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Modeling Stress Distribution Analysis On Plate With Hole Using New Mesh Method

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ABSTRACT
Stress concentration around circular holes in plates is a critical challenge in structural analysis. Traditional FEM requires fine meshes near discontinuities for accurate predictions, increasing computational cost. This study introduces a novel, adaptive, geometry-aware mesh method that refines only near the hole while keeping the rest of the mesh coarser. Simulations under uniaxial tension are compared to conventional mesh strategies and analytical solutions. Performance is evaluated by accuracy, convergence, and computational efficiency.

Keywords:*stress concentration, finite element method, adaptive mesh, plate with hole, mesh optimization, computational efficiency*

INTRODUCTION

Plates with holes are commonly used in engineering structures for functional purposes such as bolting or weight reduction. However, these geometric discontinuities induce local stress concentrations that can significantly compromise the strength and fatigue life of the component [1]. Accurate analysis of such stress distributions is essential, particularly in high-performance sectors such as aerospace and automotive engineering.

The classic analytical solution by Kirsch for an infinite plate with a circular hole provides the foundation for understanding stress concentration, yielding a stress concentration factor (SCF) of 3 for uniaxial tension [2]. Yet, real-world structures are finite and involve complex loading and constraints, for which exact solutions are not feasible. Consequently, the Finite Element Method (FEM) is extensively employed to analyze these stress fields in practical designs [3].

An important aspect of FEM is mesh quality. Accurate stress prediction around holes typically demands fine meshes in high-gradient regions. However, over-refinement leads to excessive computational cost. Therefore, modern research efforts focus on improving mesh strategies, including adaptive meshing and geometry-sensitive approaches that allow finer resolution only where necessary [4].

This research introduces a new mesh generation method that aims to enhance stress resolution near circular holes while minimizing global mesh density. The performance of the new method will be evaluated by simulating stress fields in a 2D plate under uniaxial tension and comparing the results with both conventional FEM approaches and analytical benchmarks.

RESEARCH METHODOLOGY

Geometric Model

A 2D rectangular plate (300 mm × 200 mm) with a central circular hole (20 mm diameter) is built in Salome-Meca. Boundary conditions and loads are set for uniaxial tension in a benchmark configuration consistent with literature studies [3], [7]

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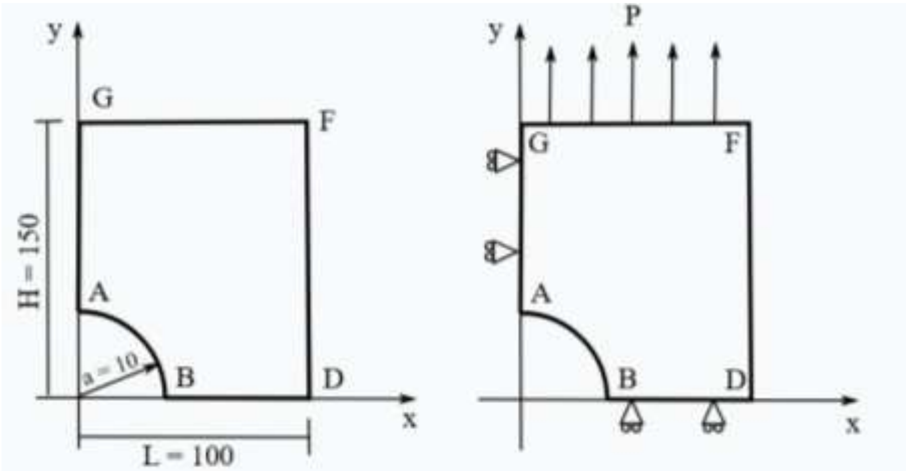

Figure 1. Plate with hole geometry and load condition [7]

