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Short Communication

Unveiling coastal dynamics using telecommunication fiber optic cables

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Rising sea levels and climate change are reshaping coastal landscapes, exacerbating erosion, and increasing flood frequency, posing serious threats to the ecological balance, economic growth, and the livelihoods of coastal city residents [1]. This necessitates advanced monitoring to mitigate climate impacts and strengthen coastal resilience. While geophysical methods for first-order coastal properties monitoring have gained traction in academia [2,3], traditional monitoring techniques are limited by sparse and unevenly distributed observation stations, failing to meet the needs for detailed regional monitoring. Moreover, the complex social and cultural environments of coastal cities challenge sustained and intensive monitoring efforts. Therefore, developing new generations of coastal dynamics monitoring methods suitable for complex urban environments is urgently needed.

Distributed Acoustic Sensing (DAS) is a sophisticated technology that leverages Rayleigh backscatter in fiber optics to measure local properties such as vibrations. Recent advancements in fiber optic communications and network expansion have significantly propelled the growth and application of DAS [4–7]. This technology enables continuous, distributed detection of acoustic vibrations, transforming urban telecommunication cables into extensive seismic sensor arrays. Researchers have recently applied urban telecommunication cables in various studies, such as imaging shallow subsurface structures, conducting geothermal investigations, monitoring seismic activities, and tracking traffic [8,9]. These applications demonstrate the effectiveness of urban telecommunication cables for both short-term geophysical observations and long-term monitoring. Despite its growing application, there has yet to be any reported use of urban telecommunication cables for coastal dynamic monitoring.

The Qiantang River, connecting the inland to the East China Sea, offers a unique perspective for studying the impact of tides on coastal geological structures due to its distinct tidal bore phenomenon, making the area a natural laboratory for coastal dynamics research. To explore the feasibility of using urban telecommunication cables for long-term monitoring of nearshore geological structures and coastal dynamics, we partnered with Hangzhou Junyun Technology Co., Ltd. to conduct a fiber optic sensing experiment along the Qiantang River. This study reports the preliminary findings and discusses the prospects of urban telecommunication cables for coastal dynamics monitoring and disaster risk assessment.

We utilized a 62 km stretch of urban telecommunication cable located along Zhijiang Road by the Qiantang River in Hangzhou for our experiment. This included a 27 km southern line and a 35 km northern line (Fig. 1a). The cable, housed within an underground pipeline (Fig. 1b), contained 128 standard single-mode fiber cores; only one spare fiber core (Fig. 1c) was connected to interrogator unit (Fig. 1d) for monitoring. The experiment was conducted independently on both lines with monitoring beginning on the southern line on May 8, 2023, and continuing to present, and on the northern line from September 17 to October 22, 2023. To maintain consistency throughout the monitoring process, the observation parameters for both lines were kept constant, with a time sampling interval of 2 ms and a spatial sampling interval of 4 m. Using DAS technology, we demodulated the 62 km cable into 15,500 seismic sensing channels, generating approximately 2.4 TB of observational data daily. This configuration achieves meter-scale spatial resolution across large-scale coverage, significantly enhancing our capability to effectively monitor extensive coastal regions.

To assess the data reliability from telecommunication cables, a nodal seismometer array was installed alongside the cable near Fuxing Bridge on Zhijiang Road. In comparing urban traffic noise

