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FINITE ELEMENT – BASED STATIC STRUCTURAL EVALUATION OF A COMPONENT ASSEMBLY (PUMP CASING) USING ANSYS

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ABSTRACT

Accurate prediction of localized stress concentrations in complex structural components is essential for ensuring structural integrity and preventing premature failure. Conventional finite element analysis (FEA) using uniformly refined meshes across entire assemblies is computationally expensive and often impractical for large-scale industrial models. This study presents an efficient global–local submodeling approach for static structural analysis of a pump housing using ANSYS Mechanical.

Keywords: Finite Element Analysis, Submodeling, Pump Housing, Stress Concentration, ANSYS Mechanical, Global–Local Analysis

1. INTRODUCTION

Finite Element Analysis (FEA) has become a fundamental tool in modern structural engineering for predicting stress, strain, and deformation in complex geometries. Components such as pump housings experience combined loading from internal pressure, assembly constraints, and operational forces, leading to localized stress concentrations.

Accurate resolution of these stress concentrations requires very fine mesh density, which increases computational cost dramatically. To overcome this challenge, global–local submodeling techniques are widely adopted.

Theoretical Foundations and Best Practices

- **Bathe (Finite Element Procedures, 2006)** emphasizes that submodeling works best under **linear elastic assumptions**, where the response in the local domain is primarily dictated by the **displacements at the boundaries**.
- **Boundary placement:**
  - Cut boundaries should be located **far enough from stress concentration regions** to avoid distortion in stress fields due to local effects.
  - Ensures submodel inherits physically realistic displacements from the global model.
- **ANSYS Recommendations:**
  - Displacement-based submodeling is suitable for **static and dynamic analyses**, including transient and harmonic problems, provided linearity assumptions hold.
  - Ensures **compatibility at cut boundaries**; nodes in the submodel receive displacements from the global solution, while internal nodes are free to resolve local stress gradients.
  - Verification includes comparing **average or maximum stresses** at the submodel boundary with corresponding global model values.

2. THEORETICAL BACKGROUND

2.1 Linear Static Finite Element Formulation

For linear elastic systems, equilibrium is governed by:

$$[K]\{u\} = \{F\}$$

Where:

- K= global stiffness matrix
- u= nodal displacement vector
- F= applied force vector

Stress is computed as:

$$\sigma = DBu$$

Since stress depends on displacement gradients, coarse meshes may underpredict peak stress values.

3D Hooke's Law:

$$\begin{bmatrix} \sigma_x \\ \sigma_y \\ \sigma_z \\ \tau_{xy} \\ \tau_{yz} \\ \tau_{zx} \end{bmatrix} = \frac{E}{(1+\nu)(1-2\nu)} \begin{bmatrix} 1-\nu & \nu & \nu & 0 & 0 & 0 \\ \nu & 1-\nu & \nu & 0 & 0 & 0 \\ \nu & \nu & 1-\nu & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1-2\nu}{2} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1-2\nu}{2} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1-2\nu}{2} \end{bmatrix} \begin{bmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_z \\ \gamma_{xy} \\ \gamma_{yz} \\ \gamma_{zx} \end{bmatrix}$$

- Relates normal and shear stresses to normal and shear strains.
- Provides full 3D elastic response, crucial for analyzing pump housings with complex fillets, holes, and ribs.

2.2 Submodeling Concept

Submodeling divides the analysis into two stages:

1. Global coarse model → captures displacement field.

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2. Local refined model → captures high stress gradients.

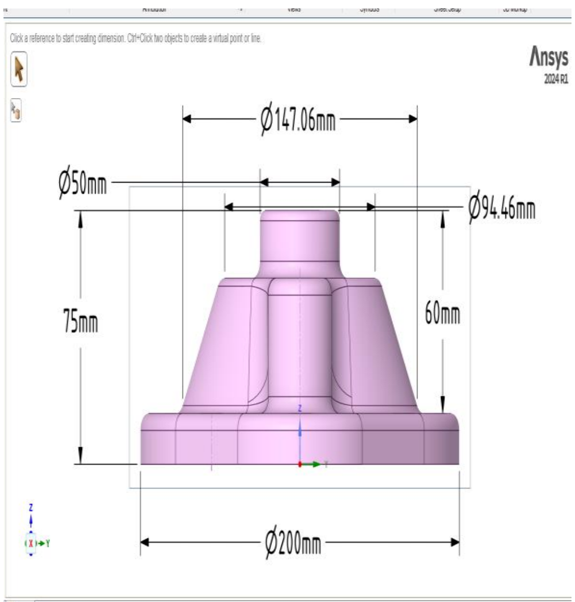
Displacements from the global model are applied to the submodel boundary:

$$u_{sub} = u_{global}$$

This ensures displacement compatibility and consistency.

