International Journal of Instrumentation Electrical Electronics Engineering
p- ISSN: 2321 – 0621 e- ISSN: 2321- 063X

APPLICATION OF OPTICAL FIBRE IN SEISMOLOGY

***Dr.S.C.Sahu*, Meteorological Centre, Bhubaneswar**
scsahuimd@gmail.com

1. INTRODUCTION

Seismic waves are waves of energy that travel through the Earth's layers, and are a result of an earthquake, explosion, or a volcano that imparts low-frequency acoustic energy. Many other natural and anthropogenic sources create low amplitude waves commonly referred to as ambient vibrations. Seismic waves are studied by geophysicists called seismologists. Seismic wave fields are recorded by a seismometer, hydrophone (in water), or accelerometer. Optical fibers are used as hydrophones for seismic and sonar applications. Hydrophone systems with more than one hundred sensors per fiber cable have been developed. Hydrophone sensor systems are used by the oil industry as well as a few countries' navies. Both bottom-mounted hydrophone arrays and towed streamer systems are in use. The German company Sennheiser developed a laser microphone for use with optical fibers.

The propagation velocity of the waves depends on density and elasticity of the medium. Velocity tends to increase with depth, and ranges from approximately 2 to 8 km/s in the Earth's crust up to 13 km/s in the deep mantle. Earthquakes create various types of waves with different velocities; when reaching seismic observatories, their different travel time help scientists to locate the source of the earthquake hypocenter. In geophysics the refraction or reflection of seismic waves is used for research into the structure of the Earth's interior, and manmade vibrations are often generated to investigate shallow, subsurface structures.

A **fiber optic sensor** is a sensor that uses optical fiber either as the sensing element ("intrinsic sensors"), or as a means of relaying signals from a remote sensor to the electronics that process the signals ("extrinsic sensors"). Fibers have many uses in remote sensing. Depending on the application, fiber may be used because of its small size, or because no electrical power is needed at the remote location, or because many sensors can be multiplexed along the length of a fiber by using different wavelengths of light for each sensor, or by sensing the time delay as light passes along the fiber through each sensor. Time delay can be determined using a device such as an optical time-domain reflectometer.

Fiber optic sensors are also immune to electromagnetic interference, and do not conduct electricity so they can be used in places where there is high voltage electricity or inflammable material such as jet fuel. Fiber optic sensors can be designed to withstand high temperatures as well.

2. TYPES OF SEISMIC WAVES

There are many types of seismic waves, *body wave*, *surface waves*, *S waves* and *P waves*. Other modes of wave propagation exist than those described in this article, but they are of comparatively minor importance for earth-borne waves, although they are important in the case of aster seismology.

Body waves

Body waves travel through the interior of the Earth. They create ray paths refracted by the varying density and modulus (stiffness) of the Earth's interior. The density and modulus, in turn, vary according to temperature, composition, and phase. This effect is similar to the refraction of light waves.

Primary waves

P-wave

Primary waves (P-waves) are compression waves that are longitudinal in nature. P waves are pressure waves that travel faster than other waves through the earth to arrive at seismograph stations first hence the name "Primary". These waves can travel through any type of material, including fluids, and can travel at nearly twice the speed of S waves. In air, they take the form of sound waves; hence they travel at the speed of sound. Typical speeds are 330 m/s in air, 1450 m/s in water and about 5000 m/s in granite. Primary waves also travel about 1 to 5 miles per second (1.6 to 8 kps), depending on the material they're moving through.

Secondary waves

S-wave

Secondary waves (S-waves) are shear waves that are transverse in nature. These waves arrive at seismograph stations after the faster moving P waves during an earthquake and displace the ground perpendicular to the direction of propagation. Depending on the propagation direction, the wave can take on different surface characteristics; for example, in the case of horizontally polarized S waves, the ground moves alternately to one side and then the other. S waves can travel only through solids, as fluids (liquids and gases) do not support shear stresses. S waves are slower than P waves, and speeds are typically around 60% of that of P waves in any given material.

