Introduction

The long-term monitoring of Carbon Capture and Storage (CCS) sites requires an efficient and scalable sensing solution to ensure the stability of injected CO_2 and detect any potential leakage. Distributed Acoustic Sensing (DAS) technology, utilizing underground and submarine dark-fiber networks, presents a cost-effective and high-resolution alternative for large-scale seismic and environmental monitoring(Li *et al*., 2022). South Korea has two key CCS candidate sites: a saline aquifer in the West Sea and a depleted gas reservoir in the East Sea (Figure 1). Effective geophysical monitoring of these offshore sites necessitates extensive sensor coverage, which can be achieved by leveraging the existing dark-fiber infrastructure. By repurposing pre-existing fiber optic cables, DAS provides an innovative approach to detecting subsurface property changes and monitoring induced seismicity with minimal additional installation costs. However, practical implementation presents challenges, including signal fidelity, fiber coupling conditions, and the availability of installation metadata. This study aims to evaluate the feasibility of dark-fiber DAS for CCS monitoring applications.

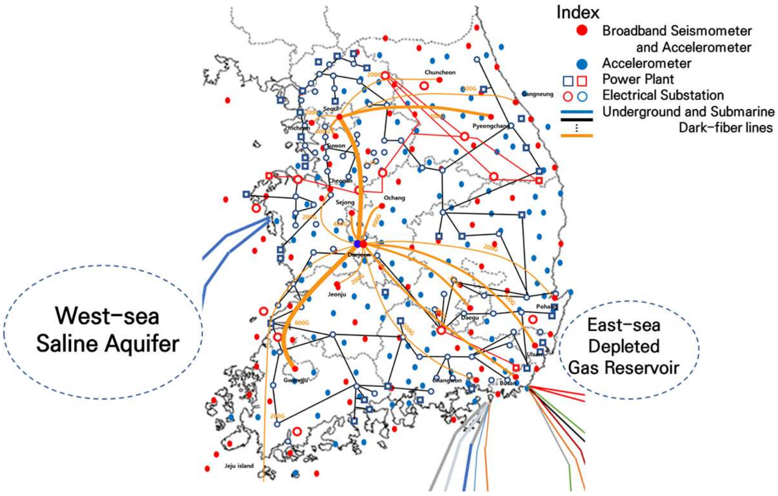

Figure 1. *Underground and submarine dark-fibers, earthquake monitoring network, and CCS sites in South Korea*

Method and Results

To validate the effectiveness of dark-fiber DAS technology in seismic monitoring and subsurface property assessment, extensive field experiments were conducted across multiple regions in South Korea. In Pyeongtaek, a 35 km dark-fiber segment provided by the Korea Electric Power Research Institute (KEPRI) was used to capture seismic signals, with data comparison against conventional seismometers confirming strong performance in the mid-frequency range ($\geq$ 3Hz). With the earthquake data, the signal-to-noise ratio (SNR) was also analyzed for the entire dark-fiber line (Figure 2). Additionally, controlled-source experiments using vibroseis and hammer tests further validated the fiber's ability to capture high-frequency seismic signals ($\leq$150 Hz), demonstrating its potential for both active and passive seismic monitoring. In Daejeon, a 13 km dark-fiber line provided by the Korea Institute of Science and Technology Information (KISTI) Korea Research Environment Open Network (KREOENT) was analyzed using channel back-tracking methods to reconstruct the fiber installation path, allowing for more precise localization of DAS measurement points even in the absence of installation metadata. This methodology is particularly relevant for CCS monitoring with dark-fiber, where accurate geospatial referencing is crucial for tracking small changes due to CO_2 injection. By refining the geo-referencing process, the study enhanced the usability of DAS data for long-term reservoir surveillance and anomaly detection.

Beyond seismic applications, the study also expanded DAS-based traffic and infrastructure monitoring. In Gyengju, fiber lines were deployed along a major to detect traffic-induced vibrations, enabling classification of vehicle weight and speed through signal processing. In addition to the ability to distinguish different vehicle types using passive DAS data, this experiment also shows its potential as a non-invasive alternative for subsurface property monitoring with dispersion analysis for surface wave. Meanwhile, in Paju, a combined DAS and geophone experiment investigated the feasibility of North Korean infiltration tunnel detection. Despite surface coupling challenges, these results indicated that DAS can be utilized for subsurface anomaly detection, suggesting broader applications in national security and defense besides CCS monitoring applications.

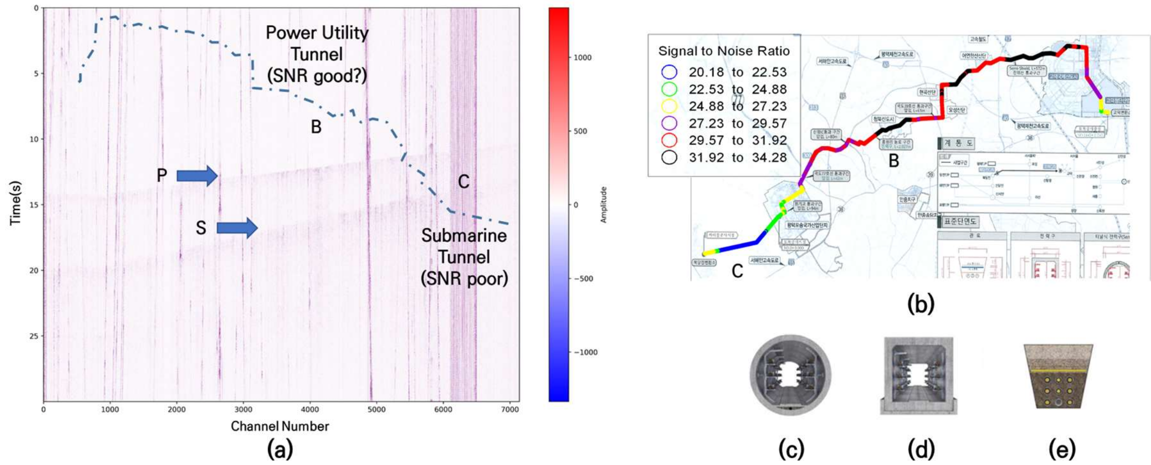

***Figure 2**. (a) Micro-earthquake($M < 2$) recoded by the entire 35 km(5m × 8,000 channels) dark-fiber in Pyeongtaek, (b) SNR analysis for the dark-fiber line with M 4.5 West-sea earthquake (21.01.19) and various deploying conditions for dark-fiber including (c) semi shield, (d) power utility tunnel, and (e) power conduit.*

Conclusions

This study successfully demonstrated the feasibility of dark-fiber DAS for seismic monitoring, CCS site surveillance, and subsurface property assessment. The findings highlight the usability of dark-fiber as seismometers or geophones and dark-fiber channel position back-tracking. This study also demonstrated that DAS technology can effectively monitor traffic signals and detect subsurface anomalies, further supporting its versatility in seismic monitoring, CCS monitoring, urban infrastructure safety, and defense applications. Future efforts will focus on enhancing real-time data processing and expanding DAS applications to submarine cables and underutilized optical fiber networks, paving the way for the global adoption of this transformative technology.

Acknowledgments

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