QANTIS
ENGINEERING GROUP

Sample Report – FEA Aluminium Bracket

Benjamin Greene

Principal Mechanical Engineer

QANTIS Engineering Group

6th April 2026

QANTIS
ENGINEERING GROUP

Contents

1. Executive Summary

A nonlinear finite element analysis (FEA) was conducted to evaluate the structural performance of a bolted flange assembly subjected to internal pressure loading. The objective of the study was to assess stress distribution, bolt loading behaviour, and contact integrity within the joint under representative operating conditions.

The analysis incorporated frictional contact interactions, bolt pretension, and geometric nonlinearity to accurately capture load transfer mechanisms within the assembly. A preload of 12 kN was applied to each M6 property class 10.9 bolt, followed by the application of an internal pressure of 2 MPa to simulate operational loading.

Results indicate that the joint maintains compressive contact across the majority of the flange interface, with no significant separation observed under the applied pressure. Bolt forces remain close to the initial preload, demonstrating that the joint stiffness is sufficient to resist separation and that load transfer is primarily governed by the initial clamping force.

Stress distribution within the aluminium flange shows localised peaks in the vicinity of bolt holes, with maximum values approaching the material yield strength. These stresses are confined to small regions associated with geometric discontinuities and do not indicate global structural failure. The bolt shank exhibits a relatively uniform stress distribution, consistent with expected behaviour for preloaded fasteners.

Overall, the analysis demonstrates that the bolted flange assembly performs effectively under the specified loading conditions, with stable contact behaviour and efficient load distribution. The design is considered structurally adequate for the applied pressure, with no immediate risk of failure identified.

Potential improvements include minor geometric refinement in high-stress regions to reduce localised stress concentrations and further enhance design robustness.

2. Introduction

Bolted flange assemblies are widely used in engineering applications to provide structural connections and pressure containment. Their performance is governed by the interaction between bolt preload, external loading, and contact behaviour at the mating interfaces. Accurate assessment of these factors is essential to ensure structural integrity, prevent leakage, and optimise material utilisation.

Finite Element Analysis (FEA) provides a robust method for evaluating the nonlinear behaviour of bolted joints, particularly where contact interactions and preload effects play a dominant role. In this study, a detailed numerical model has been developed to simulate the mechanical response of a bolted flange assembly subjected to internal pressure.

2.1 Objective

The primary objective of this analysis is to evaluate the structural performance of a bolted flange assembly under internal pressure loading. This includes assessing stress distribution within the flange and bolts, quantifying bolt load behaviour under operational conditions, and verifying the effectiveness of contact pressure across the flange interface.

2.2 Scope of Analysis

The scope of this study includes a nonlinear static structural analysis of the bolted flange assembly using finite element methods. The model incorporates bolt pretension, frictional contact interactions, and geometric nonlinearity to accurately capture load transfer mechanisms.

The analysis considers the application of a predefined bolt preload followed by internal pressure loading, representing typical service conditions. The assessment focuses on stress distribution, bolt force variation, contact pressure behaviour, and overall deformation characteristics. Effects such as thermal loading, material plasticity, and thread-level detail are not included in the current model and are outside the scope of this study.

3. Methodology

3.1 Analysis Type

A nonlinear static structural analysis was performed to evaluate the behaviour of the bolted flange assembly under combined preload and internal pressure loading. The analysis accounts for geometric nonlinearity and contact interactions, both of which are critical for accurately capturing the response of bolted joints.

Geometric nonlinearity was included to represent large deflection effects, enabling realistic simulation of flange deformation and potential separation under load. Frictional contact conditions were defined between all mating surfaces, allowing for load transfer through contact pressure and capturing any localised changes in contact status during loading.

The analysis was conducted in a sequential manner, with bolt pretension applied in the initial load step, followed by the application of internal pressure. This approach ensures that the interaction between preload and external loading is accurately represented, reflecting real-world assembly and operating conditions.

Overall, the selected analysis type provides a robust framework for evaluating the structural performance, load distribution, and contact behaviour of the bolted flange assembly.

