FINITE ELEMENT MODELING OF A BOLTED JOINT: PRETENSION, CONTACT, AND FAILURE

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KeyWords

ANSYS, bolt pretension, bolt yielding, contact pressure, finite element analysis, joint separation, thread stripping

ABSTRACT

The design study was conducted in ANSYS 2025R2 for assessment of pretension, contact and failure of a bolted plate bracket and pin assembly. The analysis was performed using two load steps. In the first step, bolt pretension was applied to the bolt shank based on the calculated pretension force derived from the bolt's tensile stress area and proof load. In the second step, the pretension was locked, and an external force of 25 kN was applied to the pin face in the Z-direction to simulate service loading conditions. The application of bolt pretension resulted in a uniform clamping action between the bracket and the plate. The bolt experienced an increase in axial tensile stress due to load transfer from the external force. Despite this redistribution, the contact status plot indicated no complete contact loss, confirming that joint separation did not occur at 25kN. The variation of bolt working load with increasing external force is presented for load levels of 30 kN, 35 kN, 40 kN, and the separating load case. The results obtained from both the finite element simulation and the analytical hand calculations demonstrate that the selected bolt operates well within safe limits under the applied external load of 6 kN..

Objectives

To evaluate the influence of bolt pretension on load transfer mechanisms and contact pressure distribution within the joint.

To examine joint separation and contact loss behavior under progressively increasing external loads.

To analyze bolt axial force response and stress distribution using finite element analysis (FEA).

To develop engineering insight for the safe and reliable design of bolted joints.

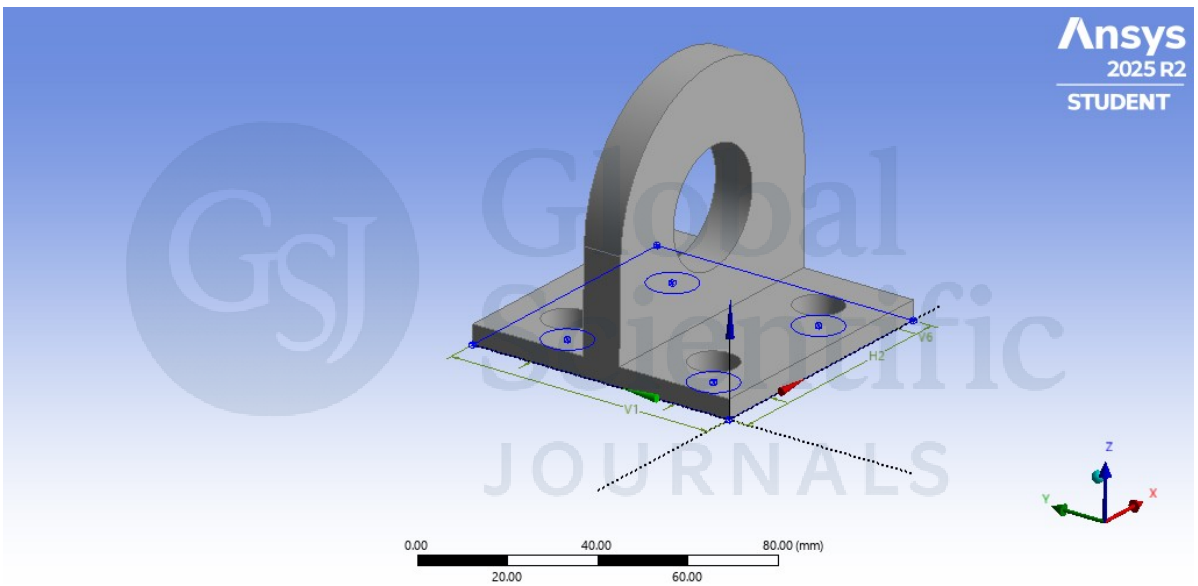
Task-1 Base line model

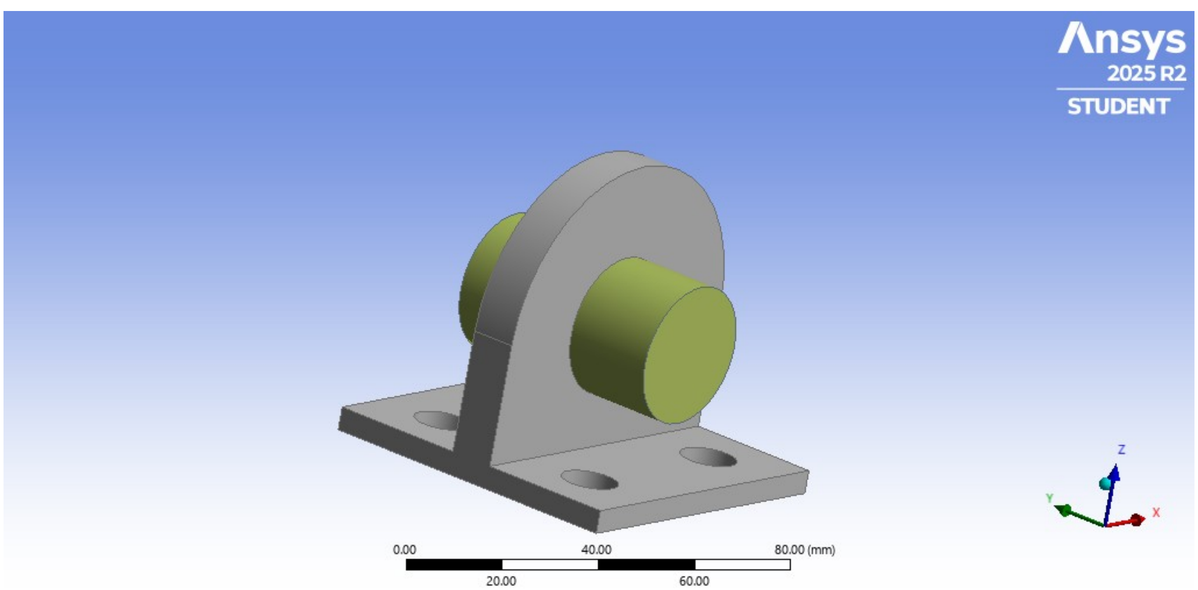
Methodology

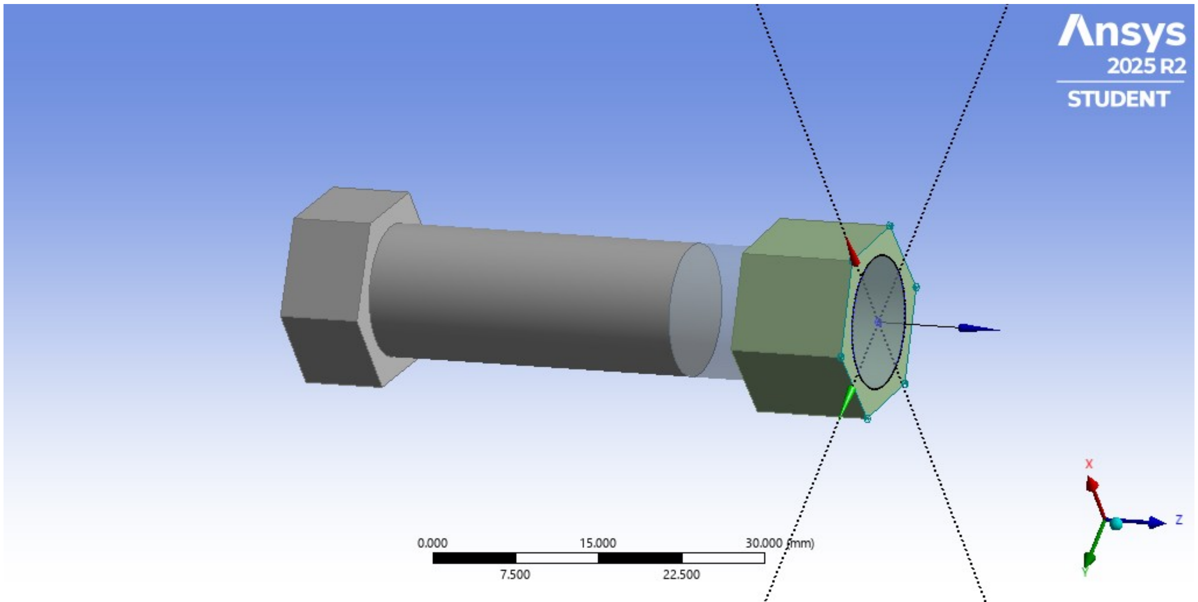
The design study was conducted in ANSYS 2025R2 for assessment of pretention, contact and failure of a bolted plate bracket and pin assembly. Below is the detailed mythology adopted for each step.

1. Geometry Modeling

A three-dimensional solid model of the bolted bracket assembly was created in ANSYS Workbench. The assembly consisted of a plate, bracket, pin, bolt, and nut, following the provided dimensions and geometry specifications. Symmetry was utilized to reduce computational cost, and the appropriate symmetry planes were defined during model setup.