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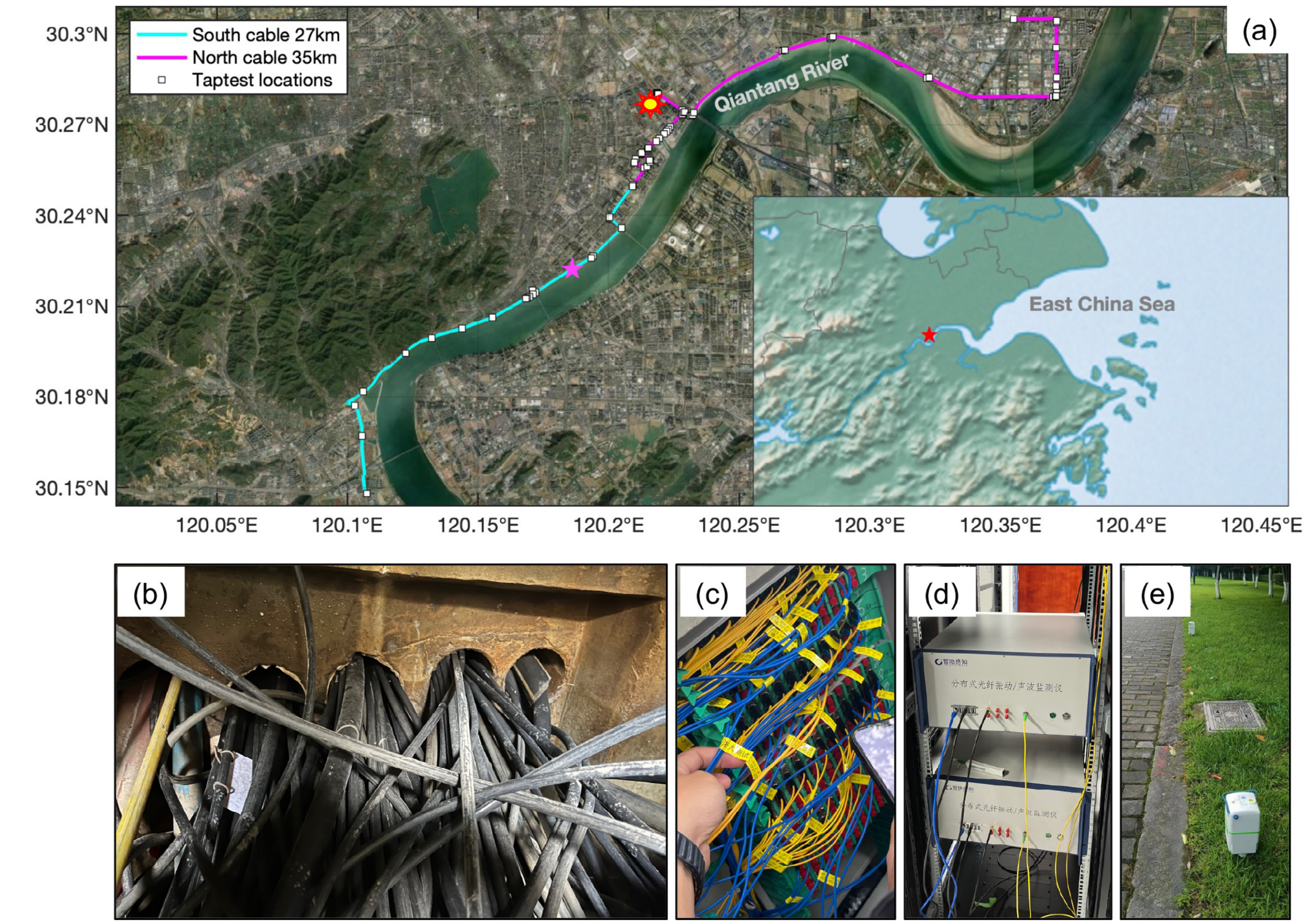

Fig. 1. Geometry map of the telecommunication cable along the Qiantang River. (a) Two telecommunication cables along Zhijiang Road by the Qiantang River, with the southern line (black) approximately 27 km long and the northern line (blue) about 35 km long. The red and yellow stars indicate the locations of the DAS demodulators, the green squares represent points along the line where tapping tests were conducted for geometry calibration, and the magenta pentagrams indicate co-located observation points of DAS and three-component node seismometers. (b) Coupling of the telecommunication cable within the urban pipeline channel. (c) Fiber optic patch cords in the telecommunication cable junction box. (d) DAS interrogator unit from Hefei Zhidi Sensing Technology Co., Ltd. (e) Smartsolo IGU-16HR 3C nodal seismometers positioned along the pipeline.