International Journal of Instrumentation Electrical Electronics Engineering
p- ISSN: 2321 – 0621 e- ISSN: 2321- 063X

Surface waves

Surface waves (L-waves) are analogous to water waves and travel along the Earth's surface. They travel slower than body waves. Because of their low frequency, long duration, and large amplitude, they can be the most destructive type of seismic wave. They are called surface waves because they diminish as they get further from the surface.

Rayleigh waves

Rayleigh waves, also called ground roll, are surface waves that travel as ripples with motions that are similar to those of waves on the surface of water (note, however, that the associated particle motion at shallow depths is retrograde, and that the restoring force in Rayleigh and in other seismic waves is elastic, not gravitational as for water waves). The existence of these waves was predicted by John William Strutt, Lord Rayleigh, in 1885. They are slower than body waves, roughly 90% of the velocity of S waves for typical homogeneous elastic media.

Love waves

Love waves are horizontally polarized shear waves (SH waves), existing only in the presence of a semi-infinite medium overlain by an upper layer of finite thickness. They are named after A.E.H. Love, a British mathematician who created a mathematical model of the waves in 1911. They usually travel slightly faster than Rayleigh waves, about 90% of the S wave velocity, and have the largest amplitude.

Stoneley waves

A Stoneley wave is a type of large amplitude Rayleigh wave that propagates along a solid-fluid boundary. They can be generated along the walls of a fluid-filled borehole, being an important source of coherent noise in VSPs and making up the low frequency component of the source in sonic logging. The equation for Stoneley waves was first given by Dr. Robert Stoneley (1894 - 1976), Emeritus Professor of Seismology, Cambridge.

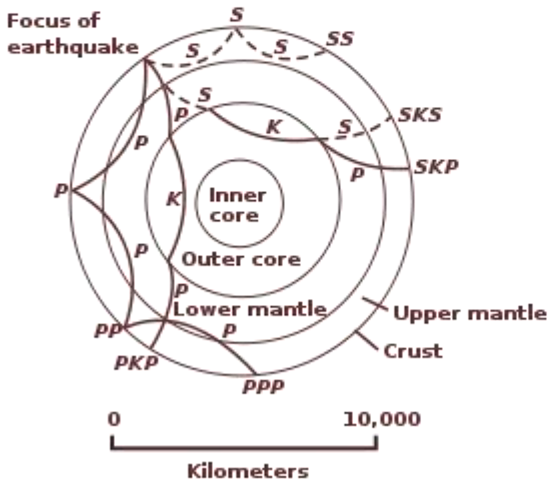
P and S waves in Earth's mantle and core

An earthquake occurs, seismographs near the epicenter are able to record both P and S waves, but those at a greater distance no longer detect the high frequencies of the first S wave. Since shear waves cannot pass through liquids, this phenomenon was original evidence for the now well-established observation that the Earth has a liquid outer core, as demonstrated by Richard Dixon Oldham. This kind of observation has also been used to argue, by seismic testing, that the Moon has a solid core, although recent geodetic studies suggest the core is still molten. he path that a wave takes between the focus and the observation point is often drawn as a ray diagram. An example of this is shown in a figure above. When reflections are taken into account there are an infinite number of paths that a wave can take. Each path is denoted by a set of letters that describe the trajectory and phase through the Earth. In general an upper case denotes a transmitted wave and a lower case denotes a reflected wave. The two exceptions to this seem to be "g" and "n".

c- the wave reflects off the outer core
d- a wave that has been reflected off a discontinuity at depth d
g- a wave that only travels through the crust
i-a wave that reflects off the inner core
l- a P-wave in the inner core
h- a reflection off a discontinuity in the inner core
J- a S wave in the inner core
K- a P-wave in the outer core
L- a Love wave sometimes called LT-Wave
n- a wave that travels along the boundary between the crust and mantle
P- a P wave in the mantle
p- a P wave ascending to the surface from the focus
R- a Rayleigh Wave
S- a S wave in mantle
s- a S wave ascending to the surface from the focus
w- the wave reflects off the bottom of the ocean

For example:

- **ScP** is a wave that begins traveling towards the center of the Earth as an S wave. Upon reaching the outer core the wave reflects as a P wave.
- **SPKIKP** is a wave path that begins traveling towards the surface as an S-wave. At the surface it reflects as a P-wave. The P-wave then travels through the outer core, the inner core, the outer core, and the mantle.



