Use of Passive Microseismic Monitoring

By Taylor Milne and Andrew Weir-Jones

WE HEAR a lot in the media about the downsides of hydraulic fracturing operations in the oil and gas sector.

Years ago, in some regards, these fears were well founded. But today, with the way the technology has developed, Passive Microseismic Monitoring (PMM) can be deployed relatively easily, and can provide enough reliable data to make decisions about the probability of induced fractures affecting aquifers, other subsurface resources, or inducing low level seismicity.

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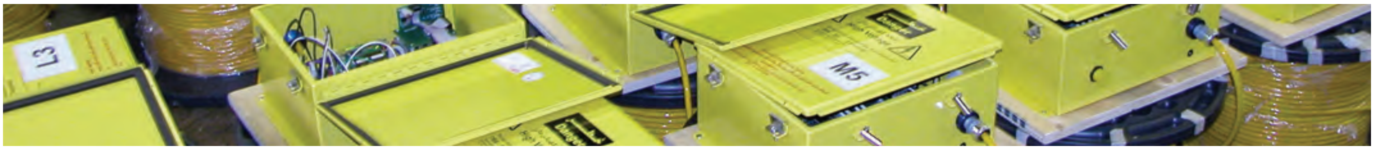
When an applied load causes rock to fracture some of the released strain energy propagates through the surrounding rock mass as vibrations, which can be detected by the appropriate sensors. In some cases these are felt or heard by people; mineworkers often hear minor events as snapping or clicking noises; small earthquakes, magnitude 3.0, can be felt near the epicentre by the general population.

The fracturing of the rock can be caused by tensile, compressive or shear forces. The location and energy released by the fracture can be determined with reasonable accuracy by analyzing the arrival times and characteristics of the vibrations.

On a global scale, this is how seismologists locate the hypocentres and estimate the intensities of earthquakes. On a local scale, the procedure can be used to locate shear surfaces beneath a landslide, or pillar failures in a mine, and on a still smaller scale, this is how the extent and location of the induced fractures created within a reservoir by a hydraulic fracturing operation can be derived.

Every natural or human activity on or in the Earth's crust causes changes in its state of stress. Under some circumstances these perturbations of the stress field can trigger events which release enormous amounts of elastic strain energy that was stored within the deformed rock mass. An example is the 1906 San Francisco earthquake, which was caused by the shear rupture of the San Andreas fault along a length of nearly 500 kilometres, the actual relative movement across the fault reached nearly nine metres in some locations.



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Sometimes the data associated with changes of stress or strain can be used to solve practical problems. One of the first applications of acoustic monitoring in a non-mining situation in Canada was the identification of multiple shear planes beneath the Downie Slide, a post-glacial feature in the Columbia River Valley in British Columbia.

There was a concern that the filling of a new reservoir would re-activate the ancient slide. To provide information about the position and level of activity on the existing failure planes, geophones and hydrophones were installed on boreholes drilled through the slide. The failure planes and the relative activity were identified, and this information was used to design an extensive slope dewatering and drainage program.

This work was done with very primitive analog instrumentation, chart recorders and magnetic tapes. It was a time-consuming task to process the data, which saw personnel going through line after line of recorded data looking for anomalies that indicated that a particular elevation was more active than another and correlating this with the results of borehole permeability testing.

Securing Integrity of Hydrocarbon Reservoir

There has been a dramatic evolution of technology over the last forty years. With state-of-the-art digital recorders, tri-axial downhole sensor packages and real-time data rendering, engineers can monitor geomechanical phenomena at depths of greater than 3,000 metres. In the oil and gas sector, production and fracking operations can be monitored in near real-time so precisely that they can shut down immediately if a safety or operational situation arises.

The optimization of the sensor arrays used to acquire passive microseismic data is dependent upon many factors. These include aspects of the array in relation to the expected acoustic source, number of sensors being deployed, acoustic dampening properties of the surrounding rock, surrounding natural and anthropogenic noise that could be heard by the sensors, and, of course, accessibility, environmental conditions and work crew safety.