data collected simultaneously by both systems (Fig. S1 online), we observed that the signal quality from the telecommunication cable was slightly lower than that of the vertical component of nodal seismometers, particularly for high-frequency vehicle signals; however, it exceeded the quality of the horizontal component of the nodal seismometer, which usually suffered from issues related to installation and calibration. Furthermore, we utilize ambient noise interferometry technology to transform urban background noise into coherent seismic signals, which can provide detailed insights into the Earth's subsurface structures [10]. The quality of seismic signals extracted from the telecommunication cable mirrors the pattern observed in the collected urban traffic noise data.

The extract seismic signals can be utilized for rapid seismic velocity imaging, which is crucial for high-resolution coastal dynamics monitoring. We employed Multichannel Analysis of Surface Waves (MASW) method to ensure the reliability of our velocity imaging [11]. Our results revealed that one hour of telecommunication cable recordings could extract high-quality seismic surface wave signals, displaying clear and continuous dispersion energy from 1.5 to 15 Hz (Fig. S2 online).

By analyzing continuous and stable observations from telecommunication cables, we are able to determine the hourly seismic velocity changes beneath the cables. Due to the dispersive nature of surface waves, velocities at various frequencies can reveal subsurface structures at different depths [12]. Using 5 Hz seismic surface waves as an example, these seismic waves predominantly reflect the stability of geological structures approximately 15 m deep according to the half-wavelength rule [13]. During our initial experiment period, we observed distinct velocity changes in the surface wave dispersion energy spectrum (Fig. 2a) and captured the relative velocity changes of the 5 Hz surface waves (Fig. 2b). Incorporating public tidal data from the Qiantang River Zakou station, our results revealed a distinct anti-correlation between tidal variations and the subsurface (~15 m) seismic velocity changes along the Qiantang River. Similar periodic tidal shifts were also noted in subsequent telecommunication cable recordings (Fig. S3 online), corroborated by dominant periodic peaks associated with semidiurnal (M2), fortnightly (Mf), and diurnal (K1) tides (Fig. 2c). Comparisons of seismic velocity changes with environmental parameters such as air temperature, air pressure, and net solar radiation revealed no significant correlations (Fig. S4 online). This suggests that the near-shore fiber-optic cable effectively captures subsurface seismic responses related to tidal dynamics.

From May 8th, decreasing tidal levels led to reduced pore pressure and soil saturation along the riverbank, causing seismic velocities to rise by up to +5%. After May 17th, as tidal levels rose, seismic velocities sharply fell within 30 h, with the largest drop reaching –4.5%. This pattern is attributed to the combined effects