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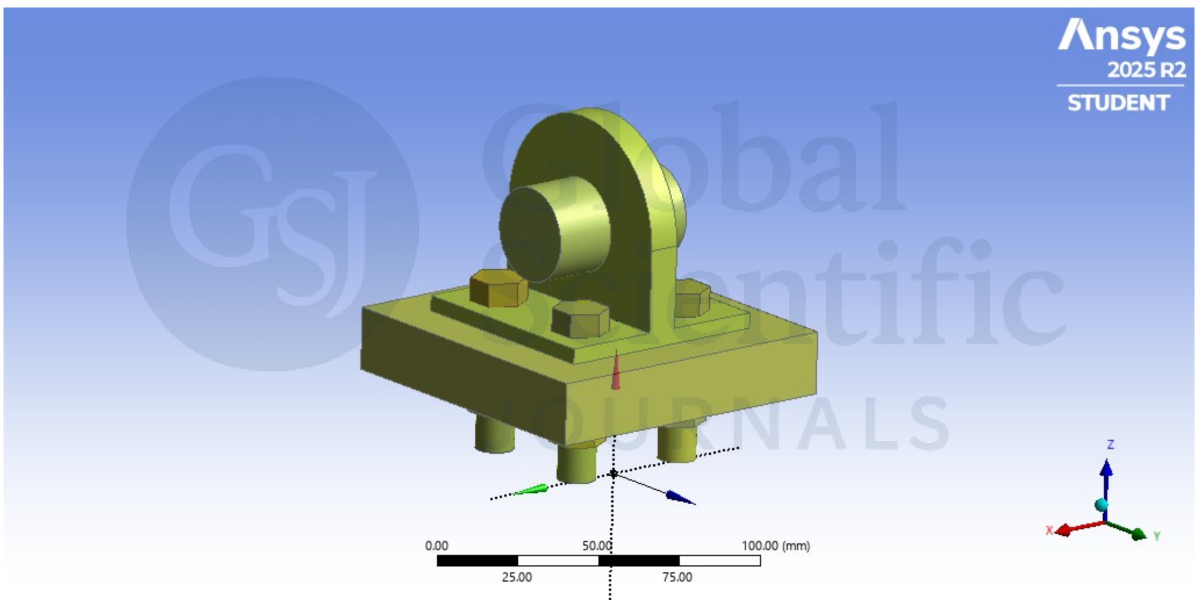
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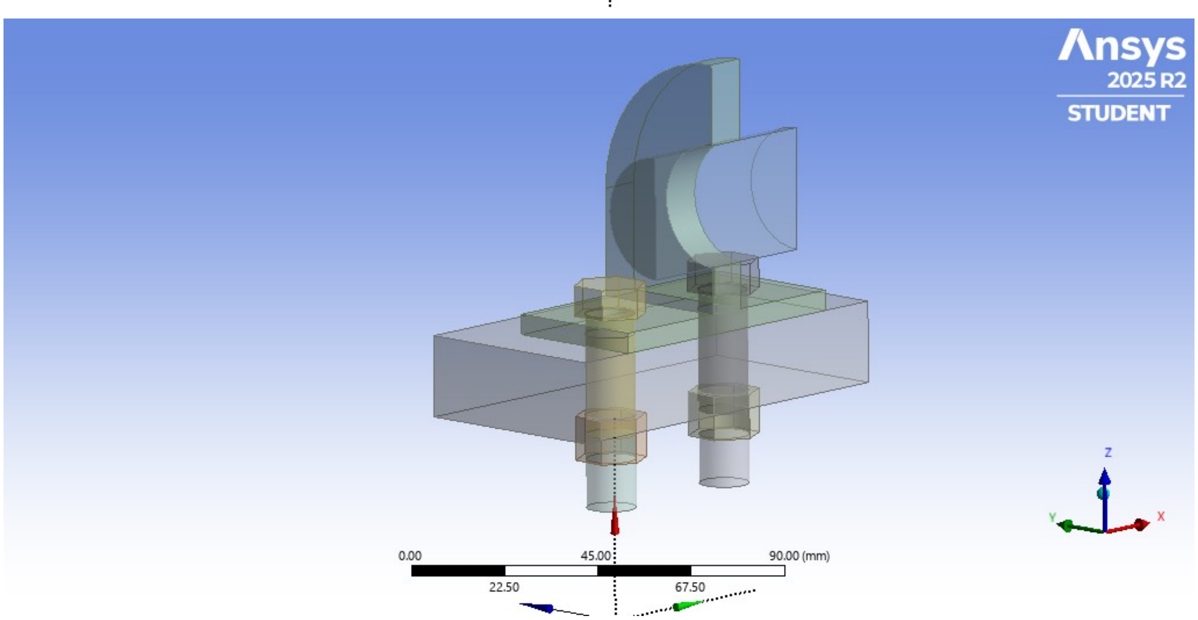
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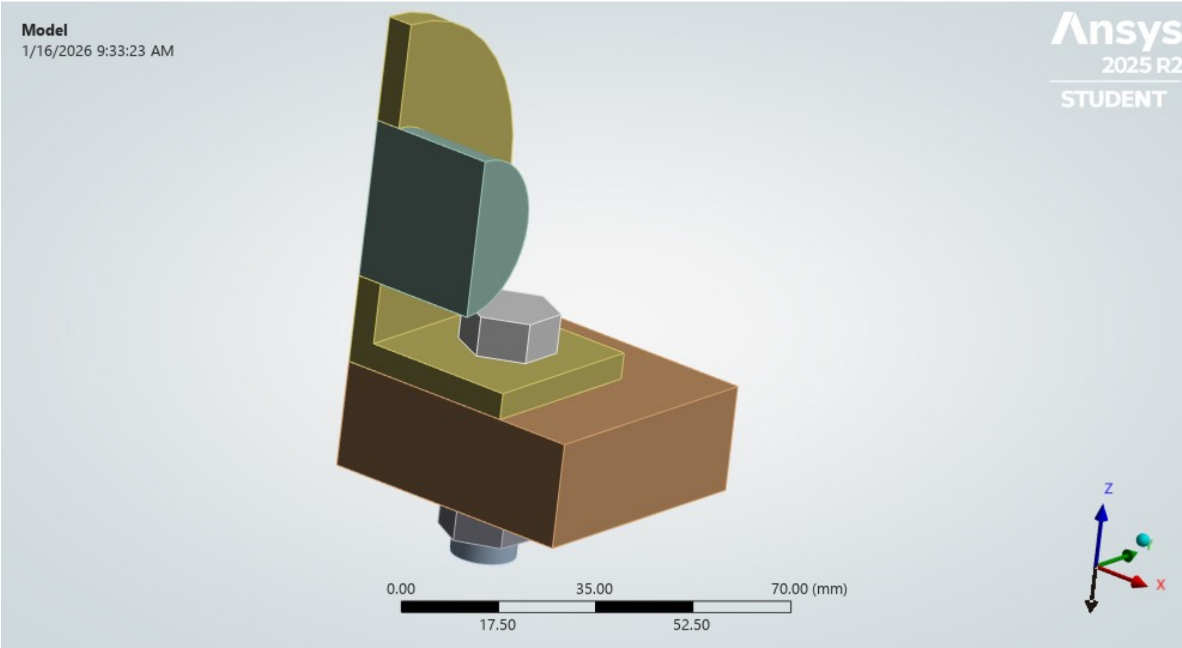
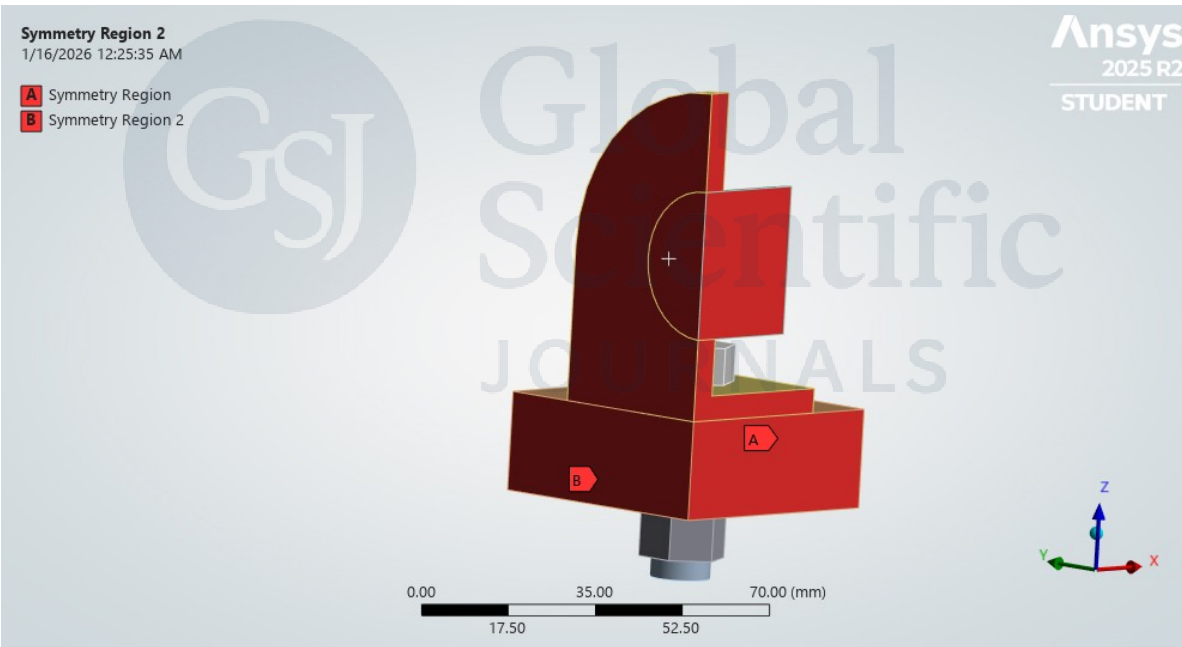
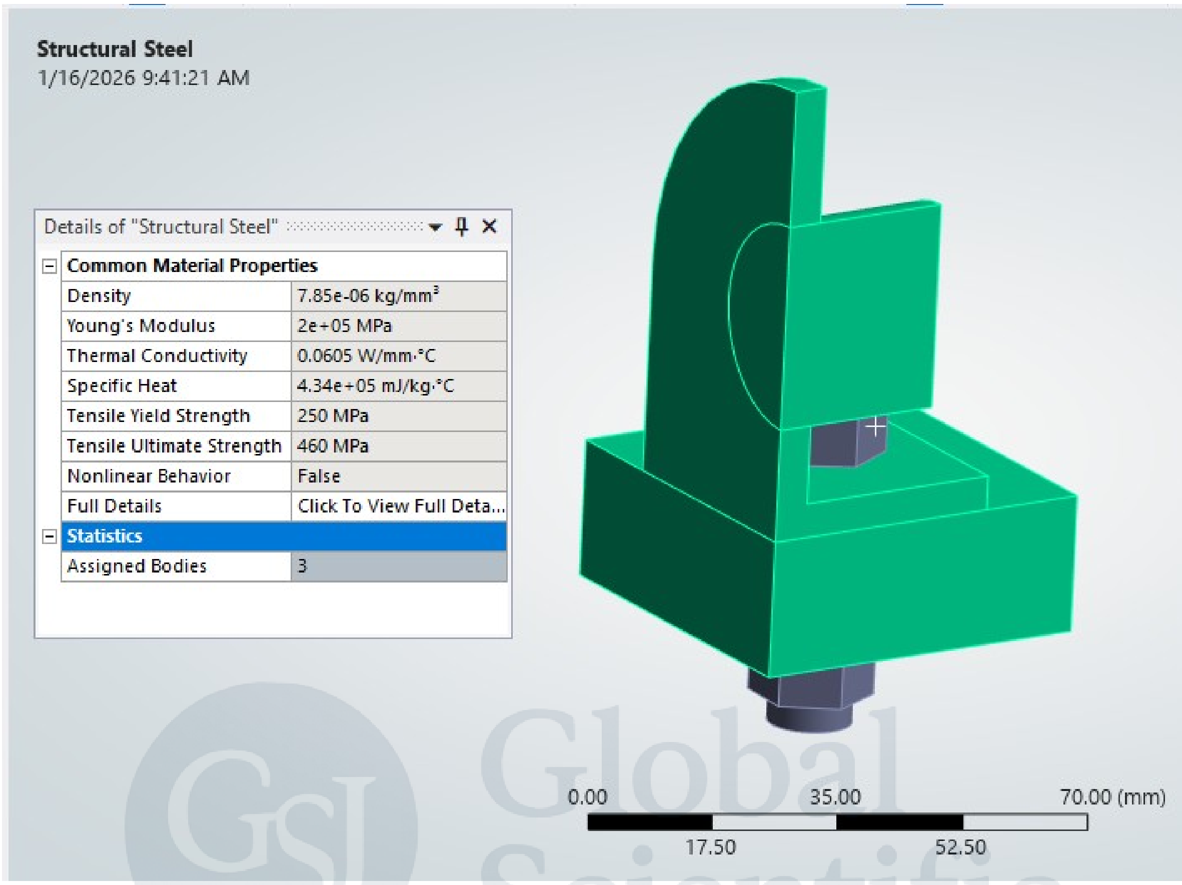
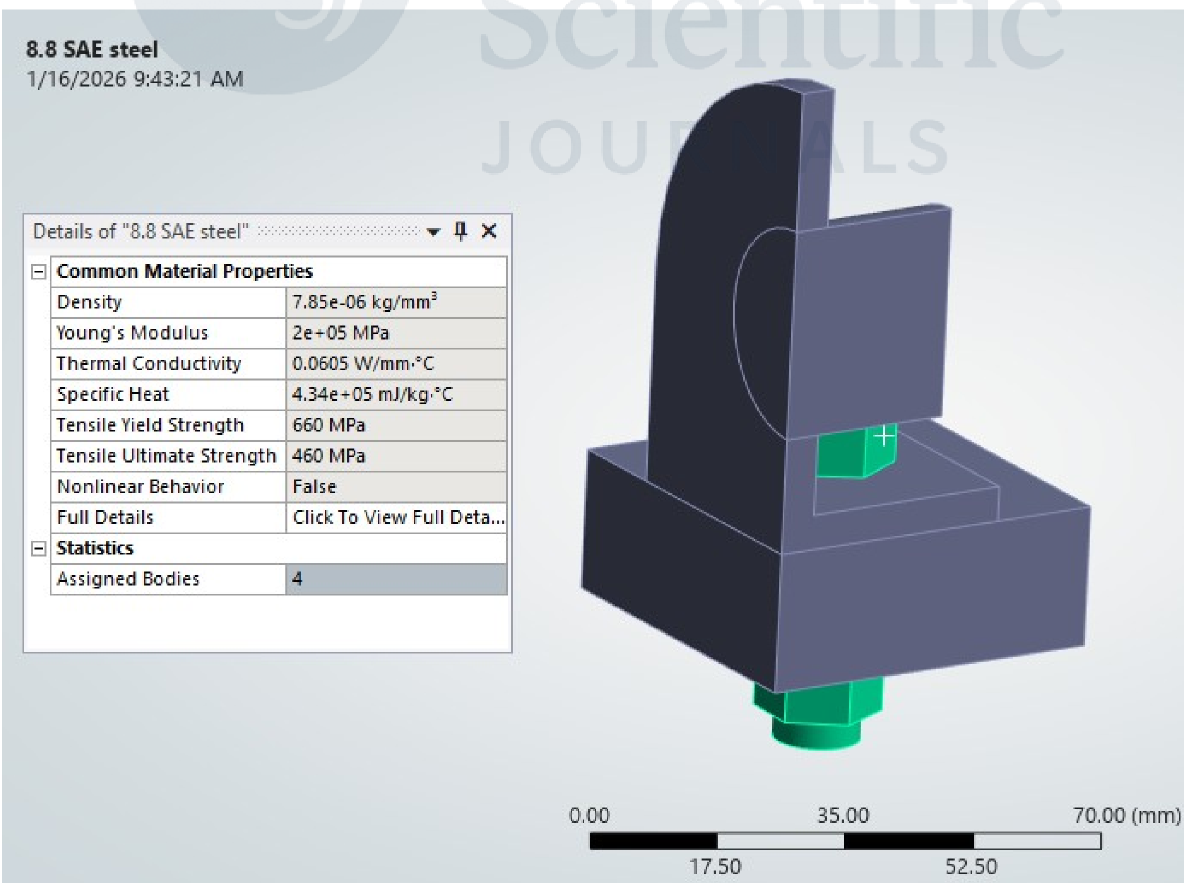




2. Material Assignment

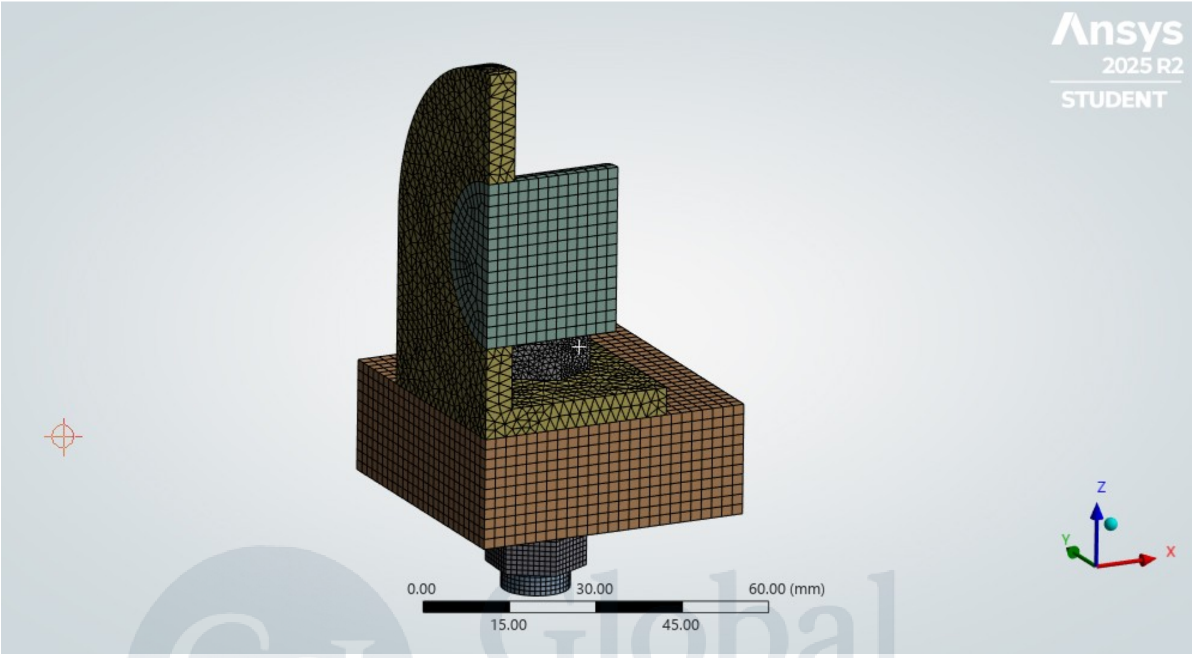
Linear elastic material properties were assigned to all components. Structural Steel was applied to the plate, bracket, and pin, while 8.8 SAE Class Steel was assigned to the bolt and nut. All materials were assumed to be homogeneous, isotropic, and linearly elastic throughout the analysis.





