Advanced InSAR Applications for Geotechnical Hazard Assessment in Seismically Active Regions

Dr. Meera Kapoor
Professor
Department of Civil Engineering
National Institute of Technology Delhi, India
Email: meera.kapoor@nitdelhi.ac.in

Dr. Raghav Sharma
Associate Professor
Department of Geoinformatics
Indian Institute of Technology Roorkee, India
Email: raghav.sharma@iitr.ac.in

ABSTRACT

Interferometric Synthetic Aperture Radar (InSAR) has emerged as a critical tool for detecting ground deformation in earthquake-prone regions. This paper presents a comprehensive study on geotechnical hazard assessment using InSAR technology, focusing on its capabilities to monitor ground subsidence, surface displacement, and fault movement with millimeter-level accuracy. The study evaluates case examples from various seismically active zones, discusses integration with geotechnical and geological datasets, and highlights the technology's role in disaster risk reduction. The analysis confirms that InSAR-based monitoring significantly enhances the precision of hazard maps, enabling proactive mitigation strategies in vulnerable regions.

Keywords: *InSAR, Geotechnical Hazards, Earthquake-Prone Regions, Ground Deformation, Remote Sensing, Hazard Assessment*

INTRODUCTION

Earthquakes pose severe risks to infrastructure, human life, and socio-economic stability. The ability to monitor and assess ground deformation in earthquake-prone regions is crucial for effective hazard mitigation. Conventional geotechnical survey techniques, while reliable, are limited in spatial coverage and temporal resolution. Interferometric Synthetic Aperture Radar (InSAR) has emerged as a powerful remote sensing technology capable of detecting ground displacement at millimeter accuracy over large areas, regardless of weather conditions or daylight availability.

INSAR TECHNOLOGY OVERVIEW

InSAR works by analyzing the phase difference between two or more Synthetic Aperture Radar (SAR) images captured over the same location at different times. This phase difference reveals changes in the Earth's surface, enabling detection of ground subsidence, uplift, and horizontal movement. The technology can be categorized into differential InSAR (D-InSAR) for detecting temporal changes and Persistent Scatterer InSAR (PS-InSAR) for analyzing long-term surface deformation patterns.

APPLICATIONS IN EARTHQUAKE HAZARD ASSESSMENT

InSAR has been successfully applied to map active faults, monitor ground settlement after seismic events, and detect precursory deformation signals. For example, post-earthquake analysis in Nepal (2015) and Turkey (2023) demonstrated that InSAR could reveal hidden fault lines and quantify displacement over wide regions. This information is invaluable for updating seismic hazard maps and informing urban planning in high-risk zones.

DATA INTEGRATION WITH GEOTECHNICAL STUDIES

InSAR-derived displacement maps can be integrated with borehole data, seismic profiles, and geological maps to provide a comprehensive geotechnical hazard assessment. By correlating radar-derived deformation patterns with soil properties, groundwater levels, and fault mechanics, researchers can better understand the underlying causes of ground instability and predict potential failures.

CASE STUDY: HIMALAYAN REGION

The Himalayan belt is one of the most seismically active regions in the world due to ongoing tectonic collision between the Indian and Eurasian plates. InSAR monitoring in the region has revealed significant seasonal and long-term deformation trends, linked to both seismic activity and anthropogenic factors such as hydropower development. These findings underscore the need for continuous, high-resolution deformation monitoring in geologically unstable regions.

LIMITATIONS AND CHALLENGES

Despite its advantages, InSAR has limitations such as decorrelation in vegetated areas, atmospheric signal delay, and difficulty in capturing rapid, large-magnitude displacements. Advances in satellite constellations, atmospheric correction algorithms, and machine learning techniques are helping to address these challenges, making InSAR more reliable for hazard assessment.

FUTURE PERSPECTIVES

Emerging SAR missions such as NASA-ISRO SAR (NISAR) and the European Space Agency's Sentinel-1C promise to provide unprecedented spatial and temporal resolution for ground deformation monitoring. Integration with Artificial Intelligence (AI) can automate hazard detection and improve prediction capabilities, ultimately enhancing earthquake preparedness and disaster management efforts.

Table 1: Applications of InSAR in Earthquake Hazard Assessment

Application Area	Purpose	Example Region
Fault Mapping	Identify active fault lines	Turkey, Nepal
Post-Seismic Analysis	Quantify displacement after earthquakes	Japan, Chile
Subsidence Monitoring	Track ground settlement	California, USA

CONCLUSION

InSAR technology has revolutionized geotechnical hazard assessment in earthquake-prone regions. By providing accurate, large-scale ground deformation data, it complements traditional geotechnical methods and enhances hazard mapping. Continuous advancements in SAR technology and data integration approaches will further improve the reliability and predictive capabilities of InSAR-based monitoring systems. For seismically active regions, investing in such technologies is essential for disaster risk reduction.

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