In order to understand how the acoustic waves are travelling from the source to the receiver, we must know the physical properties of the rock the wave is propagating through, specifically its density, seismic velocity and anisotropy. Knowing these factors allows a geophysicist to accurately trace the microseismic signal back to its correct source location, with an acceptable degree of uncertainty.

Finally, once the locations of microseismic events are known, real-time interpretations can be made with regards to fracture mapping, and hydraulic-fracture treatment stages can be modified on the fly for optimized production.

This translates directly into savings because on-site equipment, manpower and production all benefit from reduced downtime associated with past practices, in particular the need to shut down operations while local geophysicists examined multiple lines of data.

There are also a couple of different strategies for deploying sensors: the first is a surface array, usually laid out in a grid pattern over several square kilometres above the laterals being hydraulically fractured. These types of systems suffer from inherent noise problems; they tend to pick up acoustic emissions from everything including road traffic, workover rigs and pumps. For this reason, the number of sensors deployed is substantially more than in a downhole array where the inherent noise level is much less.

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Surface geology is a very important consideration when deploying a surface array. If the surface rocks encompassing the sensors have a high degree of acoustic dampening (attenuation), the signal will be difficult to see, especially in the midst of all the noise, even with advanced filtering techniques. For example, acoustic waves do not travel well through unconsolidated sand and gravel like that deposited in glacial till, which is common for surface geology. Surface arrays must be considered from region to region.

The second type is a downhole system. It is typically designed to be permanent or semi-permanent, and it is deployed after an earth model has been developed for a specific reservoir that will go into production. Alternatively, there may be environmental concerns which need to be monitored over the life of the field (LOF). There are some capital costs associated with the deployment of LOF systems, but the major benefits include security, no ambient noise to corrupt the data and reliability. These systems can be deployed and require virtually no maintenance over their useful service life, which can easily exceed 20 or more years.

Surface or buried arrays continue to evolve at an exponential rate. Reliability and clarity in the algorithms continue to provide solid data so that operators and concerned parties feel comfortable that oil and gas operations are doing everything in their power to mitigate the potential of a catastrophic failure, such as contaminating groundwater, watercourses or human occupied areas.

In addition to monitoring fracture growth and optimizing production, PMM systems are helpful for monitoring and mitigating induced seismicity. This happens when fluid injection intended for reservoir stimulation enters pre-existing faults, causing earthquakes. The pore fluid pressure reduces the friction between the two faces of the fault, resulting in a sliding motion between two rock masses, which creates seismic activity of much greater magnitude than expected from hydraulic-fracturing events.

The problem with many of these induced seismicity events is that the current array of global seismometers is not dense enough around the source to be detected. With a proper PMM installation using sensors that have enough bandwidth to detect the low magnitude microseismic events, and the higher magnitude induced seismicity fault reactivation, these hazards can be monitored and ideally avoided.

The operator and the geophysicist work together to monitor the magnitude and geometry of the seismic events, and regulate pump pressure accordingly to minimize and avoid induced seismic activity. If there is any indication that the fracture fluid is entering existing fault pathways, the operator is notified immediately and can make an informed decision for future stimulation.

According to a recent study by **Richard Davies** of the Durham Energy Institute at Durham University, there are currently three known induced seismicity events that have created earthquakes large enough to be felt on the surface. Although this is a small number compared to the amount of fracturing operations around the world, induced seismicity cannot be ruled out. Additionally, the increasing number of planned fracturing jobs means statistically there will be an increased number of induced seismicity events.

PMM provides a useful means of securing the integrity of a hydrocarbon reservoir. Each reservoir is unique and will have different geomechanical properties. Each will require different surface or buried array specifications, and will have different fracture characteristics. However, the hazards associated with fluid injection remain consistent.

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All photos provided by The Weir-Jones Group.