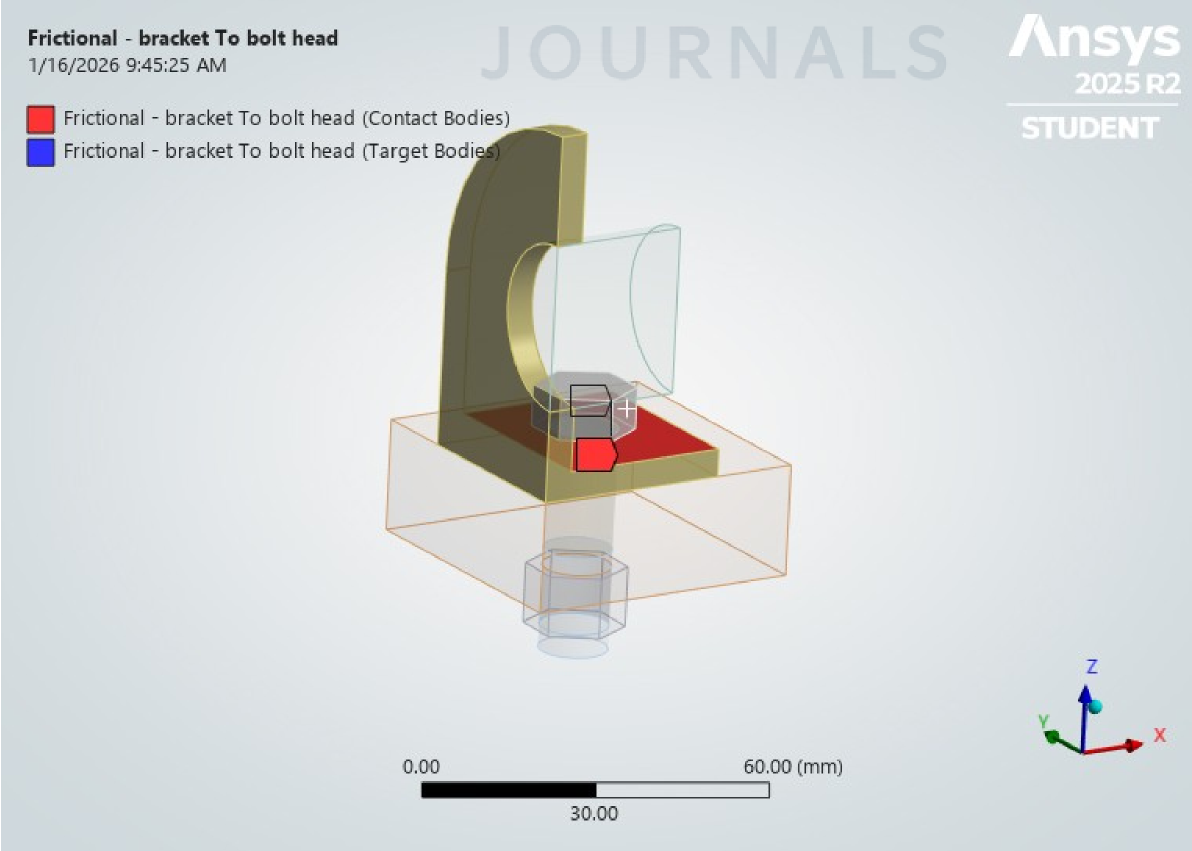
3. Meshing Strategy

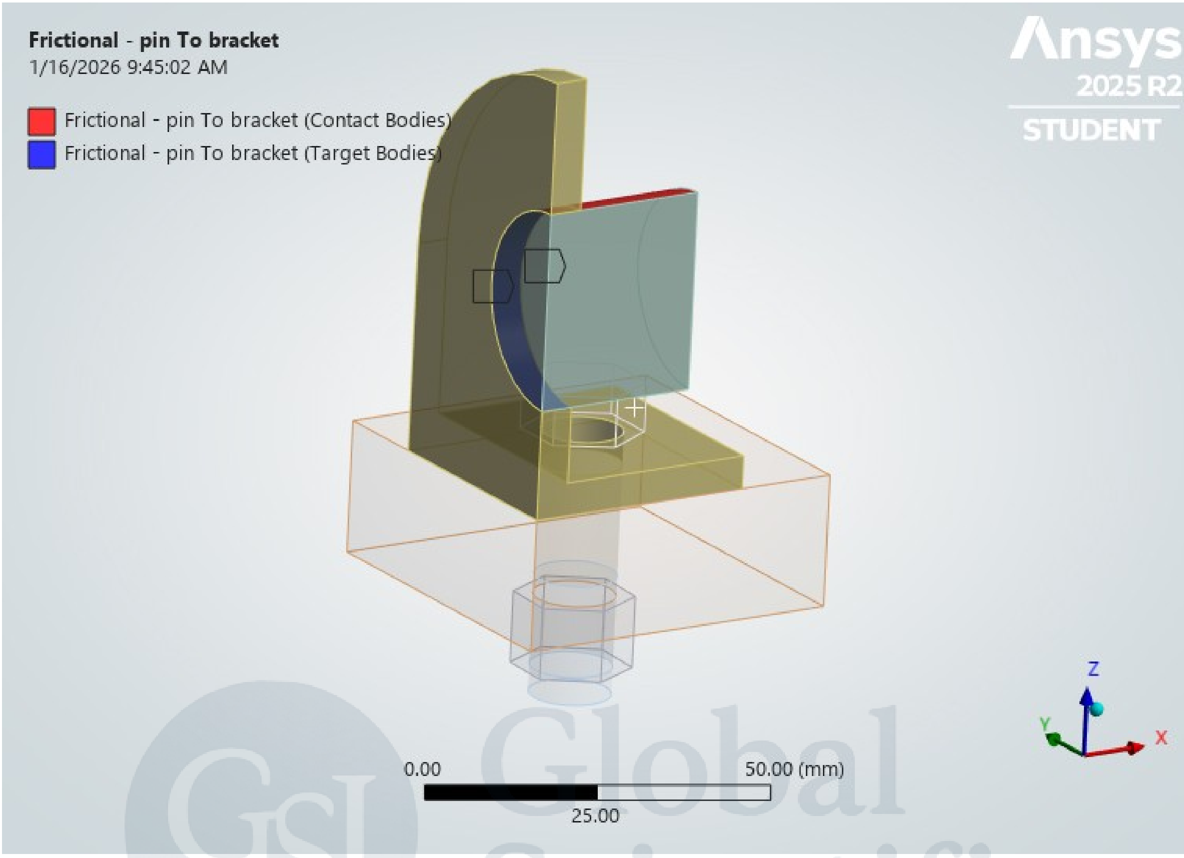
The geometry was discretized using a structured finite element mesh. Body sizing controls were applied to ensure mesh accuracy in critical regions. An element size of 1 mm was used for the bolt and nut to capture stress gradients accurately, while an element size of 2 mm was assigned to the plate, bracket, and pin. Mesh quality was verified to ensure acceptable element aspect ratios and convergence behavior.



4. Contact Definitions

Contact interactions between components were defined based on physical behavior. Bonded contacts were assigned between the nut and plate, bolt head and bolt shank, nut and lower bolt shank, nut and bolt shank, and between the lower bolt shank and bolt shank. Frictional contacts with a coefficient of friction of 0.2 were applied between the bolt head and bracket, plate and bracket, and pin and bracket. All remaining contacts were suppressed to avoid unintended load transfer.

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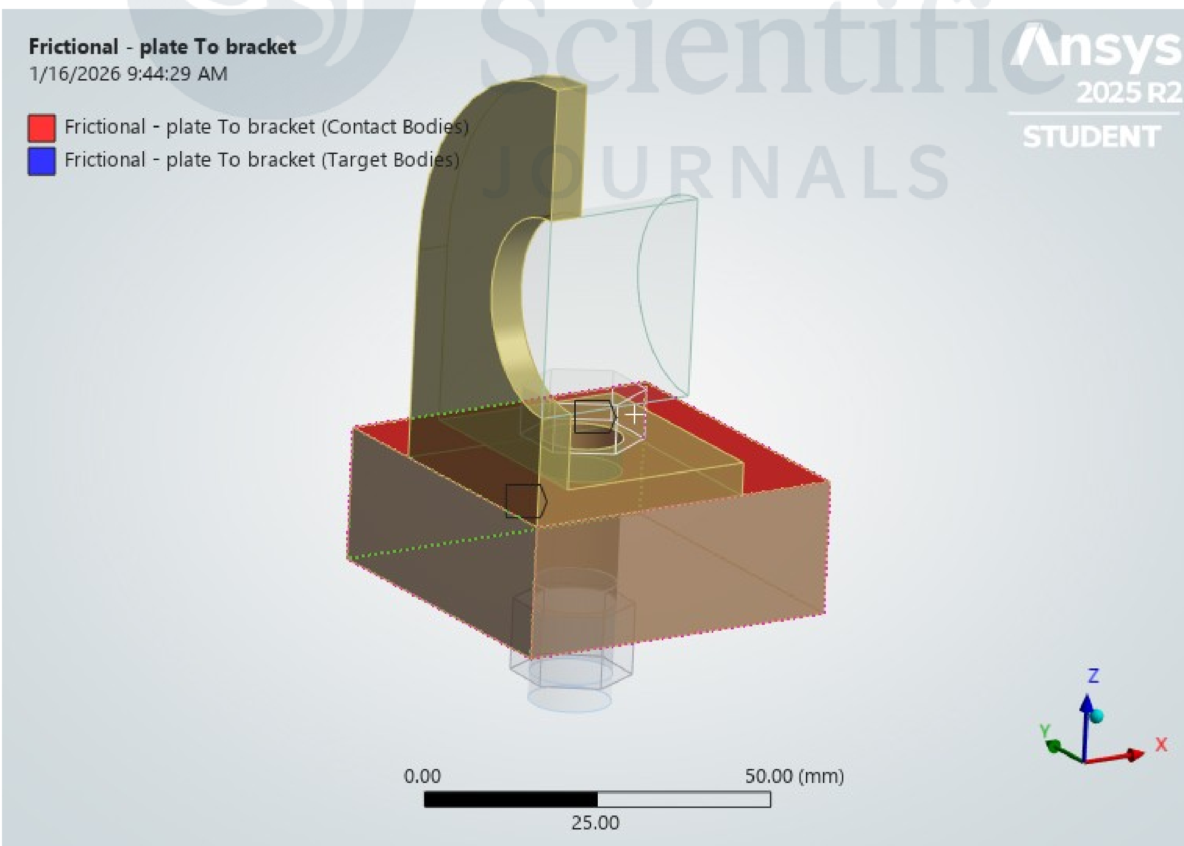
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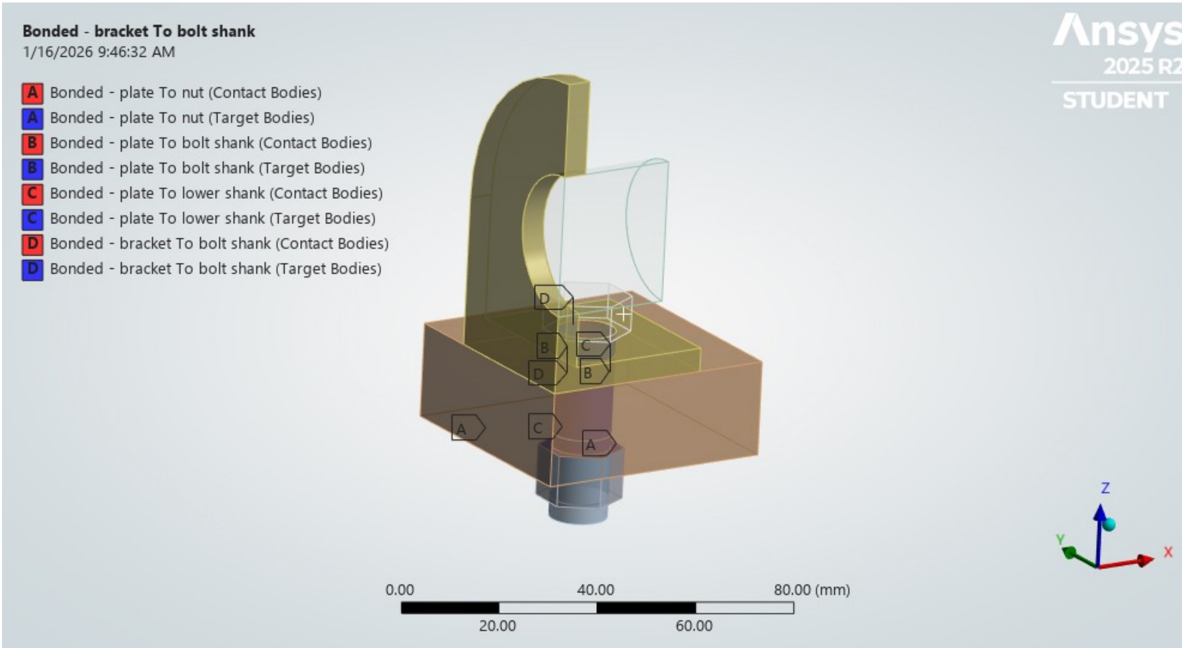
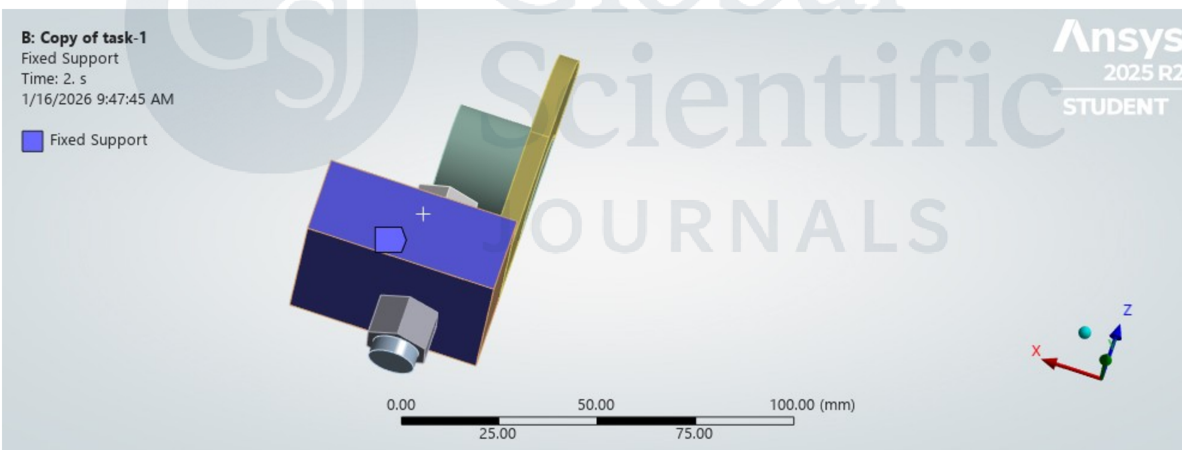
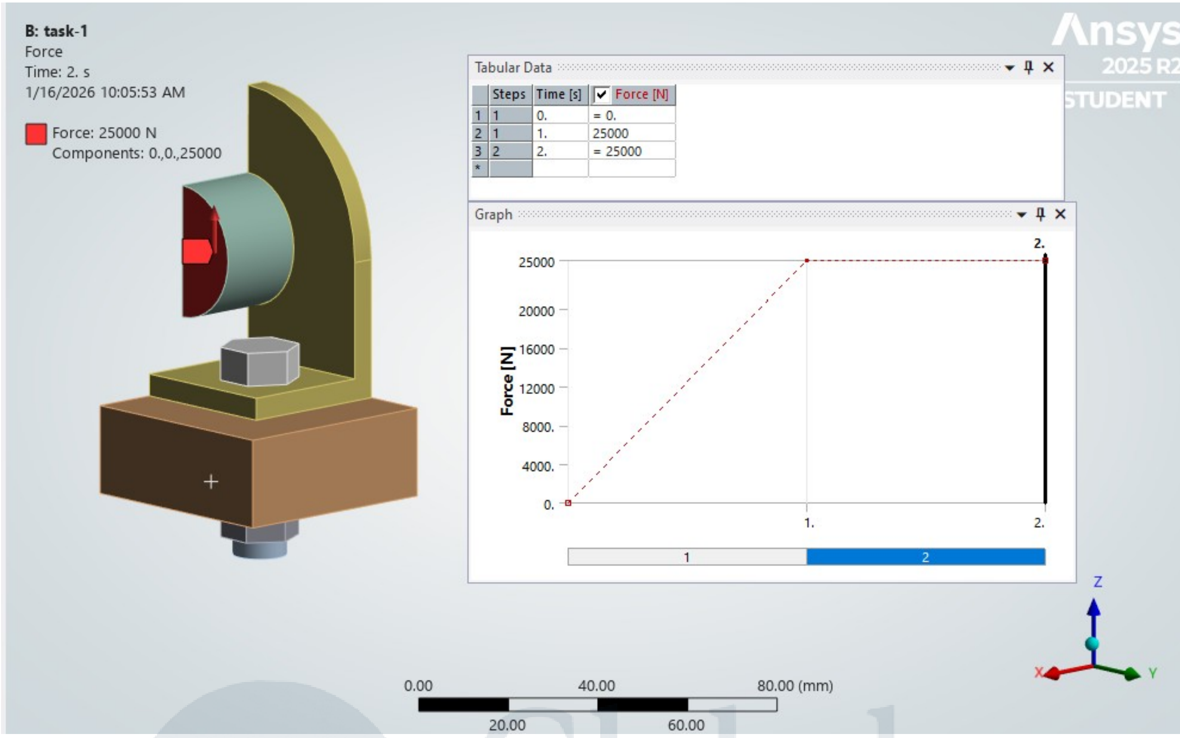


5. Boundary Conditions

Symmetry boundary conditions were applied by constraining displacement normal to the defined symmetry planes. All outer faces of the plate, excluding the symmetry faces, were fully fixed to prevent rigid body motion. These constraints ensured structural stability while maintaining realistic deformation behavior.



