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INTEGRATING PERIDYNAMIC THEORY WITH GROUND FISSURE MECHANICS: APPLICATION TO SONGZHUANG GROUND FISSURE STUDY

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Abstract. This study explores the application of Peridynamic (PD) theory in ground fissure modeling and simulation, focusing on the Songzhuang region in Beijing. Traditional methods often encounter difficulties in accurately capturing fissure formation and propagation due to discontinuities at the tips of the crack. The PD model, formulated through integral equations, effectively addresses these issues. It ensures model continuity and considers interactions within a non-local neighborhood of points. First, the study validates the numerical algorithm of the PD model through a two-dimensional tensile test of a plate with a central crack and a simulation of hidden ground fissures in Xi'an. The PD model is then applied to the Songzhuang area. The study integrated field drilling data to simulate fissure development. The results show fissures that grow in the expected direction, with significant subsidence and shear deformation on both sides. These findings provide new information on the impacts of ground fissures. Despite challenges such as high computational demands and the need for further model refinement, the study confirms the broad applicability of PD theory to geohazard mitigation. It also demonstrates the potential of the theory in improving urban planning and improving disaster response strategies.

Key words. Peridynamics, numerical simulation, ground fissure, fissure propagation, land subsidence.

1. Introduction

Peridynamic (PD) theory, developed to address the limitations of classical continuum mechanics, offers a robust framework for modeling discontinuities such as cracks and fissures. By utilizing integral equations, PD theory inherently manages crack formation and propagation, making it particularly suitable for simulating complex hazards like ground fissures.

Ground fissures are critical hazards that have been extensively studied in geosciences and geophysics. Their formation is the result of factors such as tectonic movements, changes in groundwater level, and human activities, including construction and mining. These interactions cause soil consolidation and localized subsidence[6, 13, 29], especially in urban areas with excessive groundwater extraction. In regions like Beijing, these processes have led to numerous subsidence funnels and over-extraction zones[3]. The Songzhuang area in the Tongzhou district is particularly affected, showing rapid fissure development and significant structural damage.

Early studies relied on field investigations and empirical models to characterize ground fissures and establish fissure strength criteria [5, 15, 19, 21, 23, 32, 37, 38]. However, these methods lacked the precision needed to understand the complex mechanisms of fissure formation and propagation. Research has shown that traditional numerical methods, such as finite element and finite difference methods, struggle with modeling discontinuities at crack tips and face significant challenges in

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modeling ground fissure dynamics[1, 2, 4, 9, 10, 18, 27].These methods rely on local differential equations, which become inadequate near discontinuities where stress and strain fields exhibit singular behavior. Consequently, these approaches struggle to accurately capture fissure formation and propagation, leading to imprecise predictions.Therefore, a more advanced approach is required to accurately simulate fissure dynamics and improve geohazard prediction and mitigation strategies.

Empirical models also fail to describe the complex mechanisms of fissure dynamics. They often oversimplify interactions between geological layers and the dynamic processes driving fissure growth. To address these limitations, a more advanced approach is needed. PD theory, with its non-local integral formulation, offers a robust framework for accurately modeling crack initiation and growth. In the field of geology, the PD theory has demonstrated its applicability in simulating geological hazards such as landslides and rock fractures [22, 30]. These applications, displaying the versatility of PD in capturing the complex behavior of geological materials under stress, are crucial for understanding and predicting the occurrence of geological disasters.

Despite its potential, PD theory's application in ground fissure research remains under-explored. This study aims to fill this gap by integrating PD theory with empirical data to provide a detailed understanding of fissure propagation and evolution. The study employs PD theory to model ground fissures in the Songzhuang region of Beijing. PD theory, using integral equations, effectively handles discontinuities and simulates crack formation and propagation[16]. The non-local nature of PD theory considers interactions within a finite neighborhood of points, offering a more accurate representation of fissure dynamics compared to traditional methods.

The PD model is validated through two numerical experiments. First, a two-dimensional tensile test on a plate with a central crack demonstrates the model's accuracy in capturing crack propagation. Second, the simulation of hidden ground fissures in Xi'an replicates large-scale physical experiments, further confirming the model's reliability. The validated PD model is then applied to the Songzhuang area, integrating detailed field drilling data to simulate fissure development. This approach ensures the model accurately captures the morphology and dynamic changes of the fissures.

The primary objective of this study is to apply PD theory to model and simulate ground fissures in the Songzhuang region of Beijing. This study introduces PD theory as a robust framework for ground fissure dynamics, validated through numerical experiments and applied to real-world data. Key contributions include the integration of PD theory with empirical data, demonstrating its accuracy and feasibility, and providing new insights into fissure propagation and evolution. This research enhances our understanding of geohazard, offering practical solutions for urban planning and disaster mitigation.

The article is structured as follows: The introduction outlines the background and motivation for studying ground fissures using PD theory. Next, the literature review discusses traditional numerical methods and highlights the limitations that PD theory aims to address. The methodology section details the PD model formulation and its validation through numerical experiments. Subsequently, the results section presents the application of the PD model to the Songzhuang region, integrating field data to simulate fissure development. Finally, the discussion and conclusion emphasize the broader implications of the findings for geohazard mitigation, urban planning, and future research directions.