3. GEOMETRY DESCRIPTION

3.1 Global Pump Housing Model



Casing geometry

To reduce computational cost, **geometric simplifications** are applied where local accuracy is not critical. These simplifications may include:

- Suppression of small fillets, chamfers, and minor surface details
- Idealization of bolt holes and fastener representations
- Removal of features that do not significantly influence global stiffness

The global model represents the full pump housing assembly including:

- Outer casing
- Inlet/outlet sections
- Mounting flanges
- Countersink regions
- Structural blends

Minor geometric details were suppressed to reduce computational cost.

3.2 Submodel Geometry

- Fine mesh with local refinement
- Smaller element sizes near fillets and blends
- Improved stress gradient resolution

This approach exploits the fact that **displacement solutions converge faster than stress solutions** in finite element analysis.

The submodel focuses on the **top housing blend**, identified as a critical stress region due to geometric discontinuity.

Cut boundaries were placed sufficiently away from peak stress locations to satisfy Saint-Venant's principle.

4. MATERIAL PROPERTIES

The pump housing material is assumed to be structural steel.

Property	Value
Young's Modulus	210 GPa
Poisson's Ratio	0.3
Density	7850 kg/m³
Yield Strength	250 MPa

Assumptions:

- Linear elastic behavior
- Isotropic material
- Small deformation theory

These assumptions validate displacement-driven submodeling.

5. MESH STRATEGY

Mesh Details

Mesh discretization plays a critical role in the accuracy and reliability of finite element analysis, particularly when evaluating stress concentrations. Since stresses are derived from displacement gradients, inadequate mesh resolution can lead to significant underprediction of peak stresses. In this study, a **two-level meshing strategy** is adopted in accordance with the global–local submodeling methodology: a coarse mesh for the full model and a highly refined mesh for the submodel.

5.1 Full Model Mesh

5.1.1 Element Type and Meshing Strategy

The full pump housing model is discretized using a **default tetrahedral mesh** generated by ANSYS Mechanical. Tetrahedral elements are well suited for complex three-dimensional geometries such as pump housings due to their ability to automatically fill irregular volumes without extensive manual intervention.

The meshing characteristics of the full model include:

- **Element type:** 3D solid tetrahedral elements
- **Meshing control:** Program-controlled

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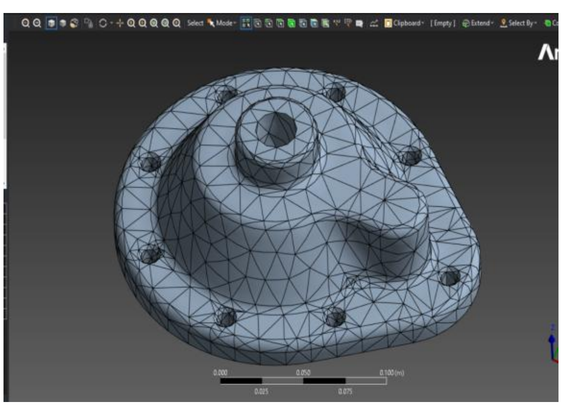
- **Element order:** Higher-order (quadratic) elements where applicable
- **Sizing:** Relatively coarse, uniform element size

5.1.2 Purpose of Coarse Global Mesh

The primary objective of the full model is to accurately capture:

- Global stiffness characteristics
- Load transfer paths
- Overall deformation behavior

Since submodeling relies on **displacement transfer**, the global mesh must ensure **displacement accuracy**, not necessarily stress accuracy. It is well established in finite element theory that:



Coarse Mesh

- **Displacements converge faster than stresses** with mesh refinement
- A coarser mesh can still produce reliable displacement fields

Thus, using a coarse tetrahedral mesh significantly reduces computational cost while maintaining sufficient accuracy for displacement-driven submodeling.

5.1.3 Computational Efficiency Considerations

A fully refined mesh across the entire pump housing would result in:

- Excessive number of elements
- High memory consumption
- Long solution times

By intentionally maintaining a coarse mesh in noncritical regions, the global analysis remains computationally efficient and suitable for iterative design evaluations.

