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Telecom Fibers Are Sensing Earthquake Hazards in Istanbul

A fiber-optic cable below Türkiye's earthquake-prone metropolis is offering new details about how seismic waves will rattle the city—and demonstrating the potential of a bigger monitoring effort.

By **Daniel Bowden**, **Ebru Bozdag**, **Ali Shaikhsulaiman**, **Andreas Fichtner,** and **Özgün Konca**
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Istanbul, Türkiye, with a population of more than 15 million, is one of the world's largest and densest metropolises. Credit: iStock.com/prmustafa

Fiber-optic telecommunications infrastructure connects homes, cities, and even continents, allowing us to see and hear each other over distances short and vast. In recent years, seismologists have been using these same fibers to also "see" and "hear" seismic signals within Earth.

Vibrations from earthquakes, explosions, and even passing cars exert stresses on buried fiber-optic cables, causing the fibers to stretch and contract (i.e., to experience strain), which ever so slightly alters how light travels through them.

These alterations—measured through a technique called **distributed acoustic sensing** (DAS)—reflect strain rate signals that reveal information about how and where vibrating waves travel underground. Among other uses, this information helps us to **identify areas most at risk** from earthquake damage, allowing civil engineers and city planners to prepare by adapting buildings and other structures.

DAS, though still a young technology, has been applied in numerous seismic studies and pilot projects in **different environments and locations**. It is now also being used to cover wide swaths of urban infrastructure [e.g., ***Spica et al.***, 2020; ***Nayak et al.***, 2021].

In Istanbul, Türkiye's largest city, scientists and engineers from the Istanbul Metropolitan Municipality (IMM) and Boğaziçi University's Kandilli Observatory, together with colleagues from Eidgenössische Technische Hochschule (ETH) Zürich in Switzerland and the Colorado School of Mines, have been testing local telecommunications infrastructure to estimate future shaking in the area and help the city better prepare for coming earthquakes.

A City Ready to Shake

Istanbul, with a population of more than 15 million, is one of the world's largest and densest metropolises. It lies just north of the Sea of Marmara and the **North Anatolian Fault** (NAF), a strike-slip fault spanning northern Türkiye with a history of producing damaging earthquakes. Seismologists have warned that a major earthquake on the extension of the NAF in the Sea of Marmara is overdue [e.g., ***Bohnhoff et al.***, 2013]. The question is not *whether*, but *when*, an earthquake will occur and how best to prepare.

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With knowledge of how strong the shaking can be in different parts of the vast city, building codes and engineering techniques can be adapted appropriately. Developing this knowledge first requires understanding how soils and sediments in the region might resonate and amplify seismic waves.

The city has experienced strong shaking in the past, including during the M_w 7.4 **Izmit earthquake** in 1999, which occurred on the NAF about 90 kilometers east of Istanbul's center. Even though that earthquake's epicenter was relatively far away, seismic strong motion instruments recorded ground accelerations of about 0.25*g* (2.45 meters per second squared) near the town of Avcılar on the European side of the city (i.e., west of the Bosporus Strait). This level of shaking—equivalent to an intensity of VII on the modified Mercalli scale—is expected to produce "negligible damage" in well-built structures but "considerable damage in poorly built or badly designed structures," **according to the U.S. Geological Survey**. In Avcılar alone, about 1,700 buildings collapsed or were severely damaged, and 273 people lost their lives, largely because the amplitudes of seismic waves from the quake were amplified unevenly as they passed through the soil [***Tezcan et al.***, 2002].

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Studies of past earthquakes using conventional seismic instruments have improved our understanding of potential shaking hazards in locations all over the world. But having sensors in place to record ongoing ground motions at very high spatial resolution represents a major improvement in monitoring capabilities. This is where DAS comes in.

Telecommunication fibers run below every corner of Istanbul’s vast urban area, as they do in many cities across the world. One such fiber, owned by the IMM, follows the coastline along the Marmara on the city’s Anatolian side as it connects surveillance cameras in various parks. About 13 kilometers offshore lies the northern branch of the NAF (Figure 1), which has been mostly dormant apart from occasional small earthquakes that pass mostly unnoticed by humans.