3. FIBRE OPTIC SEISMIC SENSORS

Fiber optic seismic sensor systems have been under development for many years at PGS, who have produced several generations of prototype seismic equipment to demonstrate the technology. Ongoing projects include applications to 4C seafloor systems, streamers and near-field air gun recording. An optical 4C seafloor cable has been successfully demonstrated during field operations in the North

International Journal of Instrumentation Electrical Electronics Engineering
p- ISSN: 2321 – 0621 e- ISSN: 2321- 063X

Sea during late 2003. These data have proven the prototype optical system meets the performance required for deepwater seismic operation. The PGS optical seismic technology is an excellent fit for conventional 4C seismic operations, and would also be the preferred solution for permanently installed reservoir monitoring systems. The dense wavelength division multiplexing (DWDM) technology used by PGS offers significant flexibility in terms of large dynamic range, the use of a very small number of optical fibers to record from several thousand channels, no in-sea electronics, light weight, reduced cost per channel, improved safety, and great reliability and durability.

But in recent years consensus seems to be building that no one application is the best answer in all cases, but rather that a combination of surface, borehole and permanent sensors can be utilized to give the best information about continuing changes in the reservoir. To that end, Weatherford has introduced Clarion, a fiber-optic seismic sensor that is installed during the completion phase and remains in place in the wellbore throughout the life of the well.

Launched at the 2003 Society of Exploration Geophysicists (SEG) convention last October, the technology has been a work in progress since the late 1990s, according to Tad Bostick, vice president of business development for Weatherford Intelligent Completion Systems. "The whole progression was, first, to demonstrate that we could actually make multicomponent seismic measurements with an optical instrument," Bostick said. "That was at the end of 1999 and into 2000.

Then we went on to shrink everything to fit into boreholes and to implement a complex, state-of-the-art optical architecture, which allowed us to build seismic arrays with optical in-well components. After that we worked on smaller, deployable, fit-for-purpose sensors, along with an optical multi-channel architecture.

The benefits are several. The system enables production optimization by making on-demand high-resolution reservoir imaging possible. This facilitates the optimal placement of development and infill wells, reduces drilling and completion costs, improves remedial action planning and implementation to manage water and gas ingress, and advances the understanding of reservoir sweep and void age replacement.

The two main barriers for widespread use of time-lapse (4D) seismic technology in the oil and gas industry are data repeatability and cost. One solution for repeatability is to fix the locations of the source points and/or receiver arrays for the repeat surveys. The best way to do this is to install them permanently. Based on the cost of current systems, this often is cost prohibitive.

Marine 4D seismic data acquisition most often uses standard towed marine streamers. These surveys suffer from repeatability problems associated with errors in the location of the deployed sources and the receivers which lead to a deterioration of the image qualities. In most cases, the additional expense of redeploy able ocean bottom sensor cables appears difficult to justify. Reconfiguring redeploy able sensors for permanent installation likely would increase the cost further. However, 4D surveys using permanent installations of sensors can be justified by the increased resolution.

4. CONCLUSION

The performance of the fiber-optic geophone matches or exceeds the performance of the standard geophone. A large number of fiber-optic channels can be deployed on each fiber, making large channel count system possible. No electronics need to be deployed with the sensor, making the sensor system robust with a potentially long survival time (as evidenced by deployment of fiber-optic sensors by the US Navy).No electric power needs to be transmitted to the sensor, nor does the fiber-optic sensor generate any electric signal, making the sensor intrinsically safe and immune from EMI/RFI.A high-temperature version of the fiber optic geophone can be manufactured using commercially available high temperature fiber.