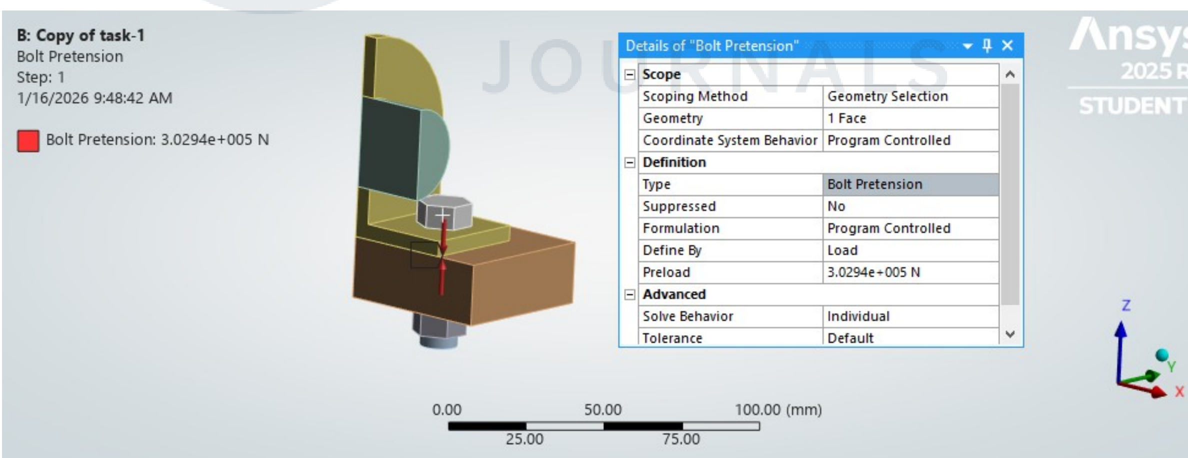


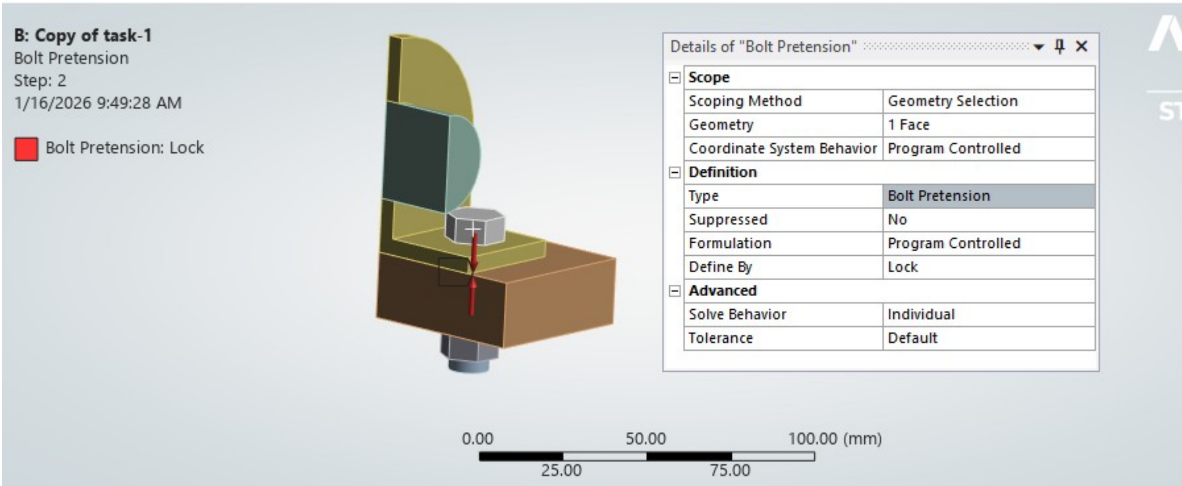
6. Bolt Pretension and Loading Procedure

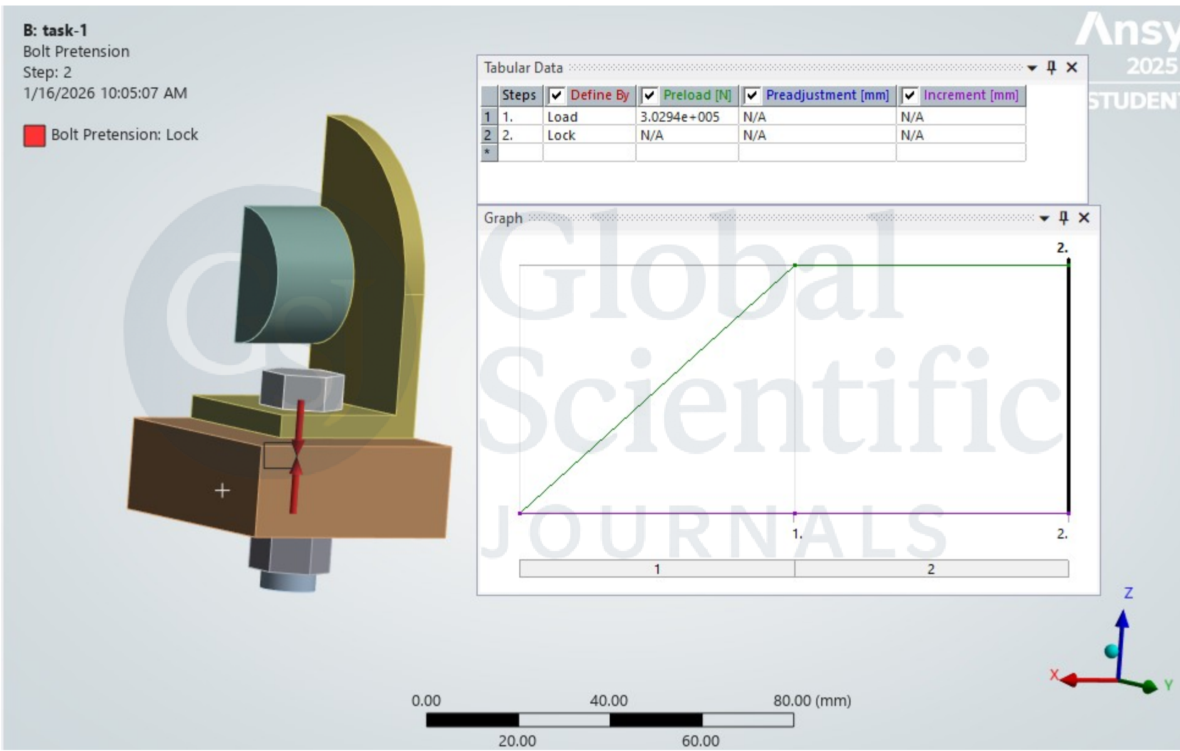
The analysis was performed using two load steps. In the first step, bolt pretension was applied to the bolt shank based on the calculated pretension force derived from the bolt's tensile stress area and proof load. In the second step, the pretension was locked, and an external force of 25 kN was applied to the pin face in the Z-direction to simulate service loading conditions.

Bolted pretension preload was found as

From table 10.2 and 10.5





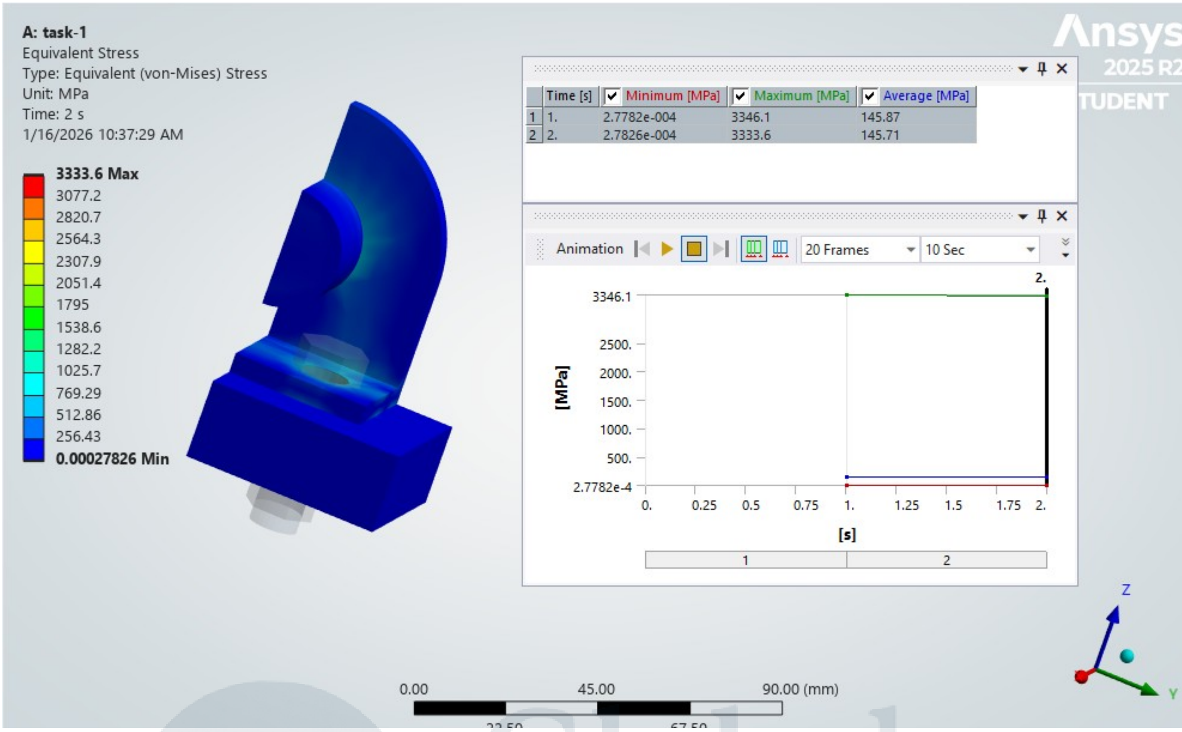


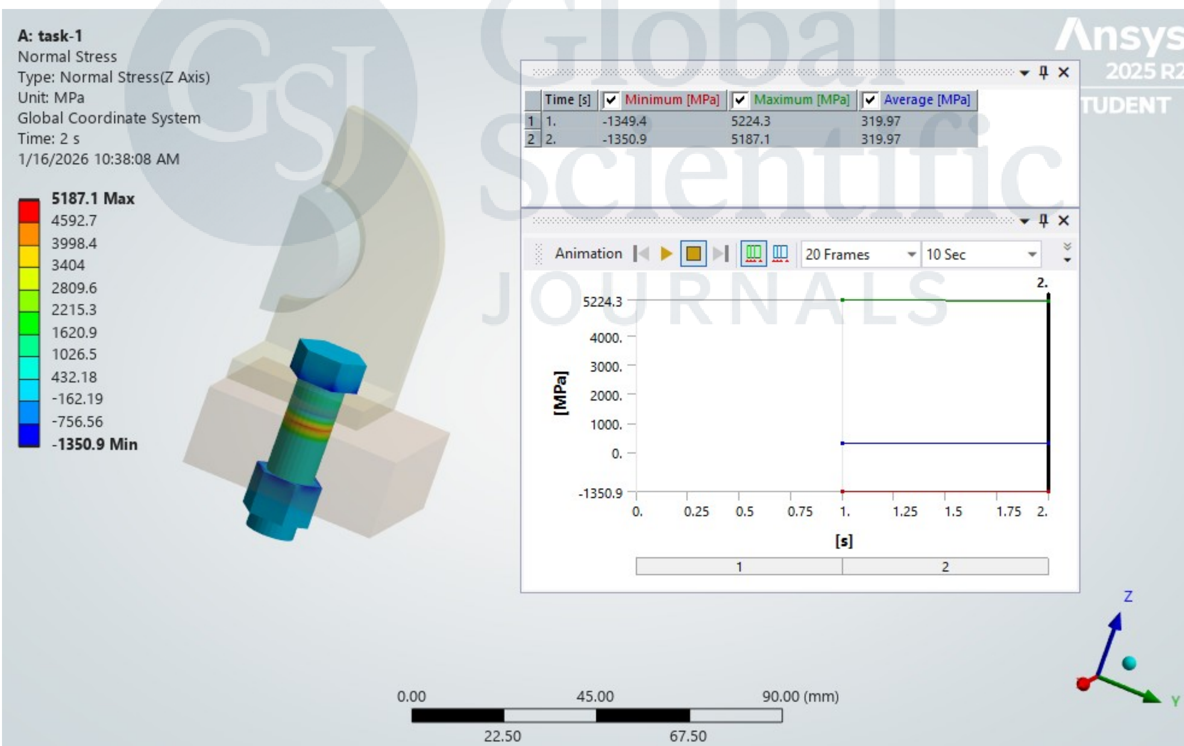
7. Solution and post-processing

The model was solved using the ANSYS Mechanical static structural solver. Post-processing was performed for both load steps to evaluate von Mises stress in the bracket, plate, and pin, normal stress in the bolt, contact pressure and contact status on the bracket's lower face, and the bolt working load. Maximum and minimum values were probed, and results were analyzed to assess load transfer behavior and joint integrity [4]. [4], [5].

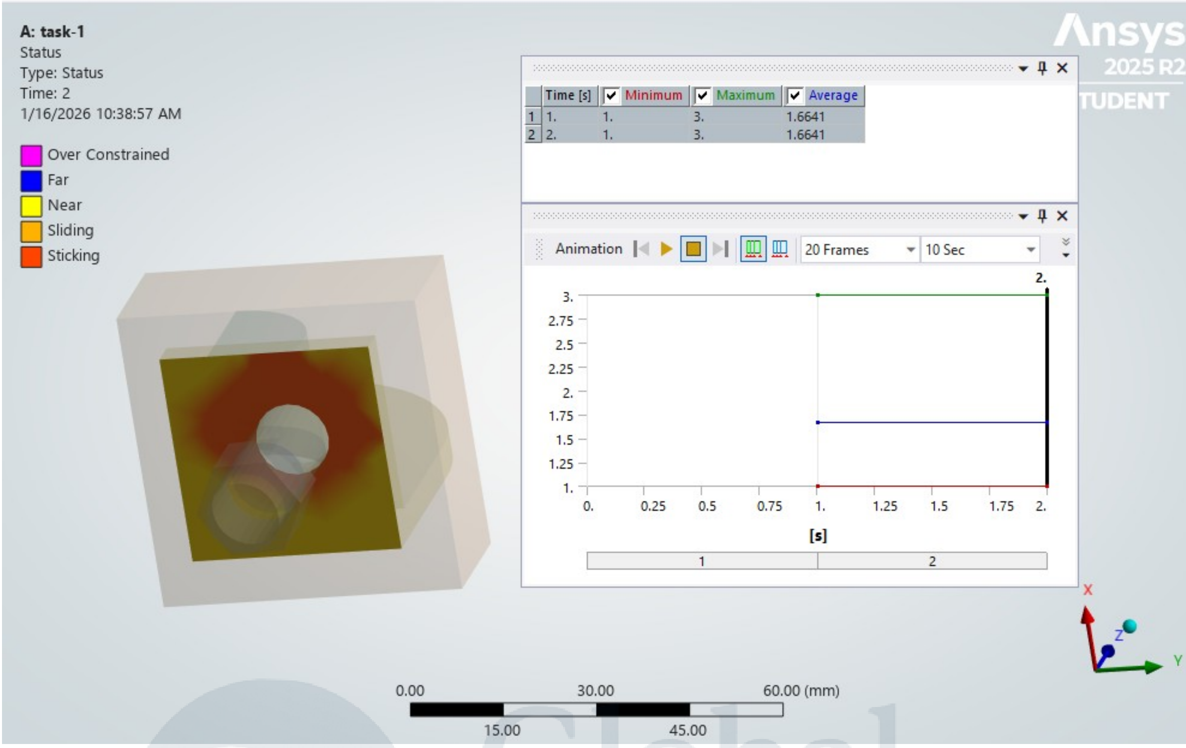
Results

The application of bolt pretension resulted in a uniform clamping action between the bracket and the plate. The von Mises stress contours of the bracket, plate, and pin showed low stress levels throughout the components, with localized stress concentrations observed near the bolt hole edges and contact interfaces. These stress concentrations are attributed to geometric discontinuities and localized compressive loading induced by the bolt preload. The normal stress distribution along the bolt indicated dominant axial tensile stress, with the maximum stress occurring at the bolt shank near the first engaged thread. This behavior is consistent with classical bolted joint theory, where pretension generates a tensile load in the bolt while inducing compressive contact pressure between the clamped parts. [1], [3].