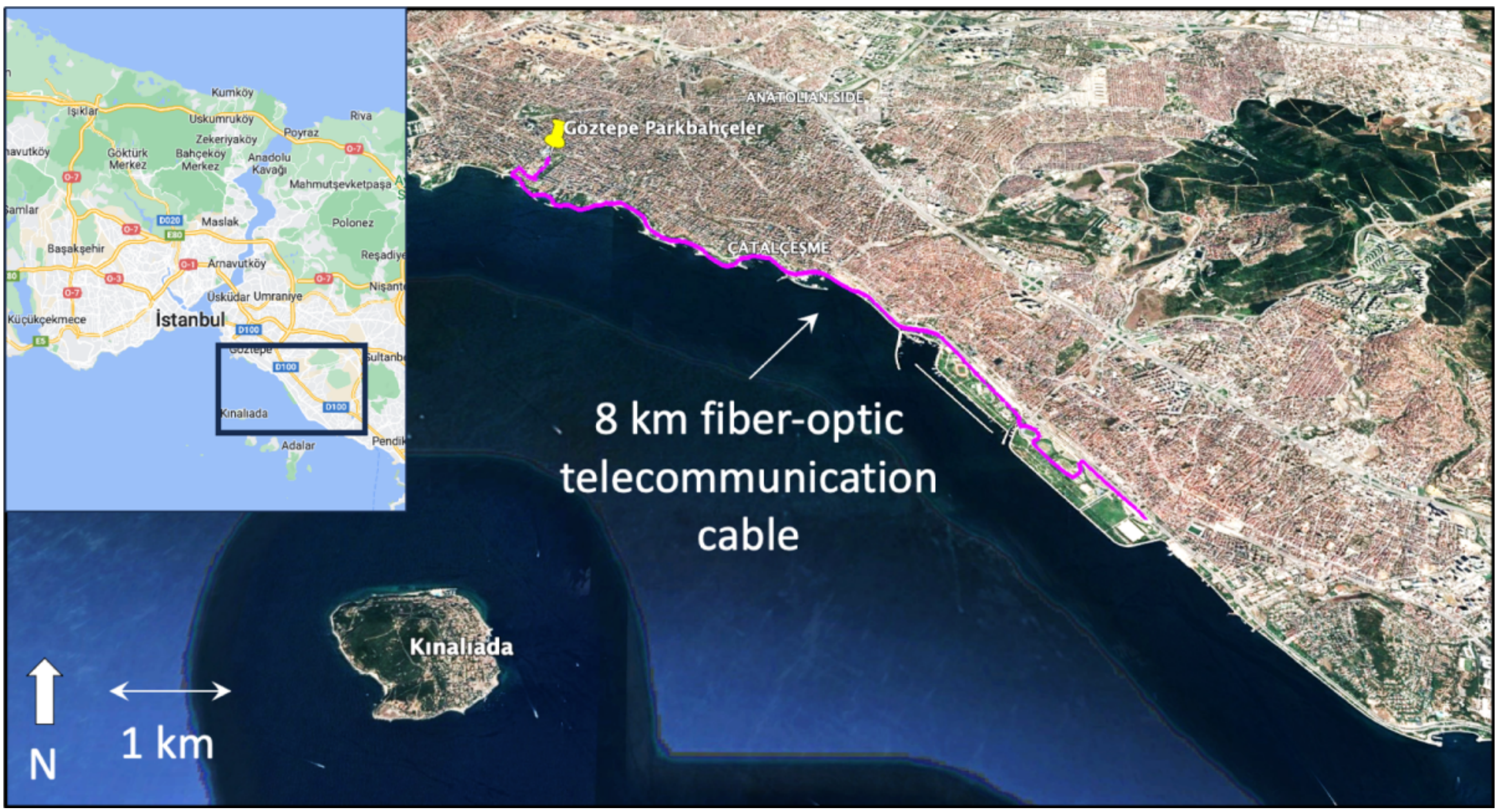

Fig. 1. Istanbul (inset) straddles the Bosporus Strait, which connects the Sea of Marmara to the south to the Black Sea. The fiber-optic telecommunications cable (magenta line) used in the pilot distributed acoustic sensing (DAS) project runs along part of the coast in southeastern Istanbul, not far from the offshore North Anatolian Fault. Credit: Inset: Map data ©2023 Google; Satellite image: Google, with data from Airbus, Maxar Technologies, TerraMetrics, DataSIO, NOAA, U.S. Navy, NGA, GEBCO

Sensing Seismicity Below Istanbul

In early 2023, our team of seismologists collected data from 8 kilometers of the IMM's coastal cable by sending pulsed laser light through it to sense strain. The fiber-optic DAS system records time series of strain rates at a resolution of a couple of meters, meaning that our system does the work of roughly 4,000 single-component seismometers. The result was a high-resolution look at how seismic waves propagate through the ground surrounding the cable that helps us understand subsurface geology and model possible future earthquake shaking.

For example, the signal from a small explosion used in a nearby subway construction project in early February 2023 was clearly recorded (Figure 2), and the resulting seismic waves were tracked as they traveled along the winding fiber. Other signals, including those from passing cars, appear in the same data but are smaller and more localized, consistent with the weaker ground motion caused by the cars.

