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Rapid detection of earthquakes and tsunamis using sea floor fibre-optic cables

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Standard methods of earthquake detection use seismic waves, which travel through the earth at speeds up to about 8 km/sec for compressional waves. The compressional waves have speeds about 75% higher than the following shear waves, which are the waves that do damage in earthquakes. This is the basis for early earthquake warning systems, which have been operational in some countries for the past several decades. For nearby earthquakes, the warning provided by compressional waves is only a few seconds, but there can be several tens of seconds warning for more distant earthquakes. The warning time is much greater for tsunamis, because their top speeds across the ocean are only about 0.2 km/sec. This explains why tsunami warning is mainly based on seismic waves. Some warning systems use Deep-ocean Assessment and Reporting of Tsunamis (DART) buoys to detect the passage of tsunamis in the ocean to supplement seismic methods, but these buoys are expensive to build, deploy and maintain. Similarly, Ocean Bottom Seismometers (OBS) are notoriously expensive, unreliable and easy to lose.

Seventy percent of the planet's surface is covered by water, and seismometer coverage is limited to a handful of permanent OBS stations. Marra et al. (2018) showed that existing telecommunication optical fibre cables can detect seismic events when combined with frequency metrology techniques by using the fibre itself as the sensing element. They detected earthquakes over terrestrial and submarine links with lengths ranging from 75 to 535 kilometres and a geographical distance from the earthquake's epicenter ranging from 25 to 18,500 kilometres. If information about the occurrence of earthquakes can be transmitted by lasers (light waves), it will arrive much sooner than seismic waves because light waves travel at 204,190 km/sec, providing much more warning time. Marra et al. (2018) proposed that implementing a global seismic network for real-time detection of underwater earthquakes could be accomplished by applying this technique to the existing extensive submarine optical fibre network.

Distributed Acoustic Sensing (DAS) is a new, relatively inexpensive technology that is rapidly demonstrating its promise for recording earthquake and tsunami waves in a wide range of research and public safety applications (Zhan, 2020). DAS systems have the advantage of being already deployed across the oceans where deployments of DART and OBS are difficult and limited. DAS systems are expected to significantly augment present seismic and tsunami detection networks and provide more rapid information for several important applications including early warning.

Fibre-optic cables are commonly used as the channels along which seismic and other kinds of data are transmitted. With DAS, the hair-thin glass fibres themselves are the sensors as well as the transmission channel. Each observation episode begins with a pulse of laser light sent down the fibre. Internal natural flaws within the fibre, such as fluctuations in refractive index in the glass, cause scattering of the pulse of laser light that is sent down the fibre (Figure 1). DAS uses Rayleigh backscattering to infer the longitudinal strain or strain change with time every few metres along the fibre; this information is sent back to the source of the pulse. The strain in each fibre section changes when the cable is disturbed by seismic waves or other vibrations passing through the network. The return signals carry a signature of the disturbance. It takes only a slight extension or compression of a fibre to change the distances - as measured along the fibre - between many scattering points. Interferometric analysis extracts how the signals from scattering points vary in timing or phase, and further processing reconstructs the seismic waves that caused the perturbance. In addition to detecting seismic waves, the data can also be used to detect pressure changes in the ocean itself, which could be used to detect tsunamis.

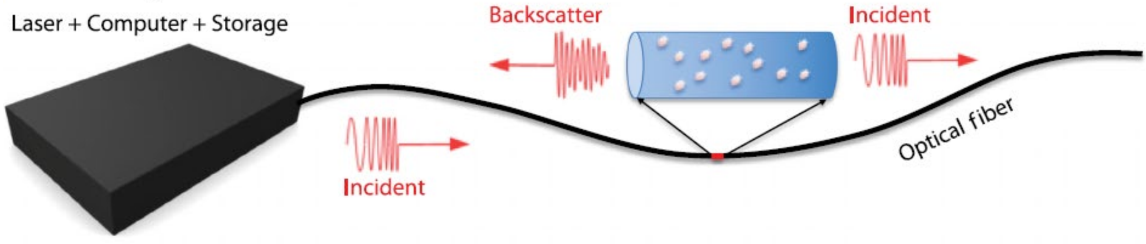

Figure 1. Backscattering from defects in the fibre that carries information about the strains in every few metres of the cable. Source: Zhan (2020).

Kamalov and Cantono (2020) point out that the links used by Marra et al. (2018) were short (under 535 km for terrestrial and 96 km for subsea) and in relatively shallow waters (~200m deep), limiting practical application of the idea. To make this method more useful, they decided to test it using links that are much deeper on the ocean floor and span much greater distances. Kamalov and Cantono (2020) explain how, in a pilot project, Google is using data obtained from its existing undersea fibre optic cables to detect earthquakes and tsunamis using the DAS method developed by Zhan (2020). Once built, it is planned to use the system to provide information that is complementary to the information provided by dedicated seismic sensors to enhance early warnings of earthquakes and tsunamis.

How much benefit might be possible? The warning time for ground shaking from offshore earthquakes, which is presently a few seconds for nearby earthquakes and several tens of seconds for more distant earthquakes, could be doubled, providing significantly more warning time to take shelter using the “drop, cover and hold on” rule. For tsunamis, the rule is to get to higher ground, and although this evacuation process takes longer than drop, cover and hold on, there are usually at least several tens of minutes of warning. However, at very close distances from the tsunami source, there may only be about five minutes of warning time, and an additional half-minute of warning could potentially save lives. Although locally-based tsunami warning systems have been installed in some Southeast Asian countries to augment regional systems since the occurrence of the 2004 Sumatra earthquake and tsunami, these local systems have not all been well maintained, and the use of infrastructure that is already in place to provide more warning time could be beneficial.

References

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