Subsurface Seismic Imaging Using Full-Waveform Inversion and Physics-Informed Neural Networks

CTIPS-009 – UTC Project Information

Recipient/Grant Number:	North Dakota State University, University of Utah Grant No. 69A3552348308
Center Name:	Center for Transformative Infrastructure Preservation and Sustainability
Research Priority:	Preserving the Existing Transportation System
Principal Investigator(s):	Kami Mohammadi, Ph.D., P.E.
Project Partners:	USDOT, Office of the Assistant Secretary for Research and Technology – $50,000 University of Utah – $50,000
Total Project Cost:	$100,000
Project Start and End Date:	5/6/2024 to 5/5/2026

Project Description

Roadway subsidence presents a significant challenge in the maintenance and safety of transportation infrastructure. This localized downward movement of the ground surface is largely due to buried low-velocity anomalies, such as highly compressible soft clay or loose sand zones, voids, and abandoned mine workings. Subsidence not only compromises the integrity of the road surface but also poses a considerable risk to the safety of the traveling. The ability to effectively assess and address this geohazard is, therefore, a crucial aspect of transportation system management. The early identification of subsurface anomalies is key to mitigating risks associated with roadway subsidence. By detecting potential hazards before they manifest as surface deformations, remedial actions can be undertaken to prevent extensive damage or catastrophic collapse of the roadway. This proactive approach to roadway maintenance ensures the continuous safety and efficiency of transportation routes, thereby minimizing disruptions and potential hazards to the public. The overall objective of this research is to integrate Physics-Informed Neural Networks with full-waveform inversion to solve the elastic wave equation in heterogeneous geomaterials and invert subsurface low-velocity anomalies.

USDOT Priorities

Roadway subsidence presents a significant challenge to maintaining safe and structurally sound transportation infrastructure. Addressing this challenge effectively ensures the preservation of road usability and minimizes the risk of accidents. This underscores the importance of employing innovative engineering solutions tailored to mitigate the risks associated with subsurface anomalies. The proposed research presents a novel seismic inversion technique aimed at accurately detecting small-scale subsurface anomalies within transportation infrastructures at a reduced data acquisition cost. The early detection facilitated by this approach allows for the prompt implementation of corrective measures, thereby avoiding significant damage or the potential for disastrous roadway failures. These outcomes are aligned with USDOT's strategic goals of safety and preservation of transportation systems.

Outputs

For the technology transfer component of this project, we envision organizing a technical session at a national conference such as the American Geophysical Union (AGU), the Seismological Society of America (SSA), or the Transportation Research Board (TRB). Additionally, The research findings are planned to be published in high-impact journals relevant to our field, including the Geophysical Research Letters (GRL), the Bulletin of the Seismological Society of America (BSSA), and the Transportation Research Record (TRR). To ensure that our work reaches a broad audience of civil engineers specializing in natural hazard mitigation, we plan to share our data and findings on DesignSafe. DesignSafe is the cyberinfrastructure arm of the Natural Hazards Engineering Research Infrastructure (NHERI), designed specifically for facilitating the dissemination and collaboration of research outcomes within the natural hazards engineering community.

Outcomes/Impacts

The anticipated outcome of the proposed research is an inversion algorithm that integrates full-waveform inversion (FWI) with Physics-Informed Neural Networks (PINNs) (objective 2), trained by synthetic seismic data for shallow embedded anomalies (objective 1), whose performance under real-world conditions is further examined by actual seismic data (objective 3). The outcomes of this project have the potential to be expanded to utilize omnipresent urban noise and vibration, such as those from passing vehicles, as a source of excitation. This approach could significantly reduce operational costs and minimize disruptions to everyday urban activities. Finally, with the fast-growing advancements in GPU-based machine learning algorithms and their public availability and simplicity, we believe the proposed inversion method can turn into a fast, robust, and practical subsurface characterization tool for transportation systems.

Final Report

Upon completion, the final report link will be added to the project page on the CTIPS website.