The bolt experienced an increase in axial tensile stress due to load transfer from the external force. The normal stress distribution showed a moderate rise compared to Step 1, demonstrating that only a fraction of the applied external load was transferred to the bolt, while the remainder was carried by the clamped members through contact pressure. This result aligns with the fundamental principle that pretensioned bolts reduce direct load transfer to the bolt by increasing joint stiffness. The contact pressure on the bracket's lower face became non-uniform after the external load was applied. Higher contact pressures were observed near the bolt region, while reduced pressure appeared on the side opposing the load direction. Despite this redistribution, the contact status plot indicated no complete contact loss, confirming that joint separation did not occur at 25kN. This suggests that the pretension level was adequate to prevent separation under the applied service load.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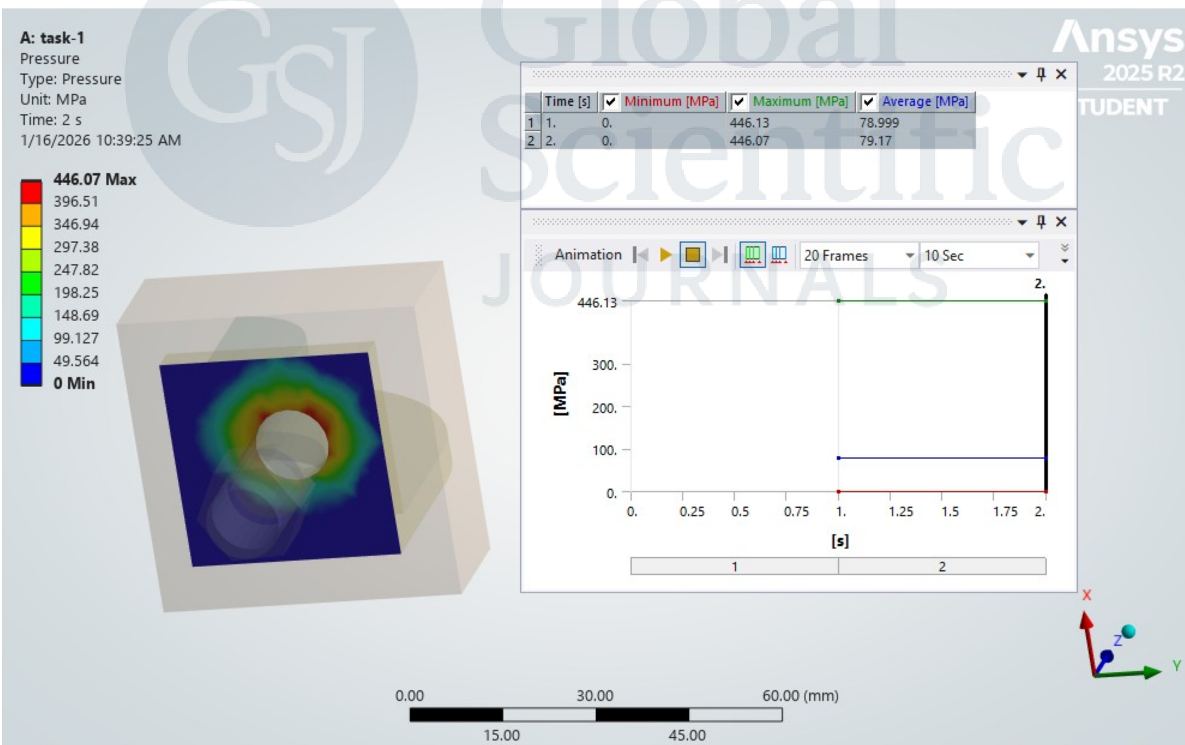
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2 | 2. | 0. | 446.07 | 79.17
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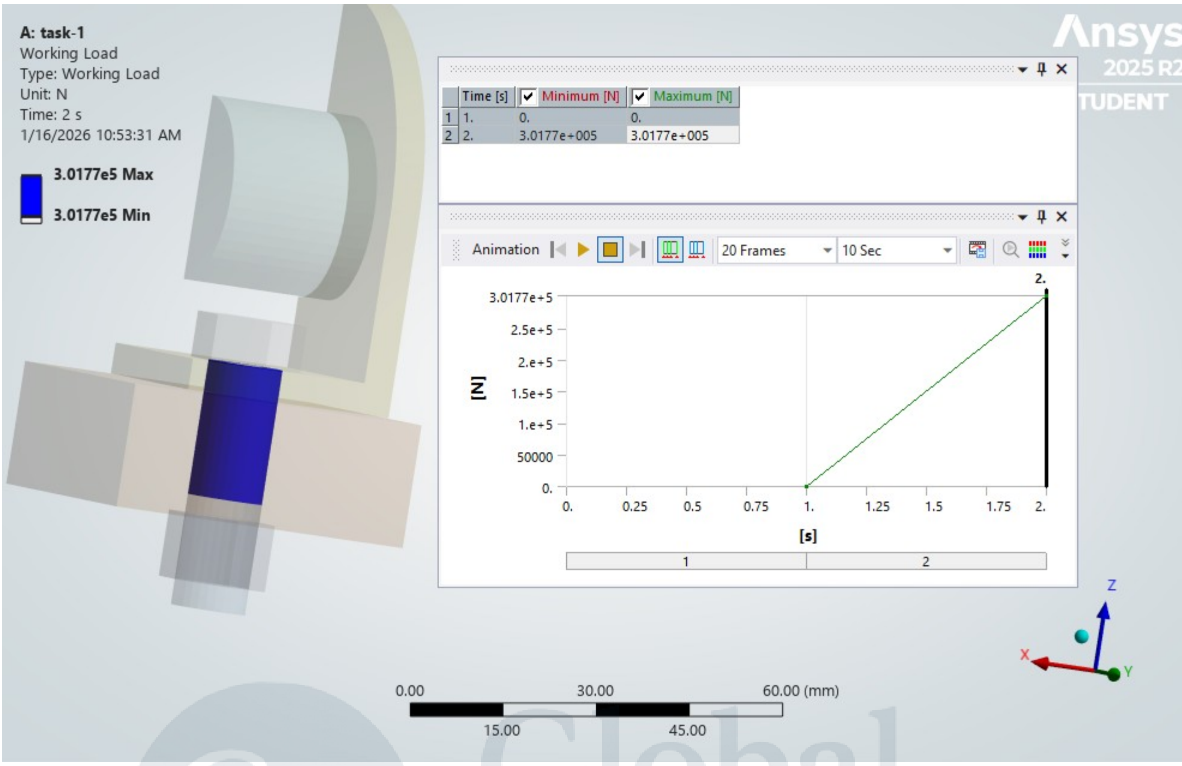


Discussion/Comparison with Literature

The contact pressure on the lower face of the bracket was continuous and uniformly distributed around the bolt hole, confirming full contact between the mating surfaces. No contact separation was observed in this step, indicating that the pretension level was sufficient to maintain joint integrity in the absence of external loading. The bolt working load obtained in this step was equal to the applied pretension force, confirming correct implementation of the pretension feature in the finite element model. Upon locking the pretension and applying a 25 kN external force to the pin, a noticeable redistribution of stresses and contact pressure occurred. The von Mises stress in the bracket and plate increased, particularly near the load application region and the contact interfaces. However, the maximum stress values remained below the yield strength of Structural Steel, indicating elastic behavior of the joint components under the applied load.

The bolt working load increased slightly compared to the pretension-only case, but the increment was significantly lower than the applied external force. This behavior confirms effective load sharing between the bolt and the joint members, which is a key design objective in safe bolted-joint configurations.

TASK-2 Effect of Increasing Force

Methodology

The same three-dimensional bolted bracket geometry developed in Task #1 was used to maintain consistency across all simulations.

Structural Steel was assigned to the plate, bracket, and pin, while 8.8 SAE Class Steel was assigned to the bolt and nut, assuming linear elastic and isotropic material behavior.

The finite element mesh from Task #1 was retained, with body sizing of 1 mm for the bolt and nut and 2 mm for the plate, bracket, and pin.

All contact definitions and boundary conditions were kept identical to the baseline model, including bonded and frictional contacts with a friction coefficient of 0.2.

Symmetry boundary conditions were applied by constraining displacement normal to the symmetry planes, and all outer faces of the plate (excluding symmetry faces) were fixed.

The bolt pretension value obtained in Task #1 was applied to the bolt shank in load step 1 and locked in load step 2.

External forces of 30 kN, 35 kN, and 40 kN were applied to the pin face in the Z-direction after locking pretension, representing increasing service loads.

A separating load case was analyzed by applying the force in the opposite Z-direction to induce joint separation and contact loss.

Each case was solved separately for applied load

Results and Discussion

Bolt Working Load

The variation of bolt working load with increasing external force is presented for load levels of 30 kN, 35 kN, 40 kN, and the separating load case. As the applied force increased, the bolt working load exhibited a monotonic rise. However, the increase in bolt force was significantly smaller than the applied external force for the non-separating cases, indicating effective load sharing between the bolt and the clamped members. For applied forces of 30 kN and 35 kN, the increase in bolt working load was moderate, demonstrating that the pretensioned joint was able to sustain additional loading primarily through compressive contact between the bracket and plate. This behavior confirms that the majority of the external load was transferred through the joint interface rather than directly through the bolt. At 40 kN, a more pronounced increase in bolt working load was observed. This indicates a reduction in joint stiffness due to partial loss of contact pressure, resulting in a higher proportion of the applied load being carried by the bolt. Nevertheless, complete joint separation did not occur in this case, and the bolt force remained within elastic limits. Under the separating load condition, the bolt working load increased sharply compared to the compressive load cases. This response confirms that once contact separation initiates, the external load is primarily transferred to the bolt, significantly increasing its axial force. This behavior is consistent with classical bolted-joint mechanics. [1], [3].

Contact Pressure on Bracket Lower Face

The average contact pressure on the lower face of the bracket decreased progressively with increasing applied force. At 30 kN, the contact pressure remained relatively uniform and continuous, indicating full contact between the bracket and plate. This confirms that the pretension level was sufficient to prevent separation under moderate external loading. At 35 kN, a reduction in average contact pressure was observed, accompanied by localized regions of lower pressure near the edge opposite the load application direction. This behavior suggests the onset of non-uniform contact pressure distribution due to increased bending effects in the joint. For the 40 kN load case, the average contact pressure decreased further, and localized regions of near-zero pressure appeared. These regions indicate partial contact loss, although full separation was not observed. This transition marks a critical loading level where the joint begins to lose its ability to transfer load through frictional contact alone.