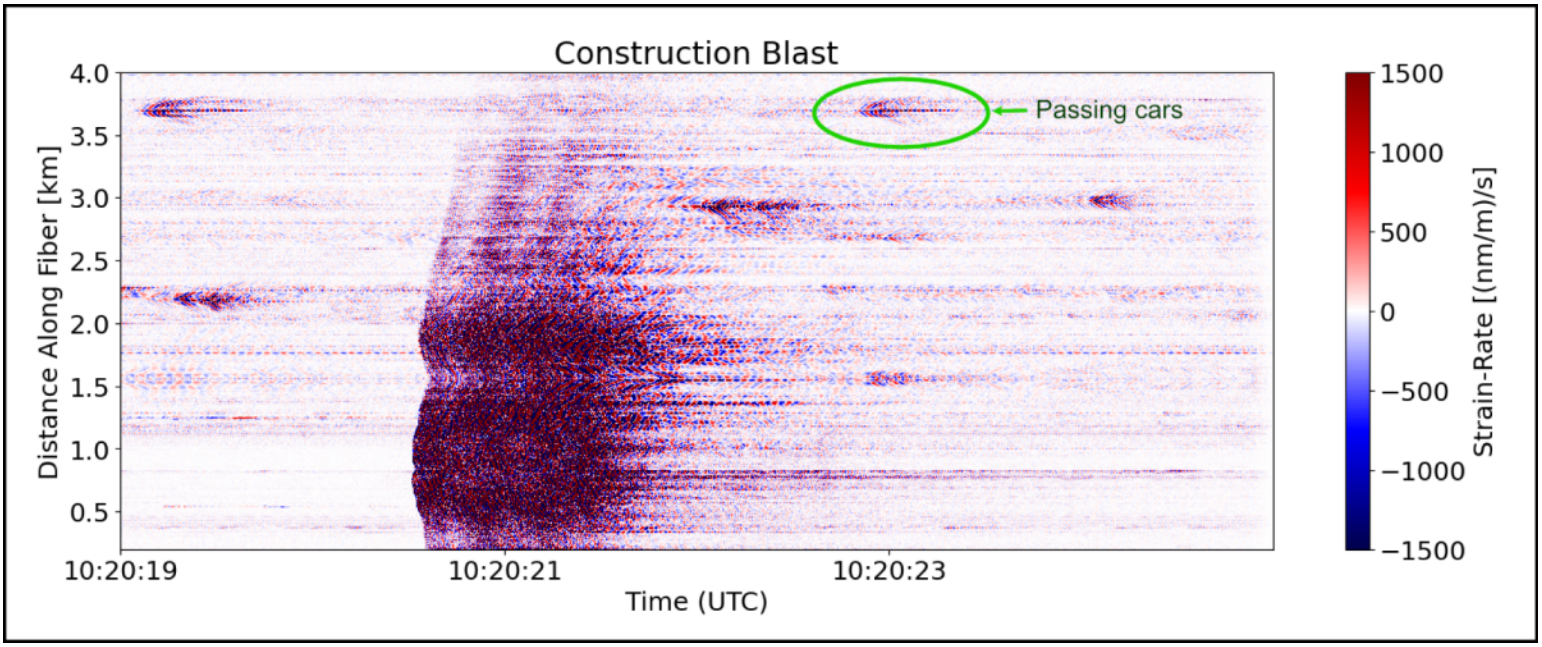

Fig. 2. DAS recordings from 2 February 2023, which show the measured strain rate (color scale) as a function of time and distance along the fiber, reveal the effects of a nearby construction demolition blast (dense signal) and of passing cars.

Apart from sensing explosions and automobiles, our DAS system also detected earthquakes big and small. On 6 February 2023, south central Türkiye and northern Syria were rocked by the devastating **Kahramanmaraş earthquakes**, which occurred along segments of the East Anatolian Fault system. The first, a M_w 7.8 event, was followed hours later by another measuring M_w 7.5 and subsequently by numerous aftershocks for days afterward. The resulting damage and disorder took the lives of more than 55,000 people and left millions in need of humanitarian assistance. Since then, engineers and seismologists have been working to understand why the source faults ruptured where and when they did, the patterns of shaking and damage they caused, and what parallels can be drawn to other areas.

Istanbul's physical infrastructure was not much affected by the Kahramanmaraş earthquakes, which occurred about 850 kilometers southeast of the city. Nevertheless, our DAS installation, as well as traditional seismic monitoring instruments throughout the city, clearly recorded the strong pulse of seismic waves as they arrived across the entire 8-kilometer fiber (Figure 3). These DAS data from the major earthquakes in February 2023 are publicly available from

Wuestefeld et al. [2024].

