Earthquake observation using optical fiber and DAS technology

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DAS (Distributed Acoustic Sensing) technology is a new sensing technology that uses optical fiber just like optical communication, but with the input and output on the same side. In other words, laser light is not directly used in the optical fiber, which propagates in the forward direction with respect to the input. Instead, the laser light is scattered against impurities and defects existing in the core of the optical fiber, backscattering the part of the light in the reverse direction. This scattered light corresponds to loss for optical communication. When stress is applied to a point on the optical fiber, the backscatter changes in amplitude and phase at the exact point. The change in the backscatter corresponds to the change in the strain of the optical fiber. The propagation speed of laser light in an optical fiber is slower than the speed of light in a vacuum due to the refractive index of the core. However, since it is a constant speed, changes in backscatter in time domain should correspond to changes in strain in the distance direction of the optical fiber. In other words, the DAS makes the connected optical fiber, a linear one-dimensional vibration measurement sensor. It mainly uses single mode fiber and can sense up to about 40km.

DAS technology has been introduced to the oil and gas industry since the beginning of the century for the purpose of monitoring pipelines and detecting intruders. However, its application to geophysical exploration began only from around 2011. Conventional DAS measures the change in the amplitude of backscatter, but it has been confirmed that there is a problem with linearity[1)]. The latest optical fiber sensing technology using differential phase data called "heterodyne Distributed Vibration Sensing" (hDVS) that solved the problem began to be used from around 2014, and good seismic data including Vertical Seismic Profile (VSP) can be acquired[2)]. Three-dimensional imaging can be performed by the 3DVSP method, and it has already come to be used in Japan[3)]. It has been reported in recent years such as SEG and the Seismological Society of Japan conferences that the natural earthquake data recorded using optical fiber and hDVS have been confirmed to be similar to data recorded using seismometers[4) 5)].

However, care must be taken when analyzing data because the two measurement principles are different. It has been confirmed that the following points are different.

a) While seismometers detect three-component vibrations at one point, DAS uses a distributed sensor to detect single-component dynamic strain.
b) The resolution of the seismometer is determined by the installed density, but the spatial resolution of the DAS is determined by the gauge length.
c) The seismometer has polarity, but the DAS has no polarity.
d) The directivity of a seismometer varies depending on the type. In the case of a geophone, the directivity changes with $\cos\theta$ with respect to the incident angle of θ, but the directivity of the DAS changes with $\cos^2\theta$.

Although DAS enables seismic observation over a wide area with a small number of devices compared to seismometers when using existing optical fibers, there are some differences in the appearance of seismic wave propagation because it detects seismic waves using different methods.

In this presentation, the principle of DAS will be explained, and the natural earthquake data actually recorded by using hDVS will be explained considering the seismic wave propagation and the installation condition of optical fiber.

References:

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