5.2 Submodel Mesh

5.2.1 Meshing Approach

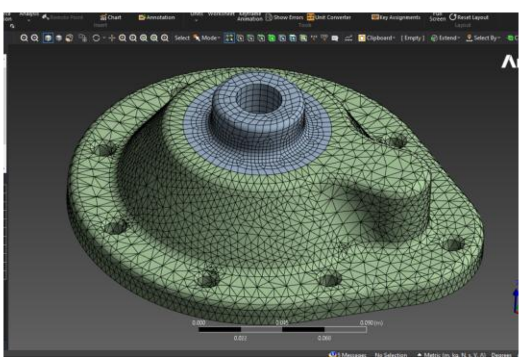
The submodel is meshed using a **hex-dominant meshing method**, which provides superior stress prediction accuracy compared to purely tetrahedral meshes, particularly in regions with high stress gradients.

Key meshing parameters include:

- **Meshing method:** Hex-dominant
- **Global element size:** 4 mm
- **Local face refinement:** 2 mm
- **Element type:** 3D solid hexahedral-dominant elements

Hexahedral elements offer improved numerical performance due to:

- Lower numerical stiffness
- Better strain and stress interpolation
- Reduced element distortion effects



Fine mesh

5.1 Global Model Mesh

- Tetrahedral mesh
- Coarse sizing
- Focus on displacement accuracy

Purpose: Capture global stiffness and deformation.

5.2 Submodel Mesh

- Hex-dominant mesh
- Global size: 4 mm
- Local refinement: 2 mm
- Improved stress interpolation

Hex elements reduce numerical stiffness and improve stress resolution.

6. BOUNDARY CONDITIONS

Theoretical basis:

- Internal pressure generates membrane and bending stresses in the housing walls.
- Pressure loading is applied normal to the surface, producing distributed forces proportional to the local surface area.

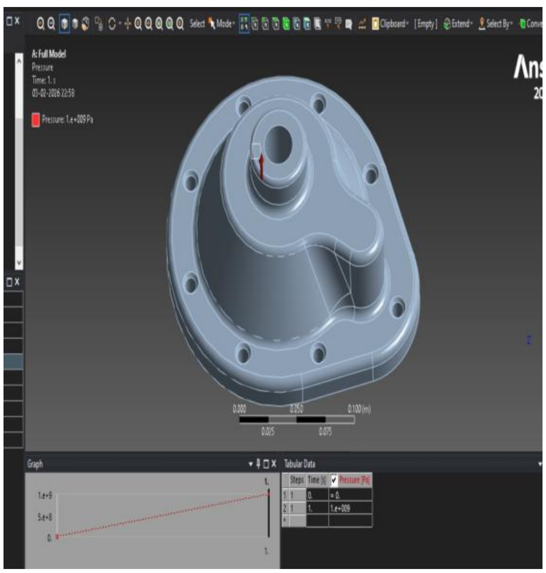
Mathematically, the pressure load contributes to the global force vector as:

$$\{F_p\} = \int_A p \cdot \mathbf{n} \, dA$$

where:

- p is the applied pressure
- $\mathbf{n}$ is the outward normal vector
- A is the pressure-loaded surface area

This pressure load is a primary driver of stress in the pump housing and significantly influences the deformation field transferred to the submodel.



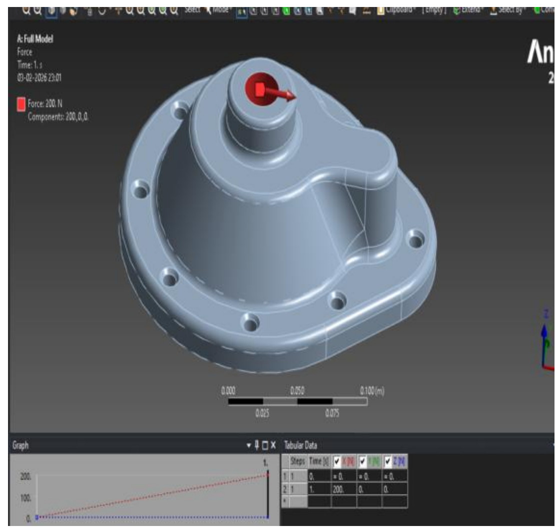
Pressure Loading

6.1.2 External Force Application

An external force of **200 N in the global X-direction** is applied at the **central cylindrical hole**, representing operational loads such as:

- Shaft reaction forces
- Coupling or misalignment effects
- Assembly-induced loads

The force is applied as a distributed load over the cylindrical surface to avoid artificial stress singularities associated with point loading.