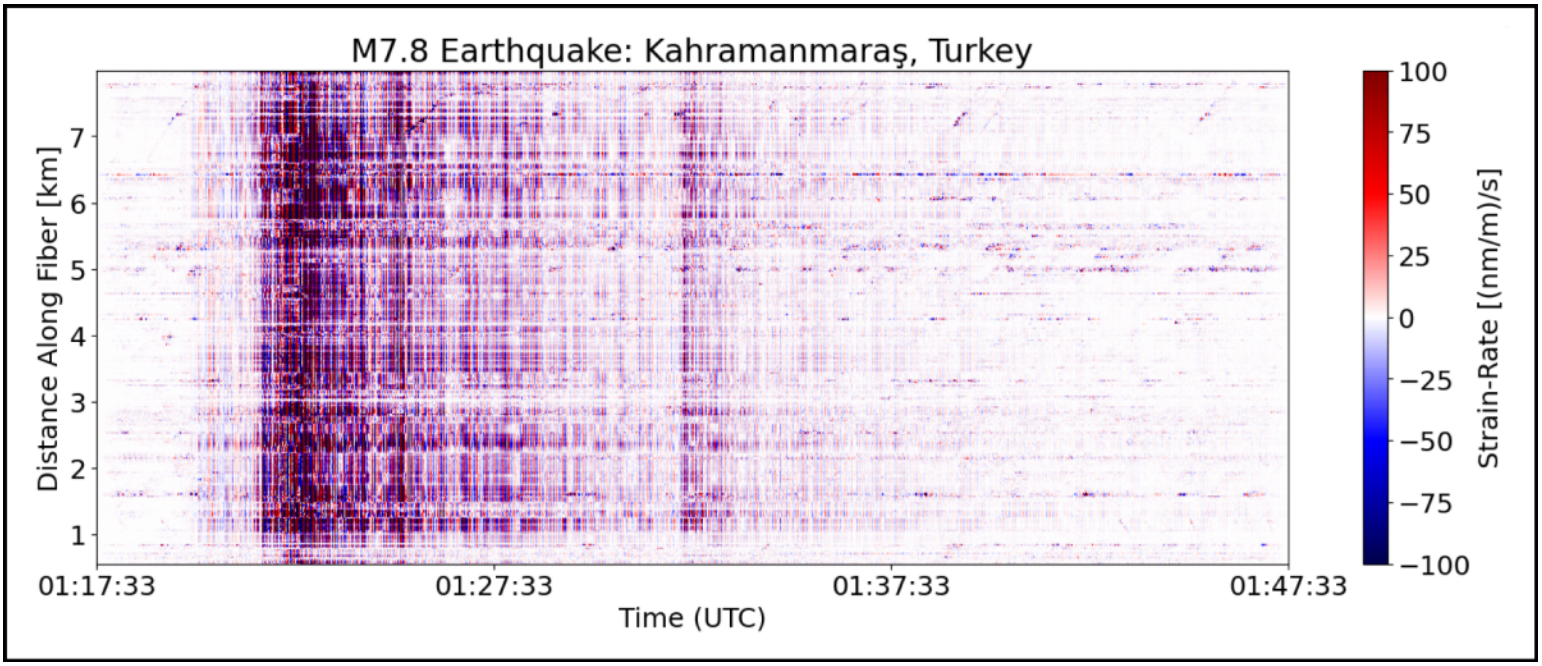

Fig. 3. The DAS system in Istanbul recorded signals from the M_w 7.8 earthquake that occurred in south central Türkiye on 6 February 2023.

If we look closely at the DAS data, we can see how the strength of the shaking varied dramatically across small distances, as local geology amplified and resonated the vibrations (Figure 4). Some variation in these recordings might also have occurred because of differences in how the fiber was coupled to the soil at different points underground or because the orientation of the fiber changes along its route. It is our job as seismologists to sort through such signals and produce maps to better advise civil engineers.