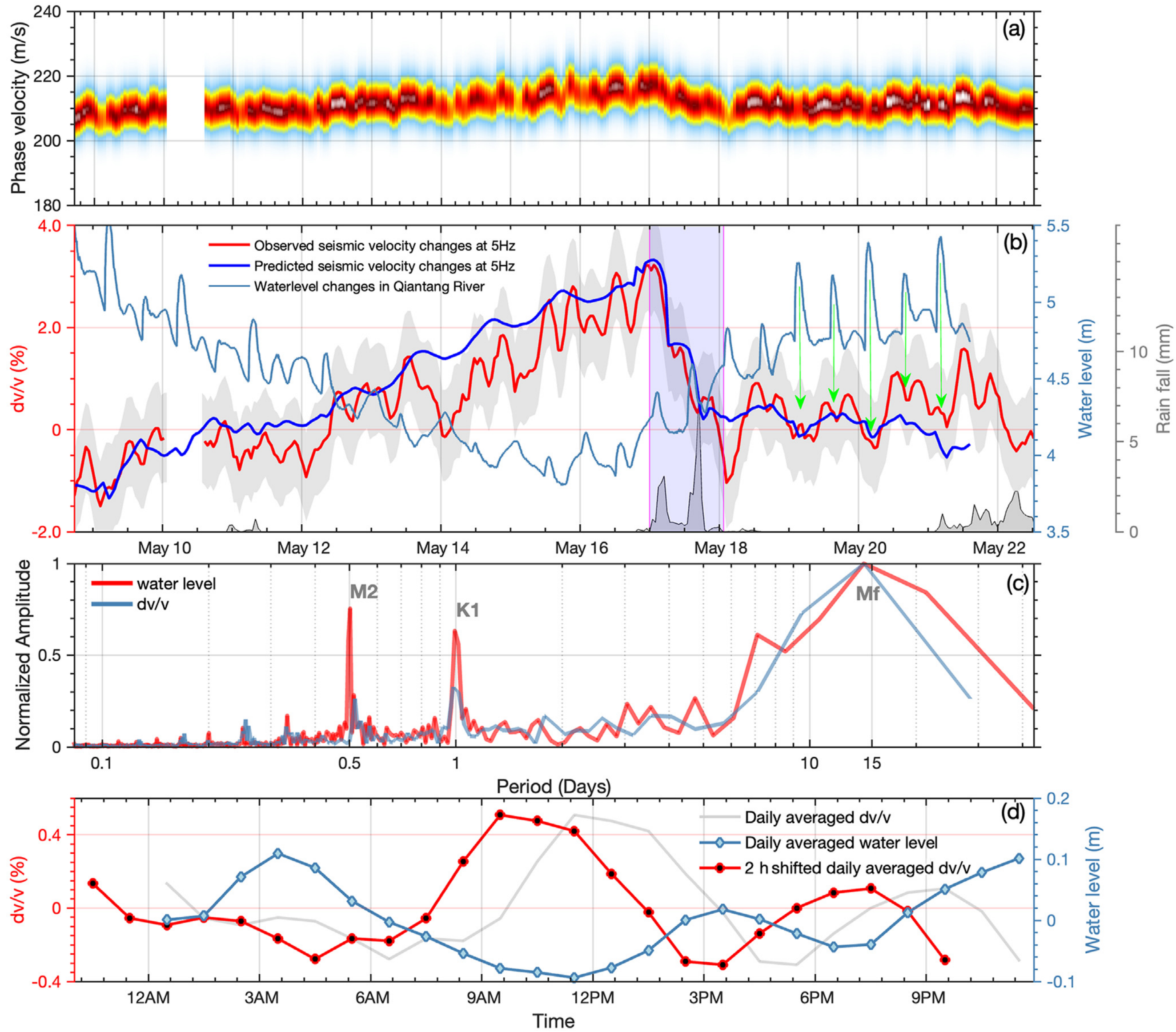

Fig. 2. Dynamic changes in subsurface seismic velocity monitored by telecommunication cable. (a) Hourly changes in the dispersion spectrum of seismic surface waves around 5 Hz recorded by the telecommunication cable from 8 to 22, May 2023. (b) Correlation of seismic velocity changes with tidal levels and rainfall events. The red curve represents the relative changes in seismic velocity obtained by extracting peak energy values from the dispersion spectrum and subtracting the median velocity within the observation period; the background gray patch indicates the picking error; the steel-blue curve shows water level recorded at the Qiantang River Zakou station; the grey histogram indicates daily rainfall changes near the Qiantang River; the blue curve depicts predicted seismic velocity changes based on rock physics modeling, which involves modeling pore pressure perturbations from observed hydraulic data (water level, precipitation, net radiation flux) using the SEEP/W module of GeoStudio software, converting these perturbations into effective stress states, and then translating these into seismic velocity variations through stress-velocity relationships. The rock physics model incorporates the geometrical configuration of the Qiantang riverbank, with flow dynamics characterized by the Richards equation and evaporation effects described using the Penman-Wilson equation. (c) Fast Fourier Transform (FFT) spectral analysis of seismic velocity changes (the steel-blue line) and tidal levels (the red line) with period peaks at approximately 0.5, 1, and 14 d, likely corresponding to periodic tidal components: M2, the principal lunar semi-diurnal component, K1, influenced by the sun's gravity, and Mf, the lunar fortnightly tide associated with lunar declination, respectively. (d) Daily averaged changes of seismic velocity (the gray line) and water level (the blue line) in (a) after the corresponding linear trends removed; the red dotted line represents the 2-hour-shifted daily averaged seismic velocity changes.