Force applied

6.1.3 Compression-Only Support on Mounting Surface

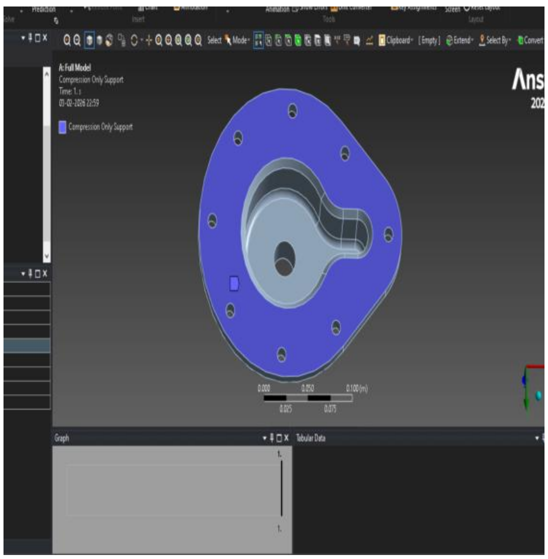
The pump housing mounting surface is constrained using a **compression-only support**, which allows:

- Normal compressive reaction forces
- Separation when tensile forces occur

Engineering justification:

- Represents realistic contact behavior between the pump housing and its base.
- Prevents unphysical tensile constraints that could artificially stiffen the model.

This boundary condition ensures load transfer only occurs when physical contact exists, improving realism without introducing contact nonlinearity.



Compression only support

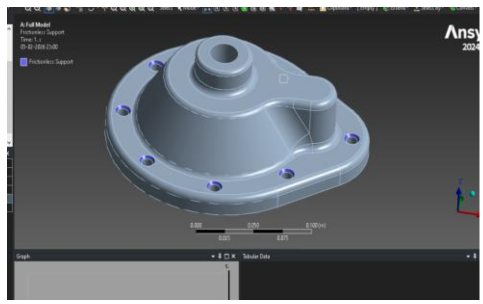
6.1.4 Frictionless Supports on Countersink Faces

Frictionless supports are applied to the countersink faces via named selections.

Purpose:

- Prevent rigid body motion
- Allow free in-plane deformation
- Avoid over-constraining the model

These supports restrain displacement normal to the surface while permitting tangential movement, closely approximating bolt seating behavior without explicitly modeling bolts.



Frictionless support

6.1 Global Model

- Internal Pressure: 1000 MPa
- External Force: 200 N (X-direction)
- Compression-only support at mounting surface
- Frictionless support at countersinks

6.2 Submodel

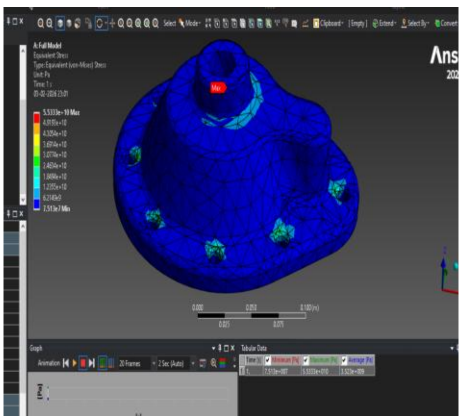
- Imported displacement boundary conditions
- Local pressure application

- Local force application
- No direct supports applied

This ensures kinematic compatibility without over-constraint.