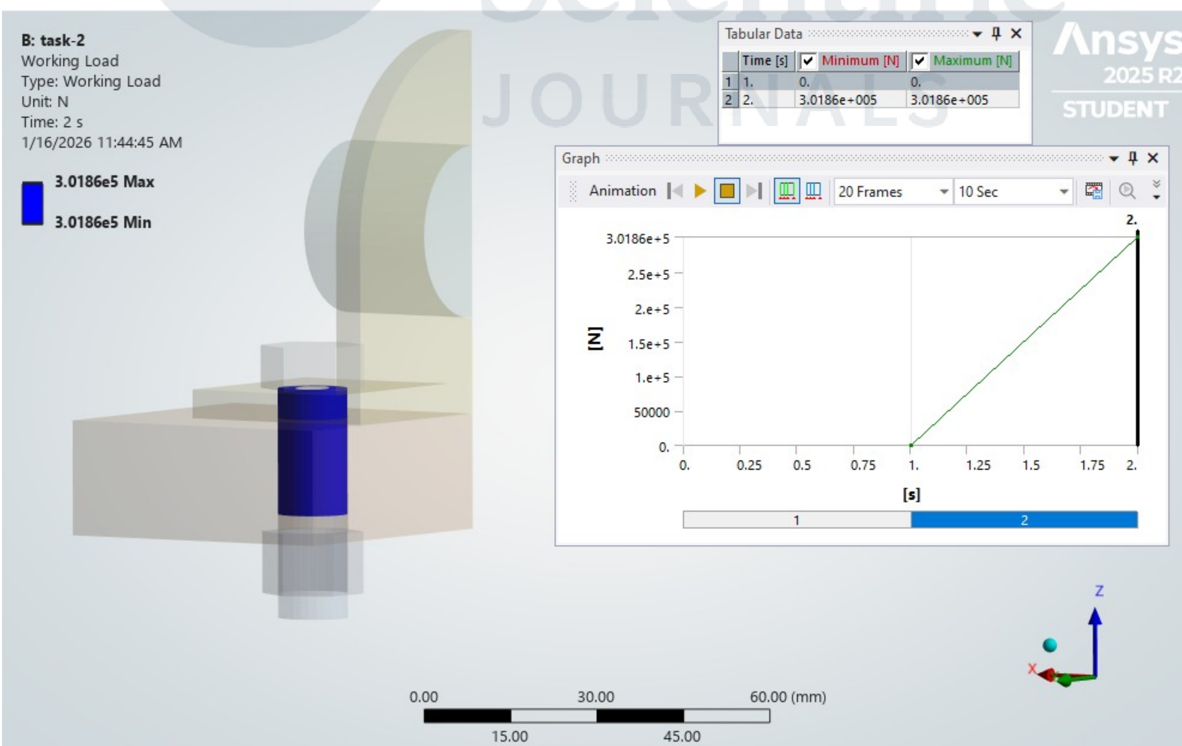


Figure 1 Bolt working load at 30 KN load

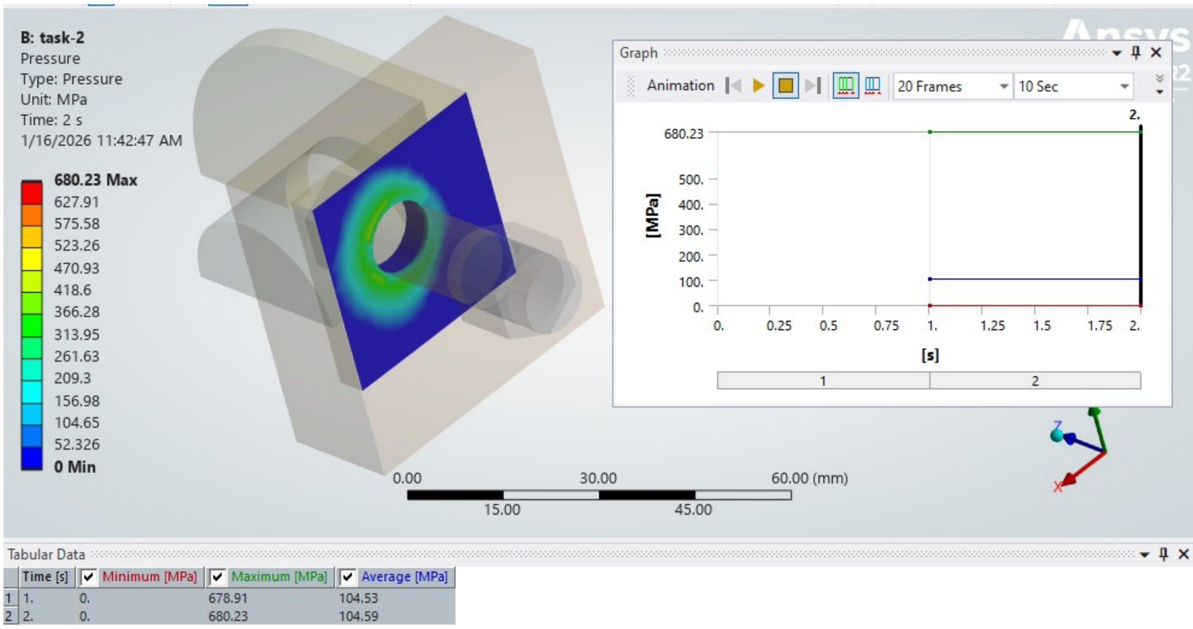


Figure 2 Contact pressure on bracket lower face at 30KN

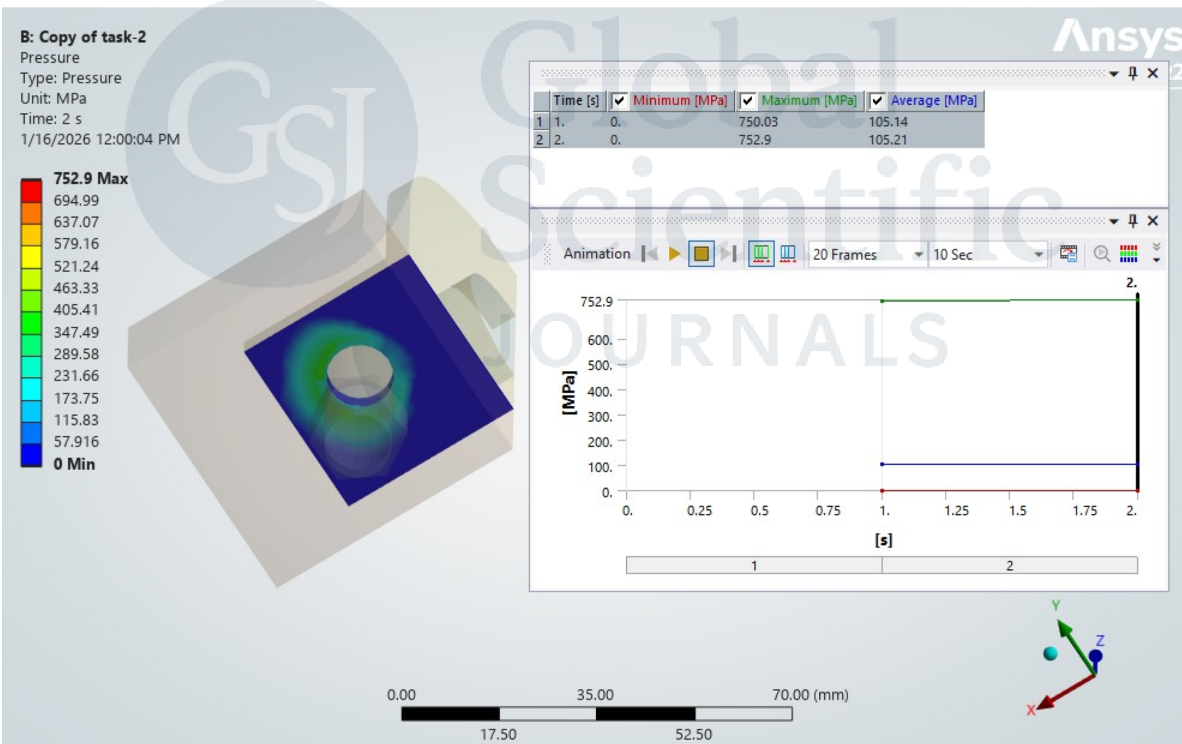


Figure 3 Contact pressure on bracket lower face at 35KN

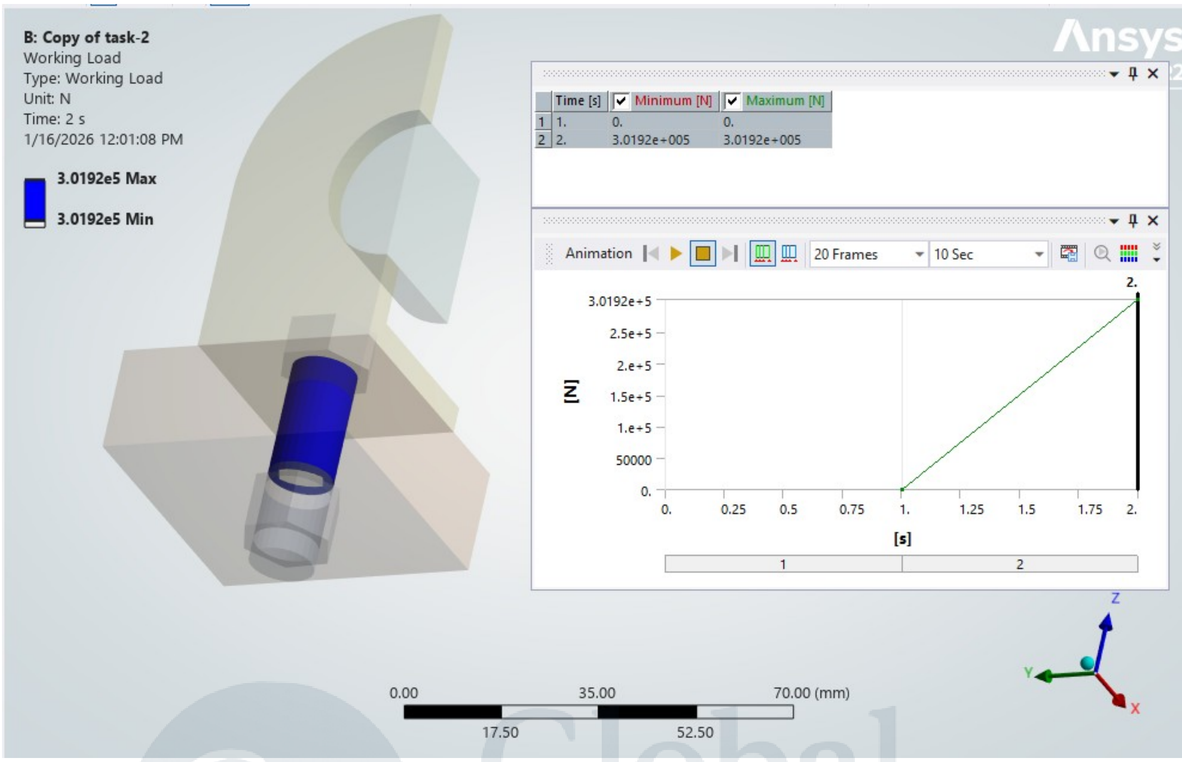


Figure 4 Bolt working load at 35KN

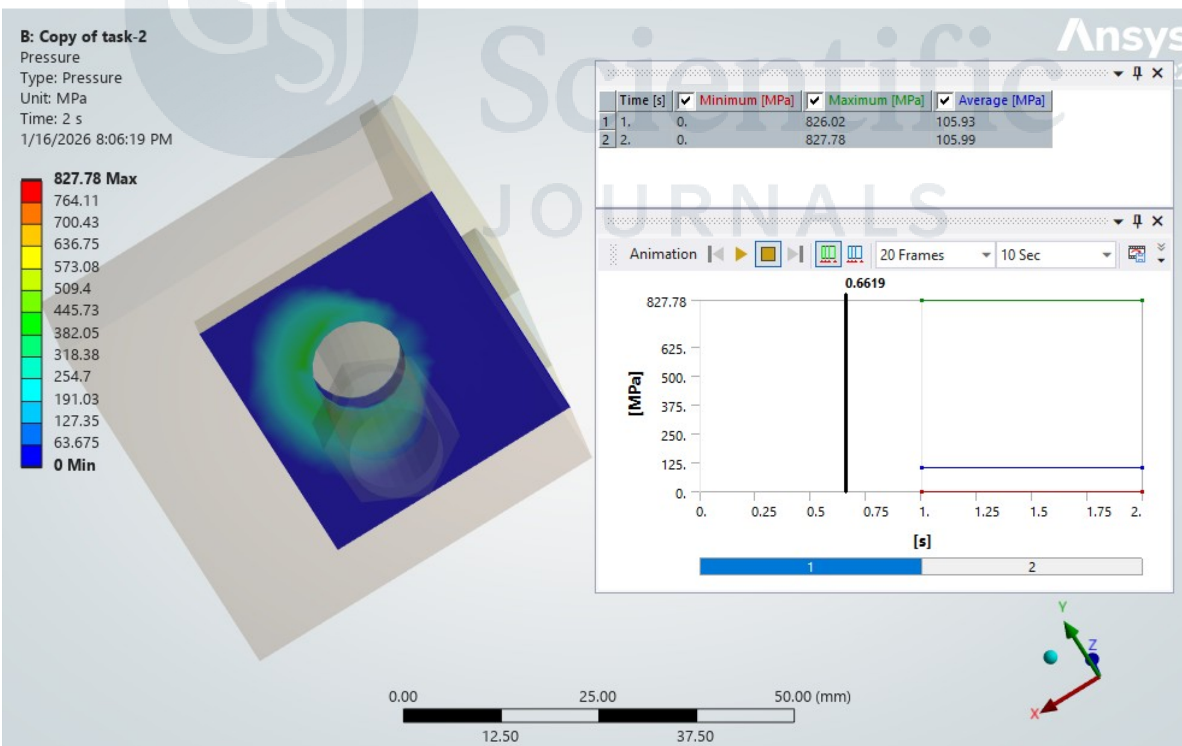


Figure 5 Contact pressure on bracket lower face at 40KN

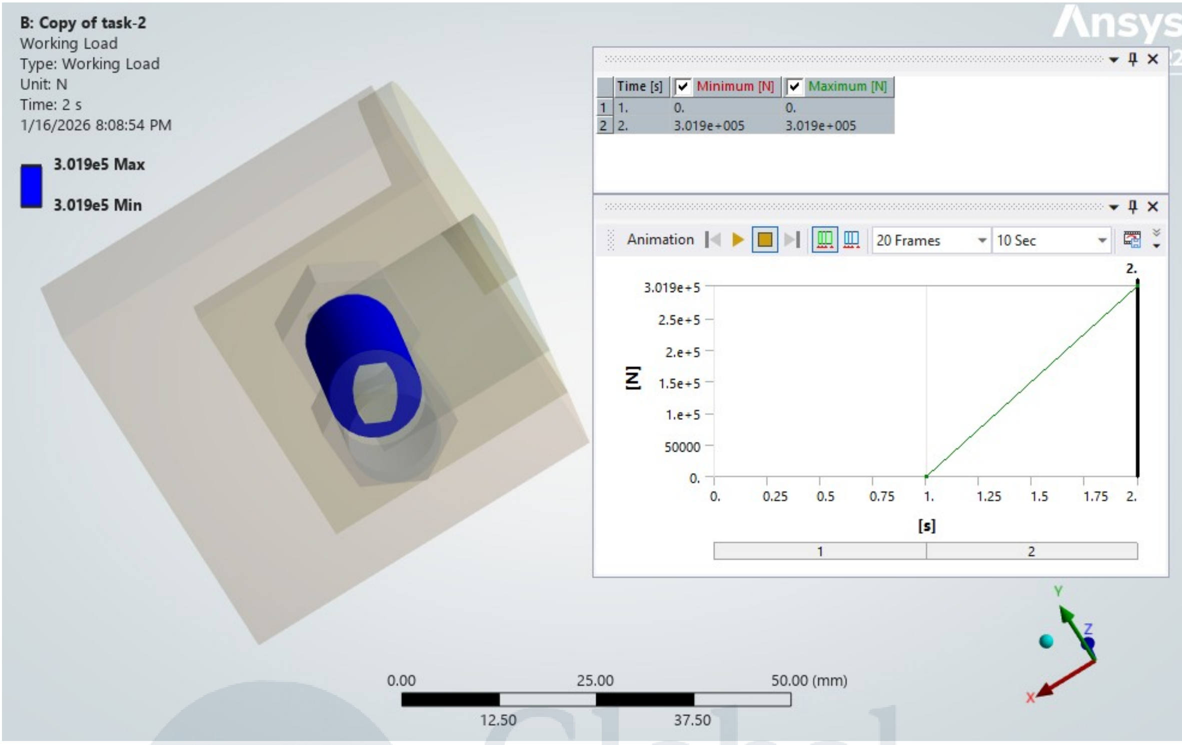


Figure 6 Bolt working load at 40KN load

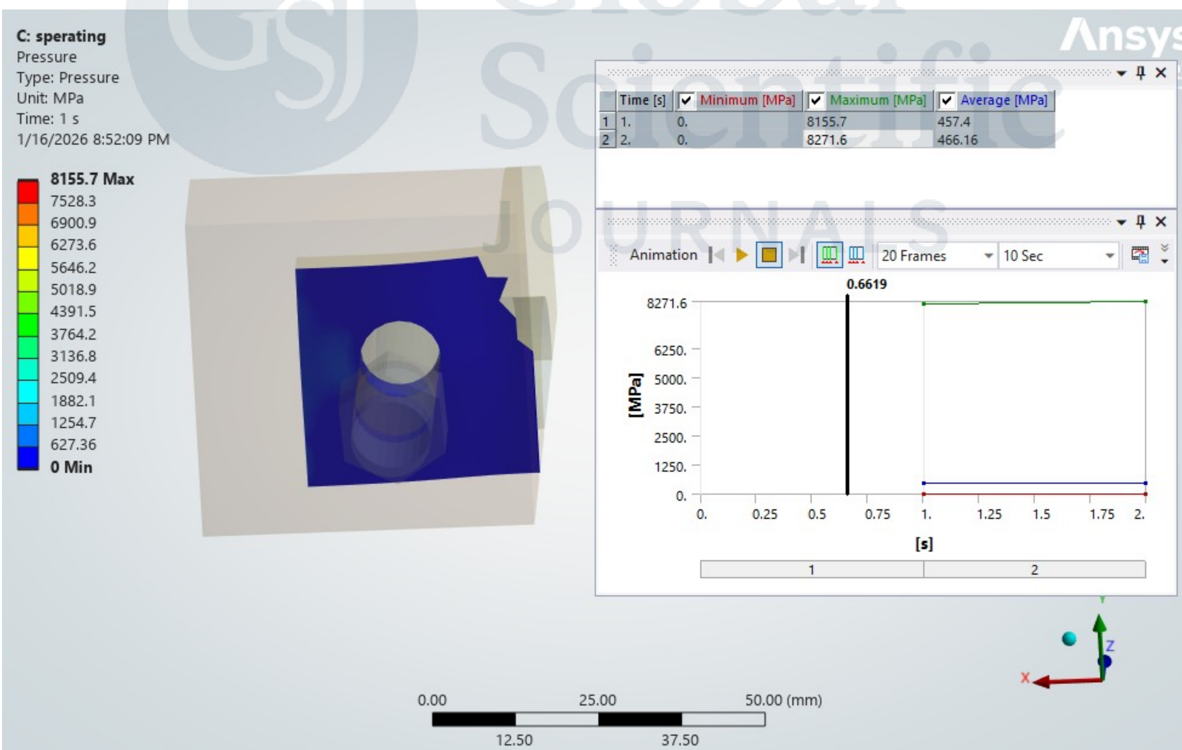


Figure 7 Contact pressure on bracket lower face at separating load

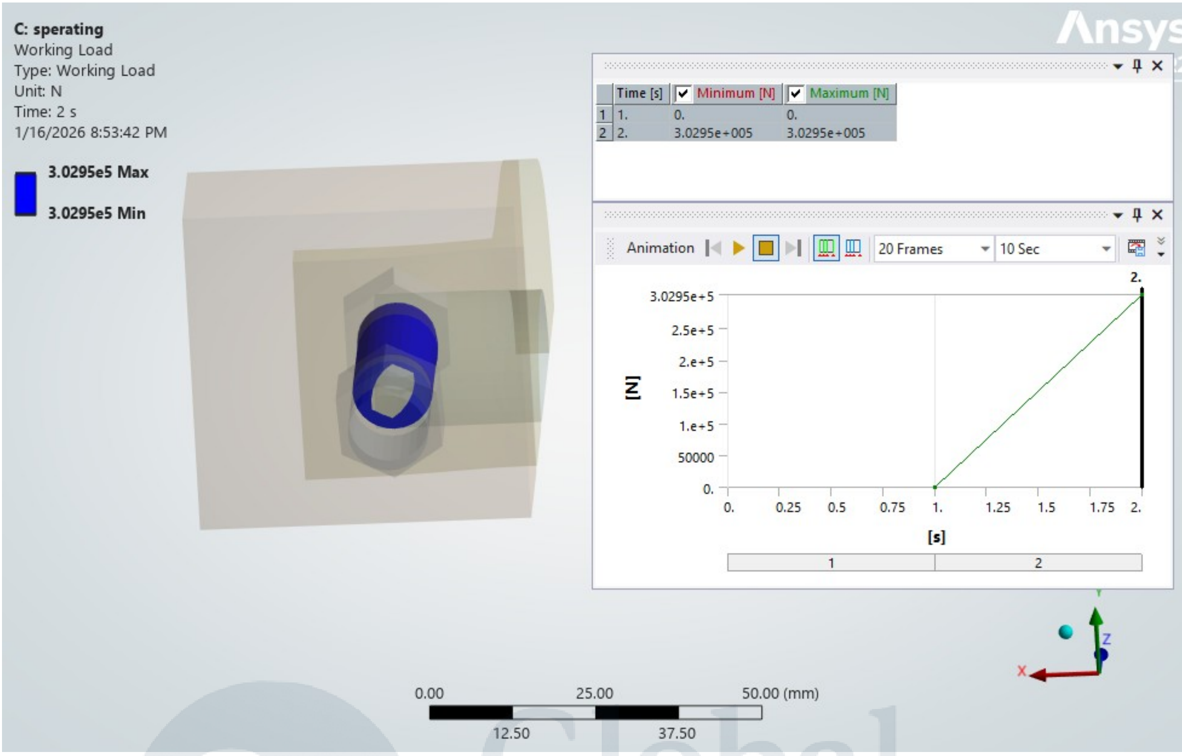


Figure8 Bolt working load at separating load

In the separating load case, the average contact pressure dropped to near zero over significant portions of the contact interface. The