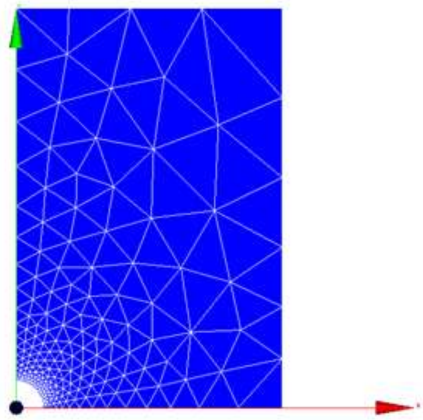

Figure 2. Plate with conventional mesh

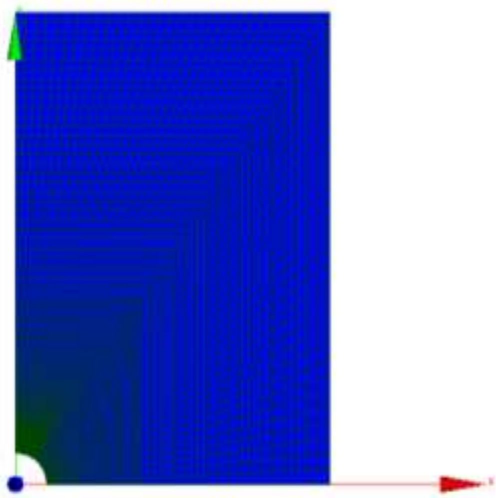

Figure 3. Plate with structured mesh (new method)

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Mesh Strategy

- Conventional mesh: Uniform and refinement near the hole
- Proposed mesh: Adaptive, structured mesh

C. FEM Simulation

Linear elastic analysis under plane-stress conditions, with material properties E = 210 GPa and ν = 0.3. Maximum stress near the hole is extracted for SCF calculation and compared to analytical expectation of 3.0 [2], [3].

D. Validation & Convergence

Convergence studies assess SCF stability with mesh refinement. Validation includes comparison with analytical and high-fidelity benchmark results. Computational efficiency and element count are tracked.

RESULTS AND DISCUSSION

Stress distribution for y-direction on nodal point B revealed that σ_y for conventional mesh provide 300 MPa. Structured mesh (fine) provides σ_y 310 MPa and the same with coarser mesh (new method). According to reference value which is 303 MPa, conventional mesh has 1% accuracy compare to new method which is 2.3% accuracy. Both mesh method showed a very good accuracy that is below 5%. Conventional mesh showed a very fine mesh near the nodal B compare to the new method. This is why conventional mesh gives better result. In the other hand, new meshing technique provides more structured mesh only coarser compare to conventional and the mesh dimension ratio is high. This will distort the element and provide a less accurate value in this modeling.

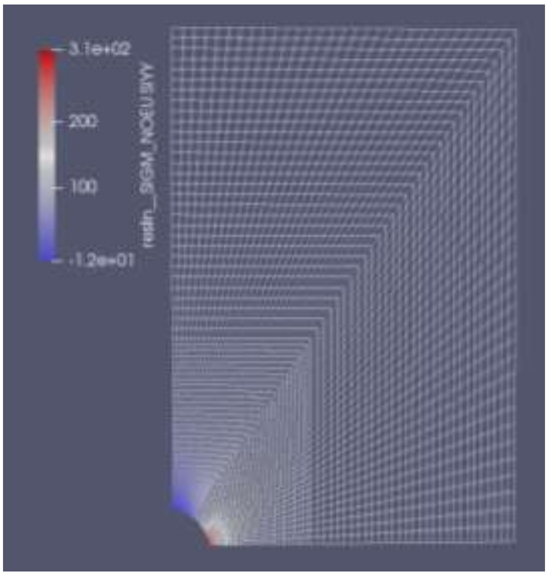

Figure 4. Stress (σy) distribution for structured mesh (new method)

To overcome the situation, the partition should be made as such to provide a better element dimension ratio. Furthermore, sensitivity test should be performed in order to determine a proper element size applied in the modeling.

In terms of σ_x on nodal A, both conventional and new method revealed the same results and the value similar to the reference value.