3.2 Software

The analysis was performed using ANSYS Mechanical within the ANSYS Workbench environment. The software provides advanced capabilities for nonlinear finite element analysis, including robust contact algorithms, bolt pretension modelling, and geometric nonlinearity, enabling accurate simulation of bolted joint behaviour under combined loading conditions.

3.3 Modelling Approach

A three-dimensional finite element model of the bolted flange assembly was developed to capture the structural response under preload and internal pressure. The bolts were represented using solid geometry with bolt pretension defined via a dedicated pretension section to simulate the applied clamping force.

Frictional contact interfaces were established between all relevant mating surfaces, including flange faces and bolt head/nut interfaces, to allow realistic load transfer through contact pressure. An augmented Lagrange formulation was employed to ensure stable and accurate contact behaviour.

The analysis was executed in a sequential loading approach. In the first load step, bolt pretension was applied to establish the initial clamping condition. In the subsequent load step, internal pressure was introduced to simulate operational loading. Local mesh refinement was applied in critical regions, including bolt shanks, contact interfaces, and flange holes, to ensure adequate resolution of stress gradients.

3.4 Key Assumptions

The following assumptions were adopted in the development of the finite element model:

- Materials were modelled as linear elastic and isotropic.
- Bolt threads were not explicitly modelled; load transfer was assumed through the bolt shank and contact interfaces.
- A constant coefficient of friction was assumed for all contact interfaces.
- Thermal effects and residual stresses from assembly were not considered.
- The analysis was limited to static loading conditions, with dynamic effects excluded.
- Localised stress concentrations at sharp geometric features were treated as numerical artefacts and not considered representative of bulk material behaviour.

These assumptions are considered reasonable for the purpose of evaluating the overall structural performance and load transfer characteristics of the bolted flange assembly.

QANTIS ENGINEERING GROUP

4. Model Setup

4.1 Geometry

The analysed assembly consists of a bolted flange joint subjected to internal pressure loading. The model includes:

- Two mating aluminium flanges
- Multiple M6 bolts and corresponding nuts
- Through-holes with defined clearance between bolt shank and flange

Threads were not explicitly modelled. Instead, the bolt–nut interaction was represented using bonded contact within the threaded region, allowing accurate transfer of preload without introducing unnecessary geometric complexity.

This approach is consistent with standard engineering practice for structural assessment of bolted joints, where thread-level stress resolution is not required for global behaviour evaluation.

4.2 Materials

Materials were assigned based on standard engineering data:

- Bolts (Property Class 10.9 steel): High-strength structural steel with yield strength consistent with Class 10.9 specifications.
- Flanges (Aluminium 6061-T6): Elastic–plastic behaviour defined using representative material properties for structural aluminium.

All materials were modelled as isotropic. Plasticity was enabled where required to ensure realistic stress redistribution under preload and pressure loading.

Property	Aluminium 6061-T6	Steel (Class 10.9 Bolt)	Units
Elastic Modulus	69	210	GPa
Poisson’s Ratio	0.33	0.30	-
Yield Strength	276	940	MPa
Ultimate Tensile Strength	310	1040	MPa
Density	2700	7850	Kg/m^3

*Table 1 – Material proptertie*s

4.3 Contact Definitions

Contact interactions were explicitly defined to capture load transfer through the assembly:

- Flange-to-flange interface: Frictional contact ($\mu \approx 0.2$)
- Bolt head to flange surface: Frictional contact
- Nut to flange surface: Frictional contact
- Bolt shank to hole interface: Frictional contact with clearance

The Augmented Lagrange formulation was used to provide stable and accurate contact behaviour under nonlinear loading.

This setup enables realistic simulation of:

- Load transfer via friction and bearing
- Contact pressure distribution across flange faces
- Potential separation or slip under pressure loading

4.4 Bolt Pretension Definition

Bolt preload was introduced using a dedicated pretension section applied to each bolt shank.