contact status plots confirmed open regions, indicating joint separation. This result demonstrates that the clamping force generated by pretension was insufficient to maintain contact when subjected to tensile separation forces.

Table 1 Results Summary

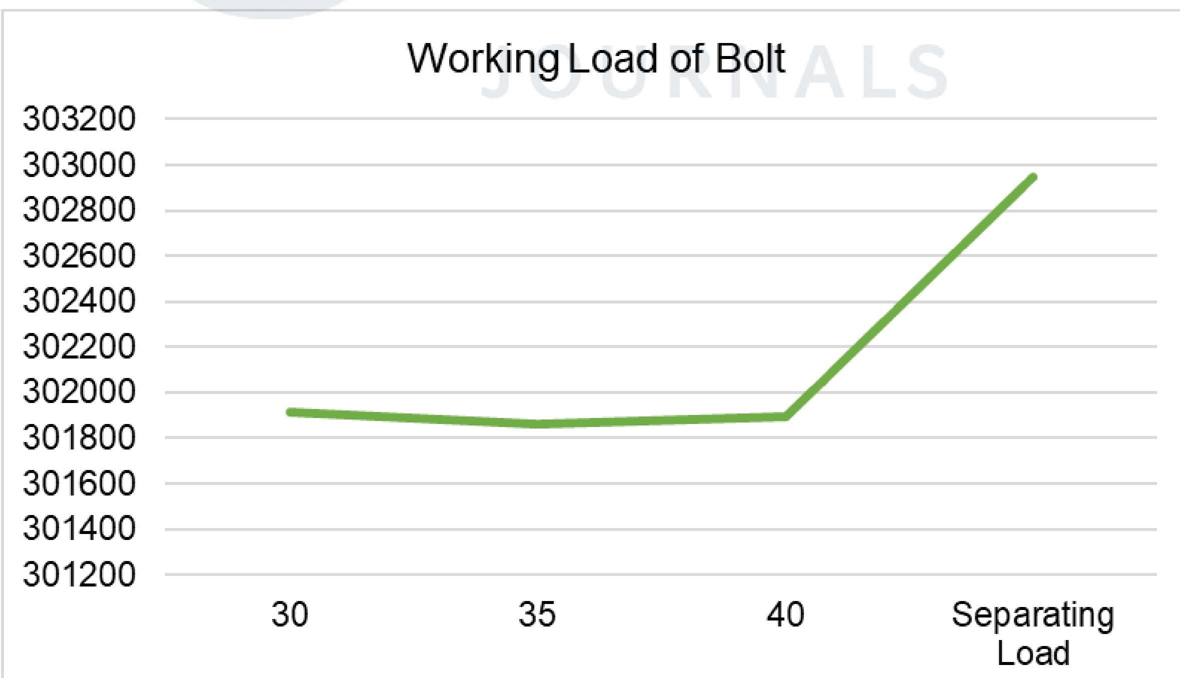


Figure 9 Working load vs applied load

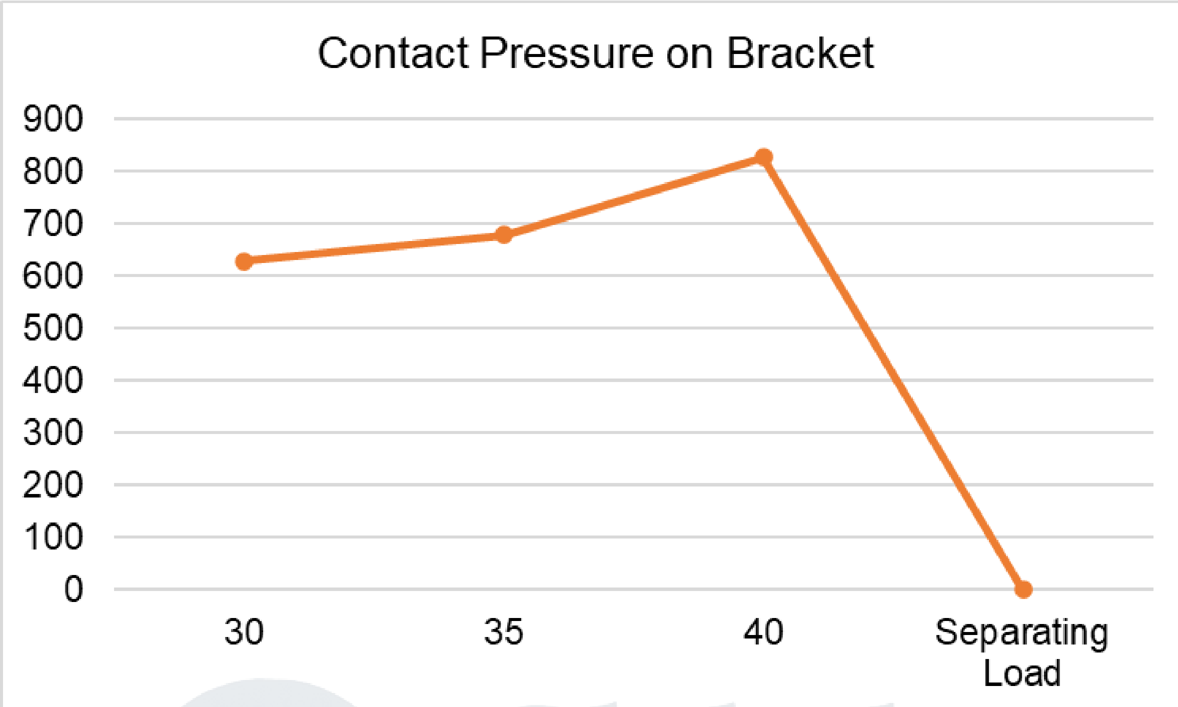
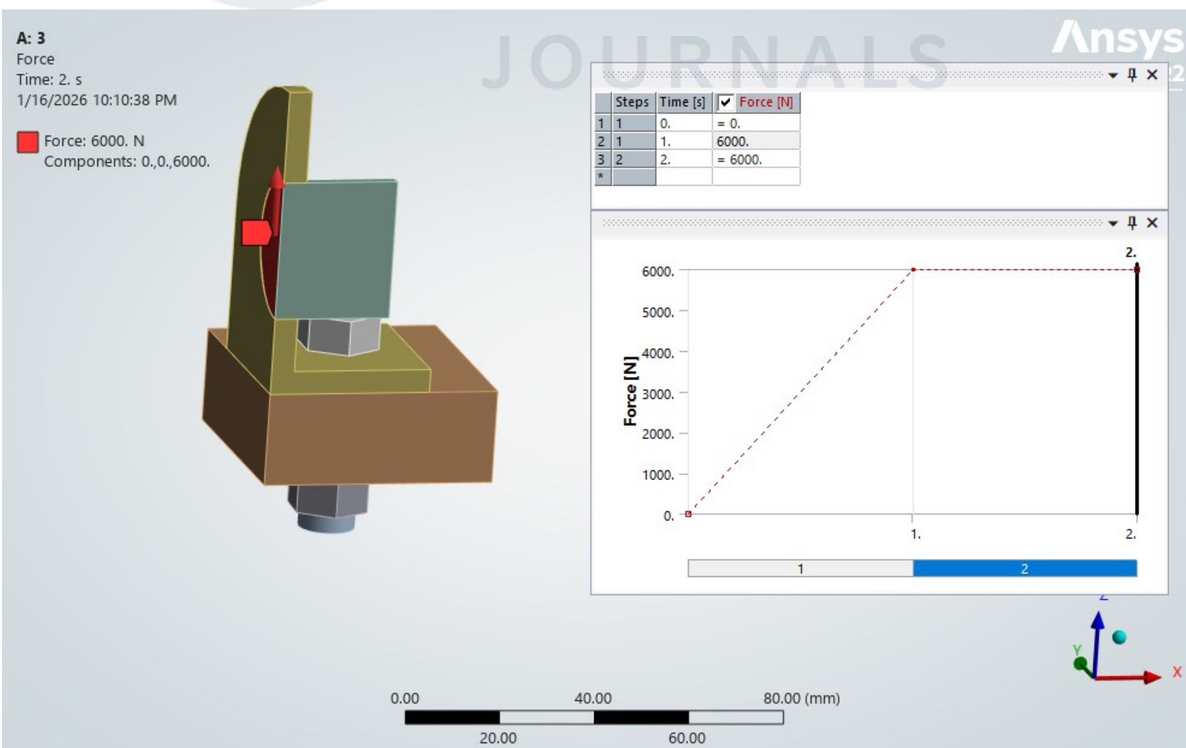


Figure 10 Contact pressure vs load

TASK-3 Bolt Yielding and Thread Stripping Assessment

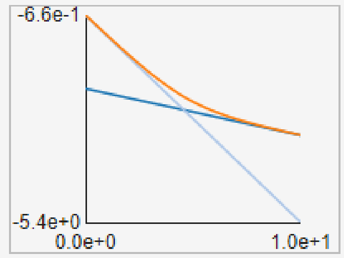
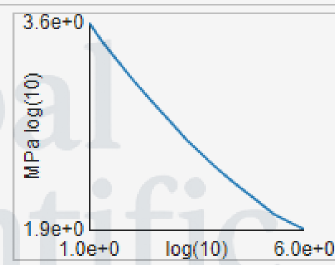
Methodology

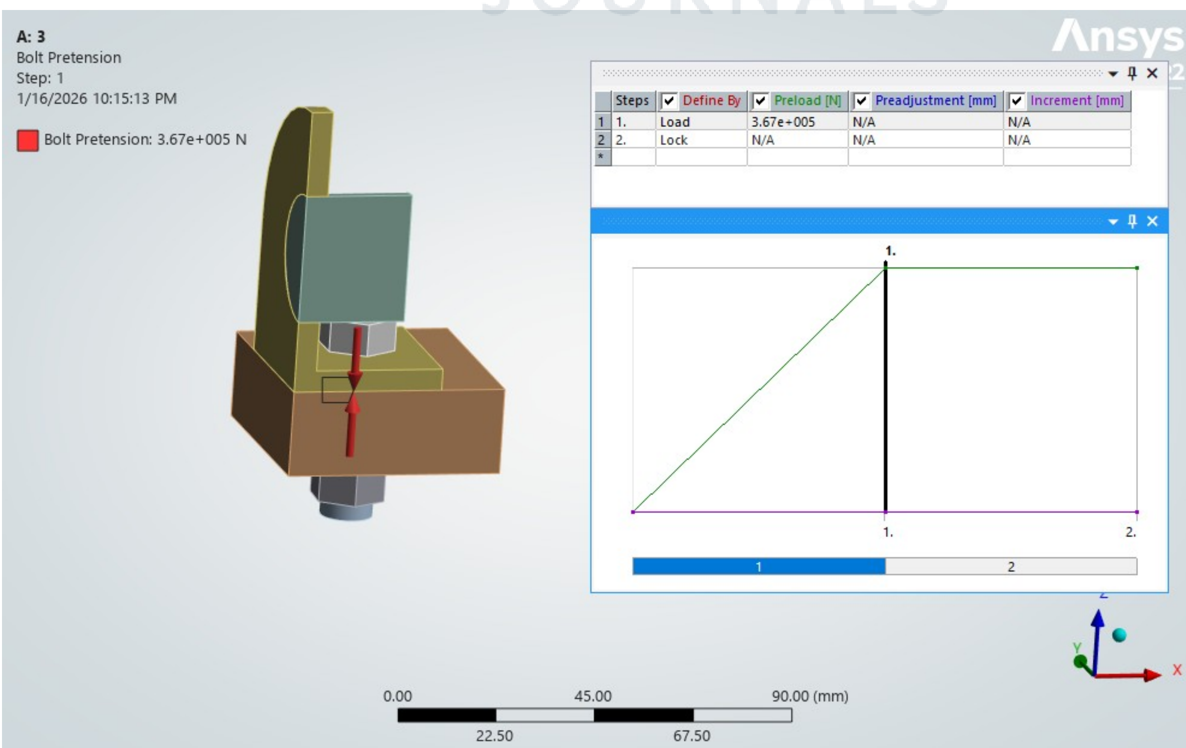
An external load of 6 kN was considered, and an appropriate ISO metric bolt size and grade were selected to prevent joint separation while ensuring simultaneous bolt yielding and thread stripping with safety factors greater than 1.2.