7. RESULTS AND DISCUSSION

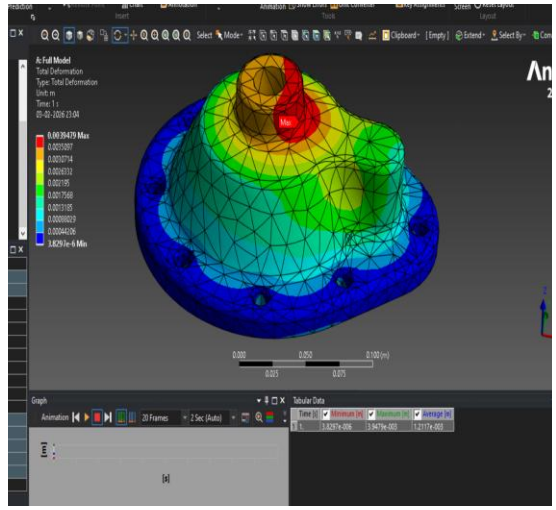
7.1 Global Model Results



Stress Distribution

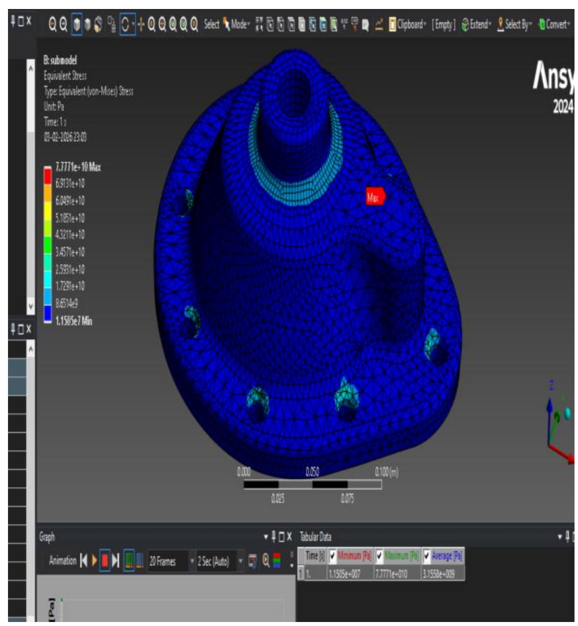
- Max deformation: 0.0039 m
- Equivalent stress: 20000 MPa

Stress contours appear smooth due to coarse mesh.



Total deformation

7.2 Submodel Results



Sub model stress distribution

- Max deformation: 0.004 m
- Equivalent stress: 26000 MPa

Submodel predicts ~39% higher peak stress.

7.3 Comparative Analysis

Model	Deformation (m)	Equivalent Stress (MPa)
Full Model	0.0039	20000
Submodel	0.004	26000

Observations:

- Global model underestimates peak stress.
- Displacement agreement confirms boundary compatibility.
- Stress gradient captured accurately in submodel.

8. ENGINEERING IMPLICATIONS

- Safety margins based on global model alone may be non-conservative.
- Fatigue life predictions require refined local stress.
- Fillet radius optimization may reduce stress concentration.
- Submodeling prevents unnecessary global mesh refinement.

9. COMPUTATIONAL EFFICIENCY

Submodeling reduces:

- Total element count
- Memory usage
- CPU time

While maintaining near fine-mesh accuracy in critical regions.

10. CONCLUSION

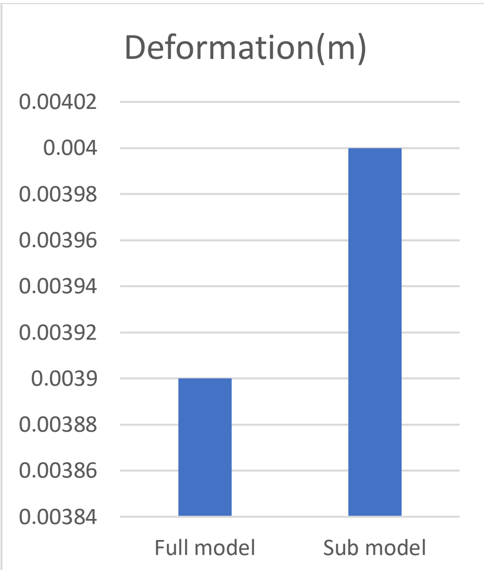
This study demonstrates that global–local submodeling is an effective method for resolving localized stress concentrations in pump housings.

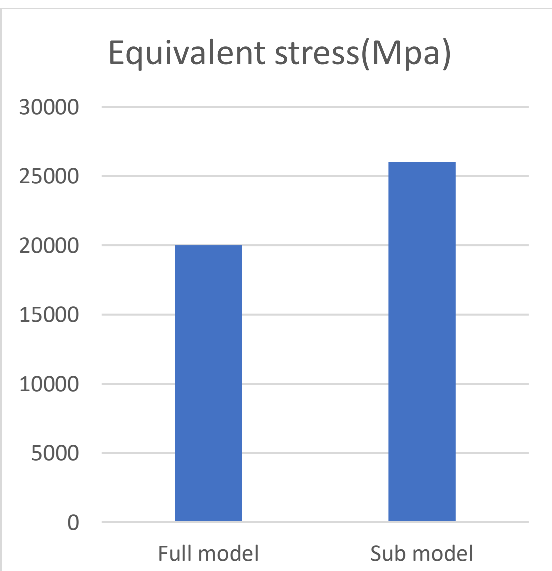
Key findings:

1. Submodeling improves peak stress prediction accuracy by ~39%.
2. Global displacement field remains reliable even with coarse mesh.
3. Proper cut boundary placement is essential.
4. Computational efficiency is significantly improved.
5. Methodology is highly suitable for industrial applications.

Submodeling is therefore recommended for detailed structural assessment of pressure-containing components.

S.No	Parameter	Deformation(m)	Equivalent stress(Mpa)
1	Full model	0.0039	20000
2	Sub model	0.004	26000





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