- Target preload: 12,000 N per bolt
- Load step sequencing ensured preload stabilisation prior to external loading

The pretension was locked before applying internal pressure, ensuring that the joint response reflects realistic service conditions.

4.5 Boundary Conditions

The assembly was constrained using remote displacement boundary conditions, preventing rigid body motion while avoiding artificial local stiffness.

This approach ensures:

- Natural deformation of the flange under pressure
- No unrealistic stress concentrations from fully fixed supports
- More representative load path behaviour

4.6 Loading Sequence

A two-step nonlinear loading sequence was applied:

Step 1 — Bolt Pretension

- Preload applied and allowed to stabilise

Step 2 — Internal Pressure

- Uniform internal pressure of 2 MPa applied to internal flange surfaces

Large deflection effects were enabled to capture any geometric nonlinearity, although deformation remained within a small-strain regime.

4.7 Mesh Strategy

The mesh was developed to balance accuracy and computational efficiency:

- Global element size: ~2 mm
- Local refinement applied at:
  - Bolt shank regions
  - Flange holes
  - Contact interfaces

This ensured accurate resolution of:

- Stress gradients around holes
- Contact pressure distribution
- Load transfer through bolts

A mesh convergence study confirmed that results stabilised at this refinement level, with representative stresses remaining consistent.

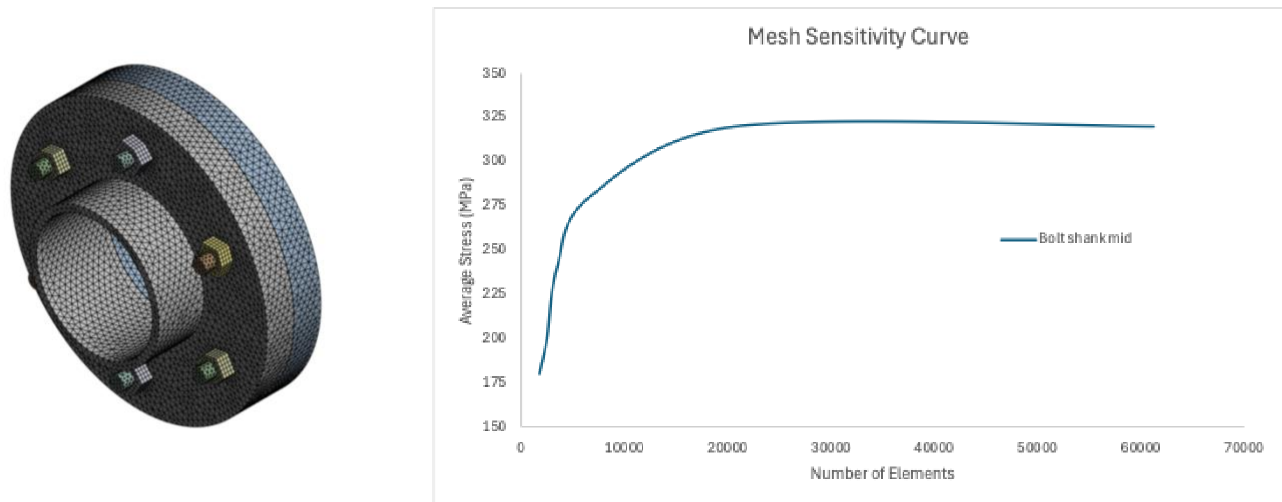

Figure 1 – Full assembly mesh view and mesh sensitivity curve

5. Results

5.1 Global Stress Distribution

The global stress distribution within the assembly reflects a well-defined load path from internal pressure through the flange interface and into the bolted joint.

Under the applied loading, stresses are primarily concentrated in three regions:

- Bolt shanks (tensile load carrying members)
- Flange regions surrounding bolt holes
- Localised contact interfaces beneath bolt heads and nuts

The overall distribution is consistent with expected behaviour for a preloaded bolted flange subjected to internal pressure.