GSJ: Global Scientific Journal

8.8 SAE steel

Derive from	Young's Modulus and Poisson's Ratio
Young's Modulus	2e+05 MPa
Poisson's Ratio	0.3
Bulk Modulus	1.6667e+05 MPa
Shear Modulus	76923 MPa
Isotropic Secant Coefficient of Thermal Expansion	1.2e-05 1/°C
Compressive Ultimate Strength	0 MPa
Compressive Yield Strength	250 MPa
Strain-Life Parameters	
S-N Curve	
Tensile Ultimate Strength	460 MPa
Tensile Yield Strength	660 MPa



Tensile stress area, proof load, tensile yield strength, and nut thickness were obtained from standard ISO bolt tables and manufacturer data for the selected bolt and nut. [2].

Hand calculations were performed to determine bolt axial stress and thread shear stress using standard analytical formulas, and safety factors against yielding and thread stripping were evaluated prior to numerical modeling.

The three-dimensional geometry of the bolted bracket assembly was modeled using the same plate, bracket, and pin configuration as in previous tasks, while updating the bolt and nut geometry to match the selected ISO metric fastener.

Structural Steel was assigned to the plate, bracket, and pin, and the selected SAE Class steel was assigned to the bolt and nut, assuming linear elastic, isotropic material behavior.

The assembly was discretized using a finite element mesh with body sizing of 1 mm for the bolt and nut and 2 mm for the plate, bracket, and pin to ensure accurate stress and contact resolution.

Bonded and frictional contact definitions were maintained as in Tasks #1 and #2, with a friction coefficient of 0.2 for all frictional interfaces and all other contacts suppressed.

Symmetry boundary conditions were applied by constraining displacement normal to the symmetry planes, and all outer faces of the plate, excluding symmetry faces, were fully fixed.

Bolt pretension calculated from hand calculations was applied to the bolt shank in load step 1 and locked in load step 2.

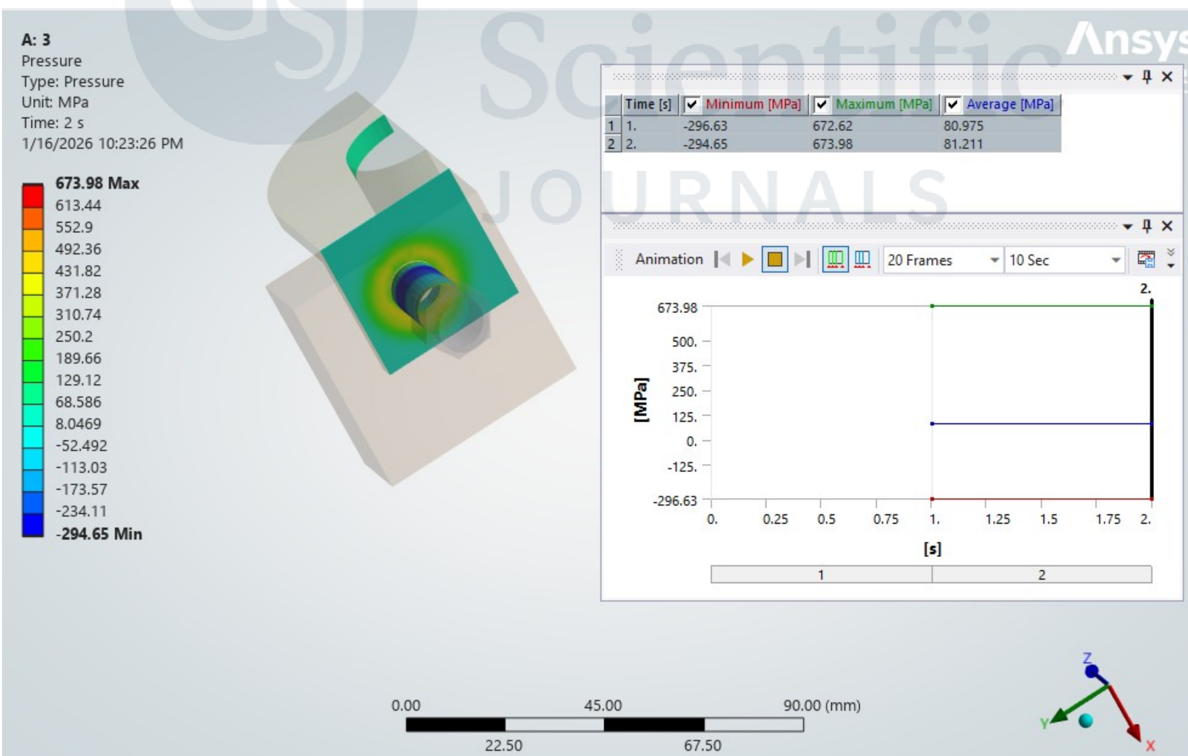
After locking pretension, a 6 kN force was applied to the pin face in the Z-direction to simulate service loading conditions.

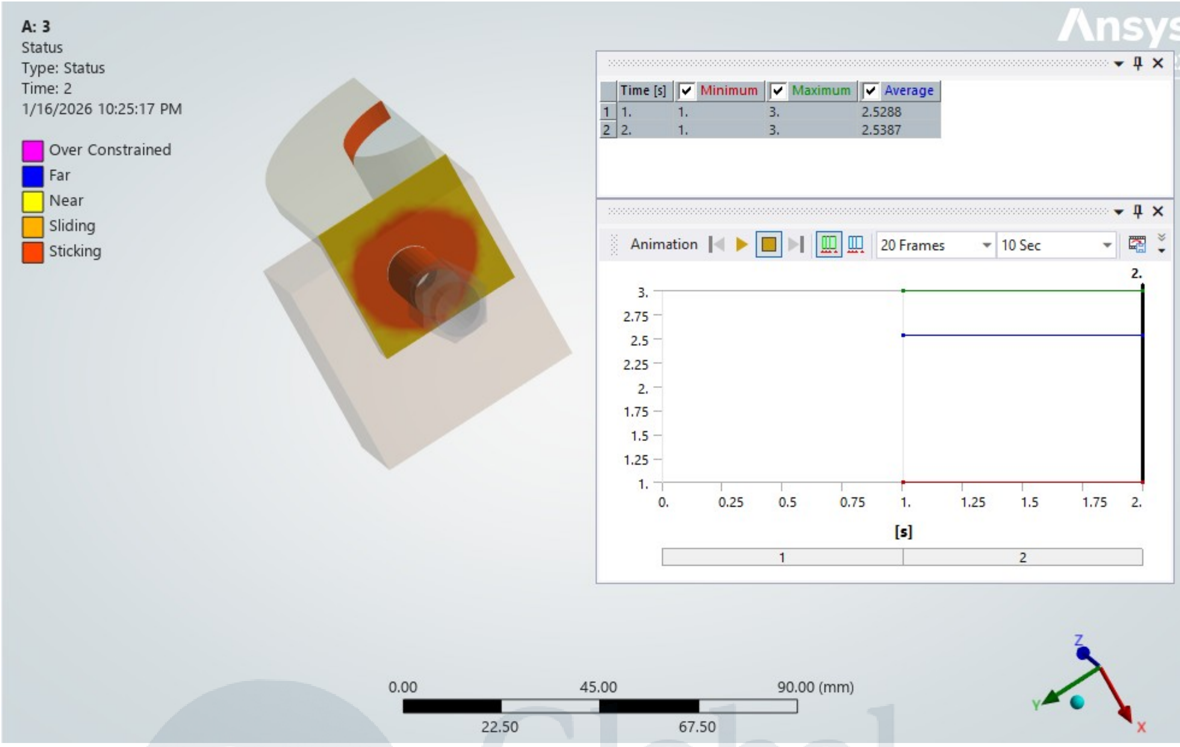
The model was solved using the ANSYS Mechanical static structural solver with contact nonlinearity enabled.

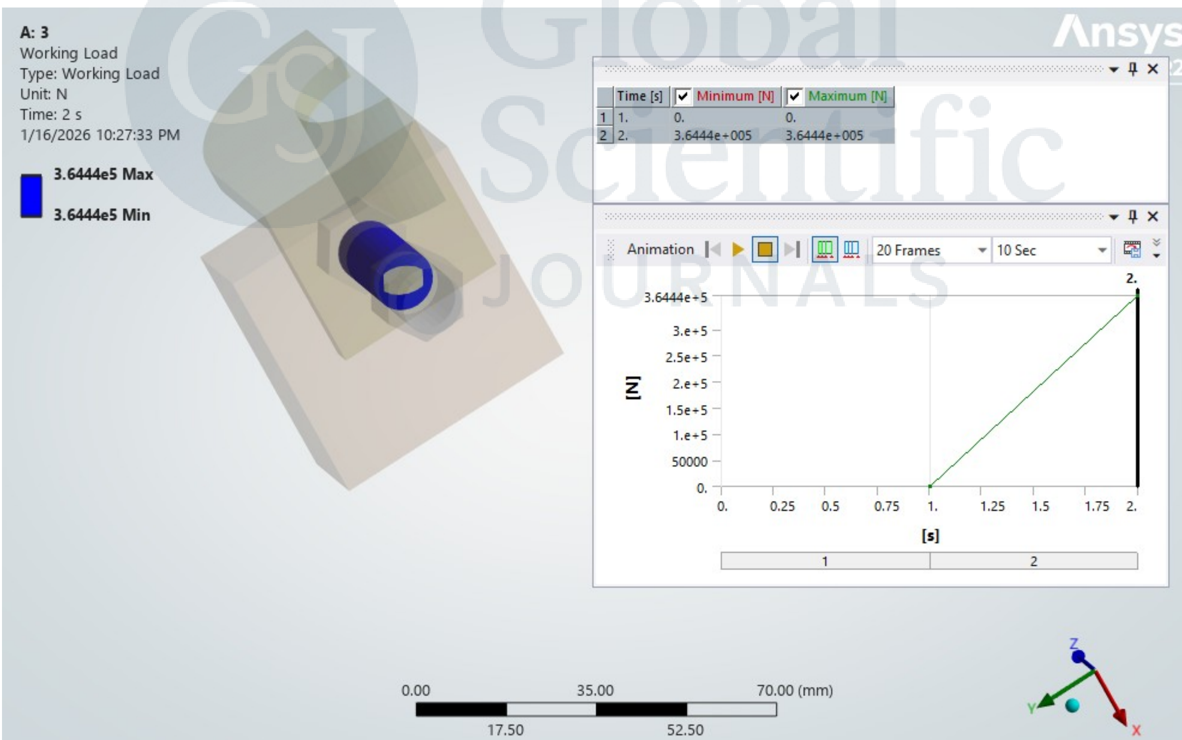
Post-processing was performed to evaluate contact pressure and contact status on the bracket's lower face and the bolt working load, which were then compared with analytical results to verify yielding and thread stripping criteria.

Hand Calculations – Task 3

Bolt Yielding and Thread Stripping Assessment
Given:







Results and discussion

The results obtained from both the finite element simulation and the analytical hand calculations demonstrate that the selected bolt operates well within safe limits under the applied external load of 6 kN. The bolt working load extracted from the ANSYS simulation closely matched the analytically calculated bolt force, confirming the correctness of the pretension application and load transfer modeling. This agreement validates the assumptions made in the analytical approach and confirms the reliability of the numerical model. The computed axial stress in the bolt remained below the material yield strength, resulting in a safety factor greater than 1.2 against yielding. Similarly, the calculated shear stress governing thread stripping was significantly lower than the allowable limit, producing a safety factor well above the minimum required value. These results indicate that neither bolt yielding nor thread stripping is expected under the prescribed loading condition. Contact pressure and contact status results further confirmed that joint separation did not occur. The clamping force generated by the applied pretension was sufficient to maintain continuous contact between the bracket and plate throughout the loading process. Consequently, the external load was effectively shared between the bolt and the clamped members, preventing excessive stress concentration in the bolts

Table 1 Results Summary

Sr #	Applied Load KN	Working Load of Bolt	Contact Pressure on Bracket
1	30	301912.80	628.091
2	35	301862.21	678.914
3	40	301895.33	826.017
4	Separating Load	302950.25	8271.6

Table 2 Bolt Yielding and Thread Stripping Assessment

Parameter	Specification
Bolt Type	ISO Metric Hex Bolt
Nominal Size	M12 × 1.75
Strength Grade	Class 8.8
Bolt Material	Medium Carbon Steel (SAE Class 8.8)
Tensile Stress Area, (A_t)	84.3 mm²
Tensile Yield Strength, (\sigma_y)	640 MPa
Proof Strength, (\sigma_p)	580 MPa
Proof Load	48.9 kN
Applied Pretension	36.7 kN
External Load	6 kN
Maximum Bolt Working Load	42.7 kN
Safety Factor (Yielding)	1.26
Safety Factor (Thread Stripping)	4.24
Joint Separation	No
Design Status	Safe

Conclusion

The results obtained from both the finite element simulation and the analytical hand calculations demonstrate that the selected bolt operates well within safe limits under the applied external load of 6 kN. The bolt working load extracted from the ANSYS simulation closely matched the analytically calculated bolt force, confirming the correctness of the pretension application and load transfer modeling. This agreement validates the assumptions made in the analytical approach and confirms the reliability of the numerical model. The computed axial stress in the bolt remained below the material yield strength, resulting in a safety factor greater than 1.2 against yielding. Similarly, the calculated shear stress governing thread stripping was significantly lower than the allowable limit, producing a safety factor well above the minimum required value. These results indicate that neither bolt yielding nor thread stripping is expected under the prescribed loading condition. Contact pressure and contact status results further confirmed that joint separation did not occur. The clamping force generated by the applied pretension was sufficient to maintain continuous contact between the bracket and plate throughout the loading process. Consequently, the external load was effectively shared between the bolt and the clamped members, preventing excessive stress concentration in the bolts.

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