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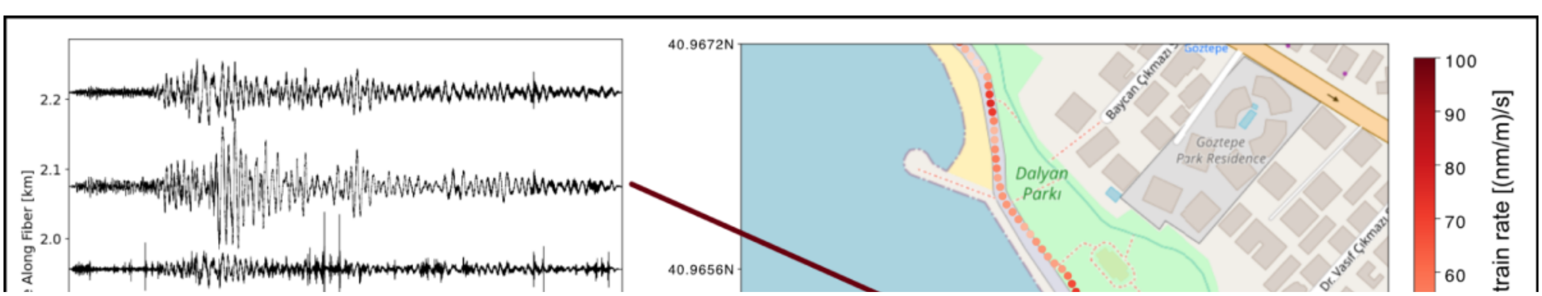
Recording and understanding large earthquakes are undeniably important for hazard assessment. But monitoring small earthquakes, most of which go unfelt by humans, also contributes to better understanding of fault geometries and to better mapping of where faults are moving and where they’re locked together—and thus where they might rupture in the future. This is a crucial part of the hazard forecasting that civil engineers rely on when designing buildings and building codes.



