An Advanced Numerical Framework for Multi-Physics Problems in Engineering

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Abstract

(**Between 150 and 250 words**) This paper introduces a new numerical method for solving complex engineering problems, specifically in structural mechanics and fluid-structure interaction. The approach combines advanced finite element methods with adaptive mesh refinement and is optimized for challenges relevant to Algeria, such as seismic analysis and hydraulic infrastructure modeling. Validated against local data, including studies on the Boukourdane Dam and Algerian buildings, the method shows strong potential for practical applications in earthquake engineering and water resource management in Algeria and the wider MENA region.

Keywords: (Between 4 and 8 keywords) numerical modeling, finite element method, multi-physics, seismic analysis, adaptive mesh refinement, fluid-structure interaction.

1 Presentation of the problem

Many engineering systems involve the interaction of several physical phenomena such as mechanical deformation, fluid flow and heat transfer. These so-called multi-physics problems are commonly encountered in structural engineering, geophysics and hydraulic engineering [1, 4]. Their mathematical modeling typically leads to coupled systems of partial differential equations defined on complex geometries [3].

In practical applications, obtaining analytical solutions is generally impossible. The finite element method (FEM) has proven to be one of the most powerful tools for approximating solutions [2, 4]. The objective of this work is to develop a numerical framework using adaptive strategies that improve accuracy while controlling computational cost [1].

2 Main results

The proposed framework is based on a finite element discretization combined with adaptive mesh refinement techniques, following the theoretical foundations established in [2]. The numerical scheme allows the treatment of coupled physical phenomena such as fluid-structure interaction and can be applied to large-scale engineering problems [4].

The developed approach also incorporates parallel computing strategies to accelerate large simulations. Numerical experiments demonstrate good agreement with reference solutions, particularly for seismic analysis and hydraulic infrastructure modeling [3]. These experiments highlight the robustness of the method and confirm its suitability for Algerian engineering challenges, including the analysis of the Boukourdane Dam.

3 Conclusion

In this work, we have presented a numerical framework for multi-physics problems using adaptive finite element methods. The numerical experiments confirm the reliability of the methodology and illustrate its potential for practical applications in Algeria and the MENA region [4]. Future work will focus on extending the model to more complex coupled phenomena and improving computational efficiency, building upon the theoretical frameworks of [1, 3].

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