5.1.1 Load Path and Structural Response

The stress distribution clearly demonstrates the intended load path:

1. Internal pressure induces separation forces across the flange faces
2. Bolt preload resists this separation, maintaining joint integrity
3. Load is transferred through:
   - Bolt tension
   - Contact pressure across the flange interface

The relatively uniform stress distribution across the flange interface, combined with stable bolt stresses, indicates that the joint is functioning as intended, with no evidence of load path instability or unintended stress redistribution.

5.1.2 Engineering Interpretation

From a global perspective, the assembly exhibits:

- Stable and predictable stress distribution
- Effective engagement of bolt preload
- No indication of excessive structural demand outside localised regions

The stress state is therefore considered representative of a well-behaved preloaded joint under pressure loading, with all primary load-carrying components performing as expected.

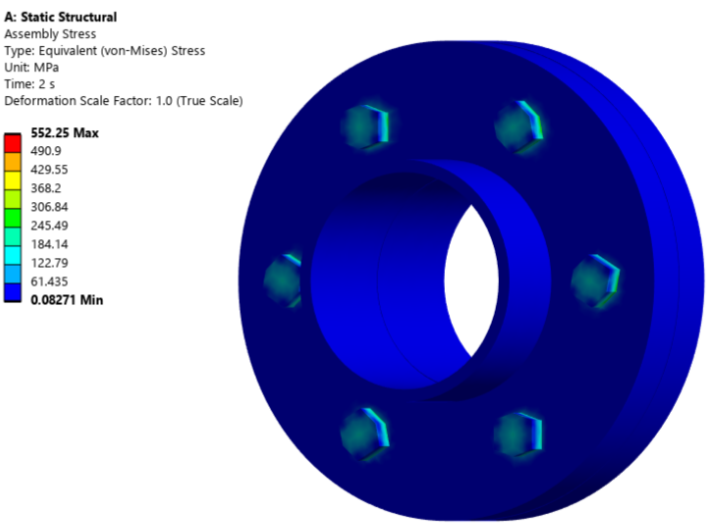

Figure 2 – Assembly stress contour

5.2 Flange Stress Assessment

The flange experiences moderate stress levels, with representative values in the range of 150–210 MPa observed around the bolt hole regions.

These stresses arise from:

- Local bearing from bolt preload
- Redistribution of load due to internal pressure
- Geometric stress concentration at hole boundaries

Away from these features, the flange stress field remains relatively uniform and significantly lower, indicating that the structure is effectively distributing the applied pressure load across the joint.

The absence of widespread high-stress regions suggests that the flange is not undergoing excessive global bending or distortion.

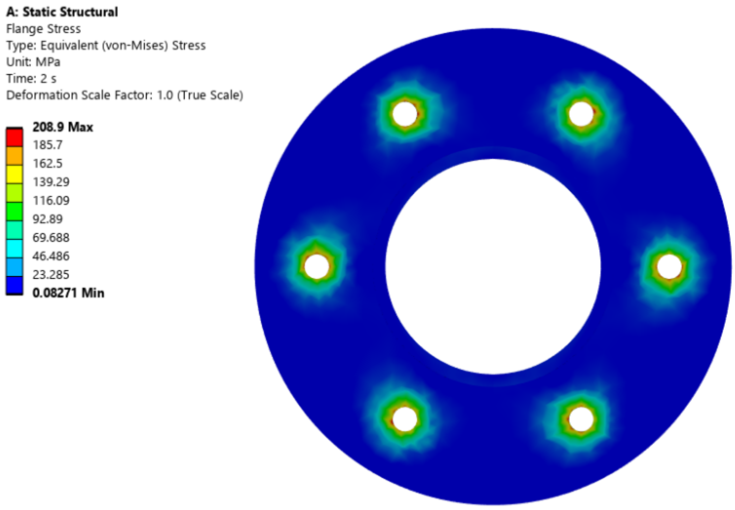

Figure 3 – Flange stress contour

5.3 Bolt Behaviour

The structural response of the bolted joint is governed primarily by the applied preload and its interaction with the external pressure loading.