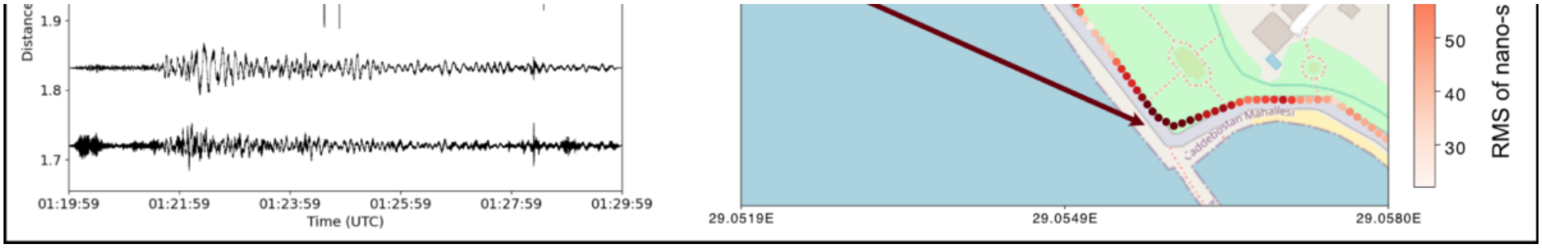


Fig. 4. A closer view of some of the signals in Figure 3 recorded from the M_w 7.8 Kahramanmaraş earthquake shows how much seismic wave amplitudes can vary over short distances. Several individual strain rate time series, recorded just a few hundred meters apart, are shown at left; at right are the root-mean-square (RMS) of signals recorded along a portion of the fiber near Dalyan Parkı. Credit: Map data from OpenStreetMap

IMM's fiber that our team used is aligned parallel to the coastline and the NAF segment not far offshore, so it could be very valuable in detecting small earthquakes and patterns of behavior that will offer clues to the fault's stability. Together with colleagues, we are currently sifting through our DAS data to find these small signals and any patterns in them.

A Fraction of the Potential

The DAS recordings here represent what is so far a pilot project; these 8 kilometers of fiber are a small fraction of the telecommunications infrastructure that exists under Istanbul. However, the clear signals from earthquakes hundreds of kilometers away—as well as signals from smaller events nearby—underscore the value of these types of measurement systems and the potential that could come from a larger effort.

We are using the data to develop a model of subsurface geology near the city, which will then be used in computer simulations to estimate how the ground will shake in future earthquakes. On the basis of the success of this pilot project, we hope the method will be used to improve hazard estimates throughout the city through future collaborations.

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Telecommunications fibers run through countless other vulnerable cities worldwide—seismologists in these places just need the right tools, workflows, and partnerships to leverage those networks.

Moving forward, expanding the network of fiber-optic cables used for DAS in Istanbul could revolutionize both earthquake monitoring and subsurface geologic characterizations there. Telecommunications fibers similarly run through countless other vulnerable cities worldwide—seismologists in these places just need the right tools, workflows, and partnerships to leverage those networks to help.

The rich data sets from such efforts bring new challenges, however. Large-scale DAS systems could easily generate petabytes of data annually, all of which would need to be analyzed in real time or stored for later analysis. Machine learning may be [one tool to help with such data volumes](), but designing a single, standardized approach that can work across noisy urban environments is not easy. Vibrations from cars and infrastructure make distinguishing earthquake signals difficult, and because every fiber follows its own winding route below a city, it can be difficult to make one algorithm or model applicable to all others.

The team of seismologists working in Istanbul and other groups around the world [*Wuestefeld et al.*, 2024] are actively collecting and sharing data sets to enable and improve such research. Hopefully someday soon, this work will allow communities globally to watch and listen to the ground beneath their feet in more detail than ever before, so they can better anticipate and prepare for hazards to come.

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