of rising tides, which increase pore pressure and soil saturation, and a significant rainfall event in Hangzhou on the 17th (depicted in the grey histogram in Fig. 2b). Preliminary rock physics modelling using GeoStudio software [14] quantifies these dynamics by linking changes in tidal levels and rainfall with variations in pore pressure and soil saturation (the blue line in Fig. 2b). This model demonstrates how increased pore pressure during high tides and heavy rainfall leads to decreased effective stress and subsequently lower seismic velocities, suggesting that short-term seismic velocity fluctuations are driven by both tidal changes and weather events. This interplay markedly accelerates velocity decreases and commonly triggers coastal disasters in Eastern China, particularly those caused by typhoons and heavy rains [15].

Following May 19th, as tidal fluctuations stabilized, seismic velocity changes showed a distinct anti-correlation, with troughs in velocity changes lagging about a few hours behind tidal peaks (highlighted by the green arrows in Fig. 2b). This lag is consistently visible in daily observations throughout the monitoring period and particularly marked with a 2-hour delay when averaging the two-week daily changes of the seismic response and the water level (Fig. 2d). This delay likely indicates the hydraulic diffusion rate in the medium, providing valuable insights into the hydrogeological processes of fluid movement and pressure transmission in porous media.

The preliminary results demonstrate that using telecommunication cables equipped with DAS technology effectively monitors coastal dynamics. By utilizing telecommunication cables, we successfully monitored changes in seismic velocity in shallow subsurface structures along the banks of the Qiantang River, shedding light on the impacts of tidal changes and weather events. This provides new insights into the mechanisms of river erosion and weather-induced disasters, aiding in the assessment of coastal resilience in the context of climate change and coastal hazards. DAS showcases its potential by transforming extensive cable lengths into seismic sensor arrays, achieving meter-scale spatial resolution across tens to hundreds of kilometers and enabling hourly tracking of coastal dynamics for cost-effective long-term monitoring. Furthermore, the high-resolution capabilities of this technology show great promise for urban geological safety monitoring, particularly in tracking landslide and levee break hazards, which have recently become pressing concerns in southern China. The reliability of using ambient urban noise as continuous seismic sources, as opposed to less consistent man-made sources, establishes DAS as a dependable tool for early warning systems and disaster prevention. Adapting this method to different settings necessitates careful consideration of local geological and environmental conditions. In regions like mountainous areas, particularly for cryosphere studies, it is essential to account for variables such as air temperature and pressure. Furthermore, specific installation parameters for fiber cables, such as those found in urban utility tunnels where cables are suspended on stands, must be thoroughly evaluated to ensure effective deployment.

However, the distributed nature of DAS poses challenges in managing large data volumes and necessitates high accuracy in rapid hazard response. Future efforts could integrate artificial intelligence and cloud computing to analyze huge DAS data in conjunction with hydrological, meteorological, and geotechnical information. With the development of smart cities and the progression of urban digital transformation, the application scope of telecommunication cables is expected to expand across entire coastal urban areas, enhancing the scope for comprehensive coastal monitoring with advanced fiber optic sensing technology.

Conflict of interest

The authors declare that they have no conflict of interest.

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Author contributions

Feng Cheng, Jianghai Xia, and Chi Zhang contributed to experiments design, data analysis and manuscript writing. Feng Cheng and Baoshan Wang conducted the experiments. Feng Cheng, Jianghai Xia, Baoshan Wang, and Chi Zhang contributed to writing reviewing and editing.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scib.2025.02.023.

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