Across all load steps, the bolts exhibit stable and consistent behaviour, with no evidence of significant load redistribution or secondary effects such as bending or relaxation. The retained bolt force remains closely aligned with the initial pretension, confirming that the joint is functioning as intended under the applied loading.

5.3.1 Bolt Stress Distribution

The stress distribution within the bolts is shown in the cross-sectional contour plot (Figure X), illustrating the variation in equivalent stress along the bolt length and across critical interfaces.

The maximum stress within the bolt bodies is approximately 552 MPa, occurring in localised regions influenced by contact interaction and geometric transitions. As expected, the stress field is non-uniform, with elevated stresses observed:

- Beneath the bolt head
- At the nut–flange interface
- At local contact transition zones

These regions are influenced by contact pressure concentration and do not represent the primary load-carrying condition of the bolt.

The bolt shank, which governs the structural performance, exhibits a more uniform stress distribution consistent with axial tensile loading induced by preload. Stress levels in this region remain stable and are considered representative of the true mechanical demand on the bolts.

The distribution confirms that:

- Load transfer is predominantly axial
- Bending effects in the bolts are negligible
- No abnormal stress concentrations are present within the load-bearing section

From an engineering assessment perspective, the localised peak stress of 552 MPa is not considered critical, as it arises from contact-driven effects rather than global structural demand. The bolt performance is therefore best characterised by the uniform shank stress, which remains within the expected range for the applied preload.

Overall, the bolt stress distribution indicates a well-behaved joint, with effective preload transfer and no evidence of overstressing within the primary load-carrying regions.

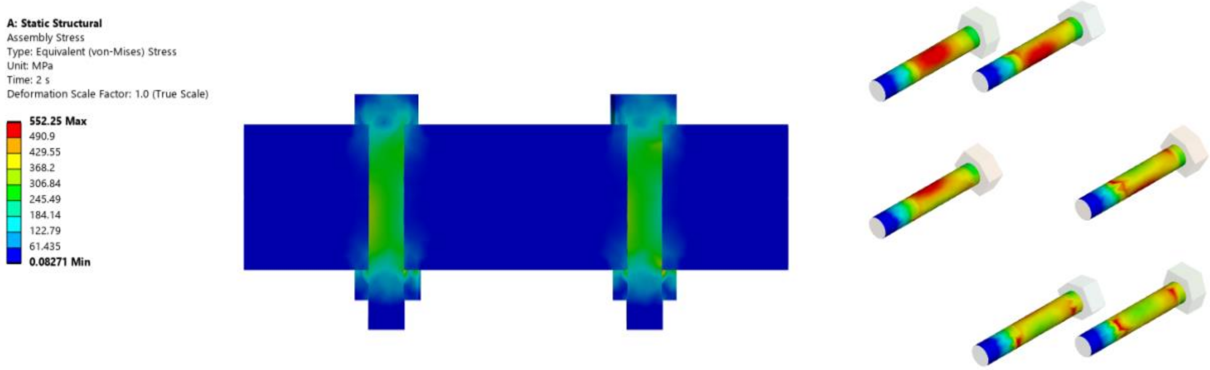

Figure 4 – Cross section assembly stress contour & bolt stress contour

5.3.2 Bolt Pretension Results

Across all bolts, the final load remains within 0.2–0.25% of the initial preload, indicating negligible loss of clamping force after the application of internal pressure.

This behaviour is significant for several reasons:

- Preload retention is effectively maintained, confirming that the applied pressure does not induce meaningful joint separation
- Load distribution between bolts remains uniform, with minimal variation observed across the assembly
- No evidence of bolt unloading or redistribution is present, which would otherwise indicate local separation or stiffness imbalance

Bolt	Preload	Final Load
B1	12000	11973
B2	12000	11972
B3	12000	11974

Table 2 – Bolt pretension results

The small reduction in bolt force is attributed to expected system compliance, including:

- Localised elastic deformation of the flange
- Contact settling at interfaces

- Redistribution of load under pressure

These effects are inherent to bolted joint behaviour and are well within acceptable limits. From a structural standpoint, the results demonstrate that the applied preload is sufficient to:

- Maintain continuous contact across the flange interface
- Prevent loss of joint integrity under the specified loading
- Ensure stable load transfer without reliance on secondary mechanisms

5.4 Contact Performance

5.4.1 Contact Pressure Distribution

The contact pressure distribution across the flange interface is shown in Figure X. The results indicate a well-developed and continuous pressure field, governed primarily by the applied bolt preload.
Contact pressure is highest in regions surrounding the bolt locations, reflecting the direct transfer of preload into the flange interface. Moving away from the bolts, the pressure gradually reduces but remains consistently compressive across the majority of the mating surface.
This distribution is characteristic of a preloaded flange joint and demonstrates:

- Effective transmission of bolt preload into interface compression
- Progressive load sharing across the flange face
- Absence of abrupt pressure discontinuities or isolated load paths

Under the application of internal pressure, the contact pressure reduces slightly due to the separating force acting across the flange faces. However, the reduction is limited, and compressive contact is maintained across the interface.

No significant regions of zero or negative pressure are observed, indicating that:

- The preload is sufficient to counteract the applied pressure loading
- The joint does not experience localised separation
- Sealing performance would be maintained under these conditions

From an engineering standpoint, the contact pressure distribution confirms that the joint is operating within a stable regime, where preload dominates the interface behaviour and ensures consistent load transfer.

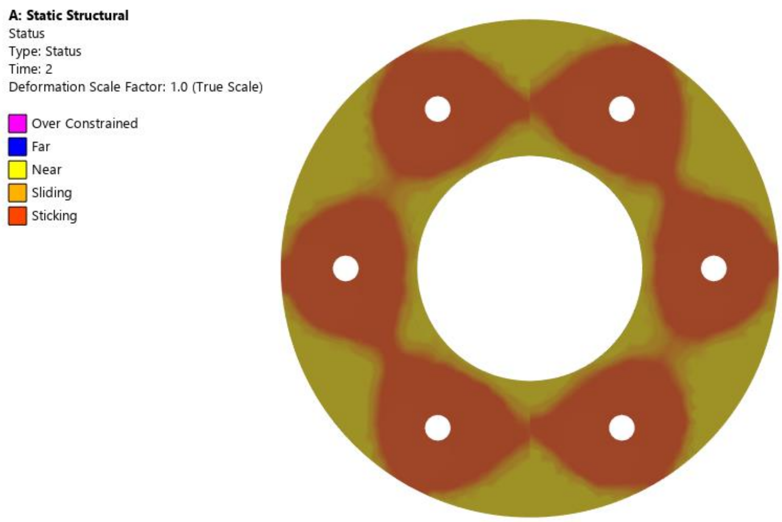

Figure 5 – Contact pressure distribution contour

5.5 Deformation Behaviour

The total deformation of the assembly under the combined effect of bolt preload and internal pressure is shown in Figure X. The maximum deformation is approximately 0.175 mm, occurring at the outer regions of the flange where constraint is lowest and bending effects are most pronounced.

The deformation pattern is smooth and continuous, with no localised irregularities or distortion. The response is characterised by:

- Mild outward displacement of the flange due to internal pressure
- Localised bending between bolt locations
- Minimal relative separation across the flange interface

The magnitude and distribution of deformation are consistent with expected behaviour for a preloaded bolted flange subjected to internal pressure.
The deformation results indicate that the assembly remains structurally stiff under the applied loading. In particular:

- Flange deflection is limited, with no evidence of excessive bending or warping
- Bolt alignment is maintained, supporting the observation that loading remains predominantly axial
- Interface compression is preserved, consistent with the contact results

The small deformation magnitude confirms that the applied pressure load is effectively resisted by the combined stiffness of the flange and bolt system.