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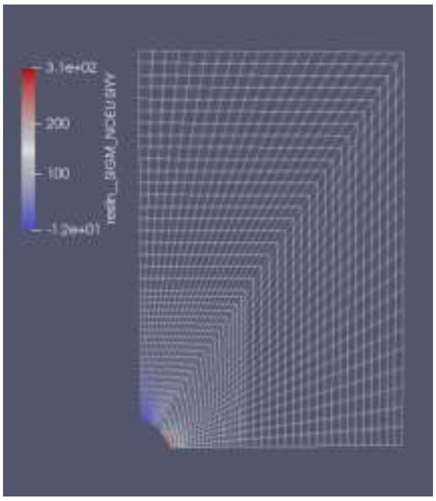

Figure 5. Figure 6. Stress (σy) distribution for structured coarser mesh (new method)

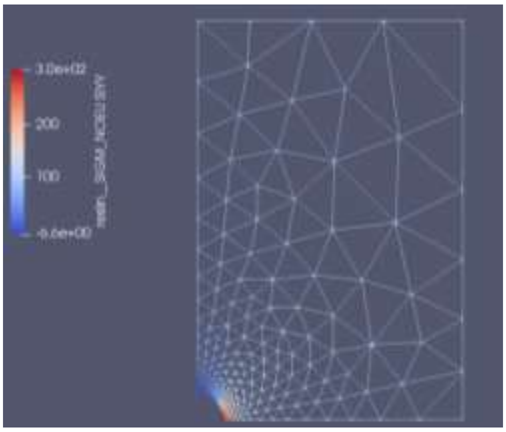

Figure 7. Stress (σy) distribution for conventional mesh

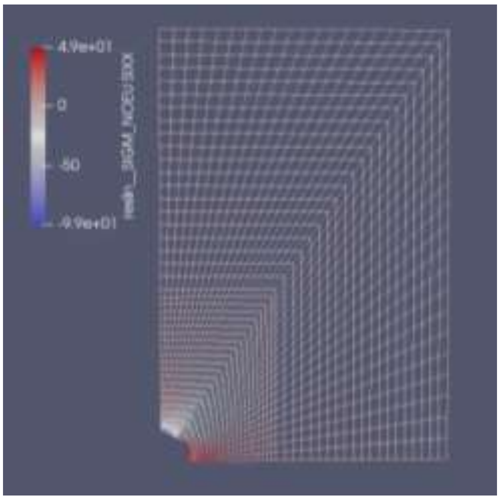

Figure 8. Stress (σ_x) distribution for new method.

CONCLUSION

The proposed mesh method aims to deliver accurate stress analysis around geometric discontinuities while reducing computational burden. By focusing mesh refinement only where needed, this approach can optimize FEM modeling for engineering applications dealing with stress concentrations.

SUGGESTION

Based on the proposed study and its anticipated outcomes, several suggestions are offered for further development and application:

1. Extension to 3D Models While the current study focuses on 2D plane stress conditions, the methodology could be extended to 3D geometries, such as plates with countersunk holes or complex aerospace components, to evaluate its performance under more realistic loading scenarios.
2. Nonlinear Material Behavior Future studies should incorporate plastic deformation, creep, or fatigue effects to assess the mesh strategy's effectiveness in nonlinear and time-dependent simulations.
3. Automatic Mesh Refinement Algorithms Integration of machine learning–based predictive refinement algorithms may further improve meshing efficiency by learning from stress distribution patterns.
4. Validation with Experimental Data Complementary experimental work, such as photoelasticity or digital image correlation (DIC), should be conducted to validate the numerical stress results and establish real-world applicability.
5. Multi-hole and Notched Configurations The proposed meshing approach should be tested on more complex configurations such as plates with multiple holes, notches, or cracks to examine generalizability across typical structural features.
6. Integration into FEM Software Packages The new mesh generation method could be developed into a plugin or built-in module for open-source FEM platforms (e.g., Code_Aster, Salome-Meca, or CalculiX) to enhance usability and accessibility for engineers and researchers.
7. Fatigue Life Prediction Since stress concentration is a critical factor in fatigue, future work can link the improved stress predictions to fatigue life models, enhancing design capabilities for safety-critical components.

By addressing these areas, the proposed method can evolve into a robust tool for advanced structural analysis and contribute significantly to the fields of computational mechanics and design optimization.

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