built using a single Timoshenko beam element that connects the two beams in the locations indicated
- ▶ The shear terms in these elements are set to zero in order to ensure that attaching this does not violate any assumptions of the Timoshenko beam model
- ▶ The bolt therefore has axial stiffness and bending stiffness (no shear)
- ▶ The bolts are modeled as cylinders with diameter 8.42mm and length 25.4mm (one inch) with the same material properties as before
- ▶ In addition to the above, discrete masses are added to the bolt nodes in such a manner that the total mass of each bolt-nut-washer assembly is 28.64g .
- ▶ Additionally, an axial stiffness of $1.2041 \times 10^9 \text{Nm}^{-1}$ is added between the bolt nodes in the bolt-axial direction



Numerical Description

Contact Model

- ▶ A 3D elastic dry friction model, implemented at the “traction-level”, is employed for this study



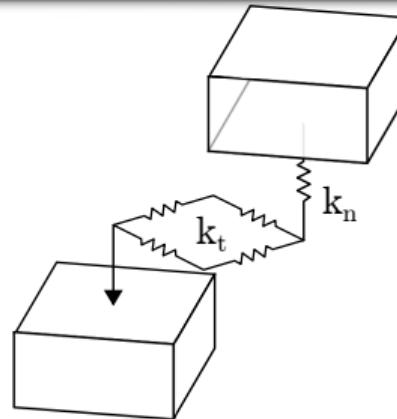
- ▶ The normal traction law is given as,

$$t_n = \begin{cases} k_n \delta u_n & \delta u_n > 0 \quad (\text{contact}) \\ 0 & \text{otherwise} \quad (\text{separation}) \end{cases}$$

Numerical Description

Contact Model

- ▶ A 3D elastic dry friction model, implemented at the “traction-level”, is employed for this study



- ▶ The incremental tangential traction law in x is given as,

$$\Delta t_t^x = \begin{cases} k_t \Delta \delta u_t^x & \text{stick} \\ 0 & \text{slip} \\ -t_{t0}^x & \text{separation} \end{cases}$$

Numerical Description

Contact Model

- ▶ A 3D elastic dry friction model, implemented at the “traction-level”, is employed for this study
- ▶ As already mentioned, this is implemented at the traction level
- ▶ As shown in the figure, this contact law is evaluated between pairs of quadrature points on the interface
- ▶ The tractions evaluated at the quadrature locations are used to obtain nodal forces and moments through numerical integration (2D Gauss Legendre quadrature points used)

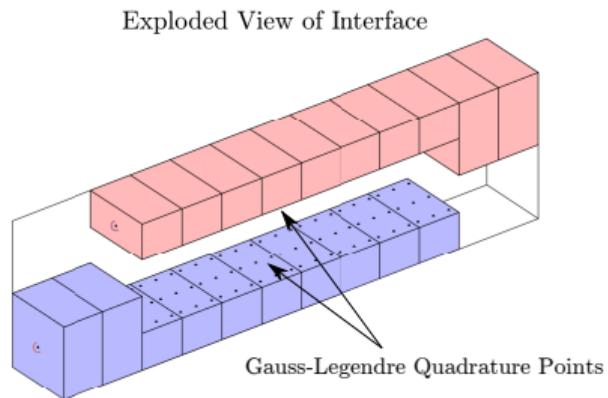


Figure: Interface implementation Schematic