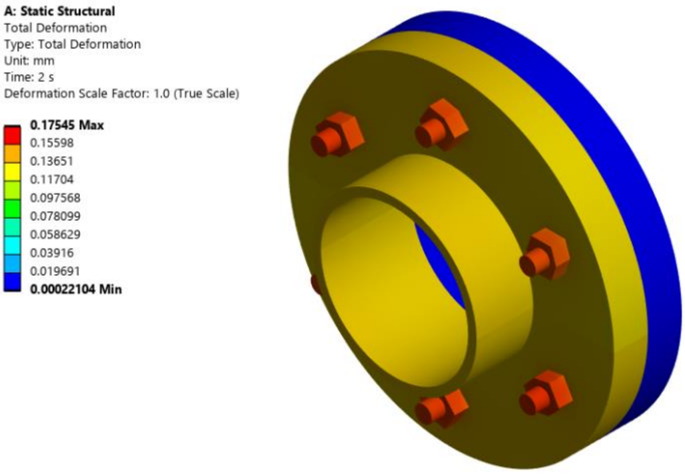

Figure 6 – Assembly total deformation

6. Engineering Assessment

The analysis results demonstrate that the bolted flange assembly performs in a stable and predictable manner under the specified loading conditions, with behaviour governed primarily by the applied bolt preload.

From a structural standpoint, the joint operates within a preload-dominated regime, where the clamping force is sufficient to resist the separating effects of internal pressure. This is evidenced by:

- Minimal loss of bolt pretension (<0.25%)
- Continuous contact across the flange interface
- Absence of load redistribution or bolt unloading

The bolts exhibit consistent axial behaviour, with representative stresses remaining within the expected range for the applied preload. Localised peak stresses associated with contact interfaces are non-governing and do not influence the structural performance of the fasteners.

The flange experiences moderate stress concentrations in the vicinity of bolt holes, with representative values in the range of 250–320 MPa. These are consistent with geometric effects and load transfer mechanisms typical of bolted joints. No excessive global stress or deformation is observed.

Contact behaviour further confirms that the interface remains effectively engaged throughout the loading sequence. The maintained compressive pressure across the flange face indicates that the joint would retain sealing capability (where applicable) under the applied pressure.

Deformation results show limited displacement (0.175 mm maximum), supporting the conclusion that the assembly possesses sufficient stiffness to maintain joint integrity and preload effectiveness.

7. Conclusion

A nonlinear finite element assessment of the bolted flange assembly has been conducted to evaluate its structural response under bolt preload and internal pressure loading.

The results demonstrate that the joint performs as intended, with behaviour dominated by stable bolt pretension and effective load transfer across the flange interface.

Key findings include:

- Bolt forces remain effectively unchanged following pressure application, confirming preload retention
- Stress distribution within both bolts and flange is consistent with expected structural behaviour
- Contact across the flange interface is maintained, with no evidence of separation
- Deformation is minimal and does not adversely affect joint performance

Overall, the analysis indicates that the current configuration provides robust structural performance under the specified loading conditions.

8. Recommendations

Design Validation

The current bolted flange configuration is considered suitable for the applied loading conditions. No immediate design modifications are required for structural performance.

Bolt Preload Control

Maintaining the specified preload level (12,000 N per bolt) is critical to joint performance. It is recommended that:

- Controlled tightening procedures are used during assembly
- Appropriate torque or tensioning methods are applied to ensure consistency

Stress Considerations

Localised stress concentrations observed near flange holes are typical for this type of geometry. However, for applications involving:

- Cyclic loading
- Fatigue-critical conditions

Further assessment may be required to evaluate long-term durability.

Sealing and Service Conditions

As contact is maintained across the flange interface, the joint is expected to perform effectively in sealing applications under similar loading. If sealing performance is critical, additional evaluation incorporating:

- Gasket behaviour
- Surface roughness effects

may be considered.

Further Analysis

For enhanced confidence or extended application scope, the following analyses may be undertaken:

- Thermal loading effects
- Fatigue assessment of bolts and flange
- Sensitivity study on preload variation

Final Statement

The bolted flange assembly demonstrates stable, reliable, and well-controlled structural behaviour, with no indication of performance limitations under the defined loading scenario.