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California's dense urban environment spawns friendlier 3D seismic survey design

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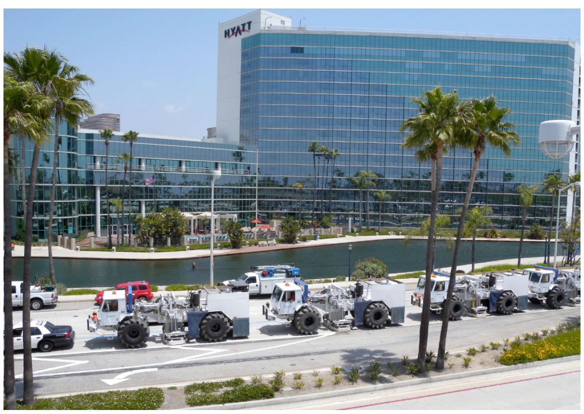
Southern California oil producers have long faced the added challenge of making exploration and production compatible with urban life.

When the first oil boom began in the Los Angeles basin in the 1890s, cities rose quickly alongside oil discovery and development. Over the decades, exploration and production became increasingly more difficult as urban populations became denser and community standards became more stringent.



A four-truck seismic fleet sourced on Shoreline Drive and other city streets in Long Beach as part of a 3D seismic survey for Signal Hill Petroleum Inc. Image courtesy of NodalSeismic.

The Los Angeles basin—deemed to be the richest basin in the world in terms of hydrocarbons per volume of sedimentary fill—is a unique oil province. It contains a tremendous amount of oil, but the combination of cultural, logistical, and geological obstacles make economical recovery a challenge.

These obstacles also make seismic data difficult to acquire.

In April 2012, NodalSeismic completed the unprecedented Long Beach 3D seismic study for Signal Hill Petroleum Inc. (SHPI). The survey has proved that seismic acquisition in a dense urban environment can be done effectively and efficiently if you have the right formula.

The survey area

Long Beach oil field, discovered in 1921, is one of many prolific fields along the Newport-Inglewood Fault Zone, which is a major fault system running through the Los Angeles basin. In just 2 sq miles, it has produced 1 billion bbl of oil and is still going strong.

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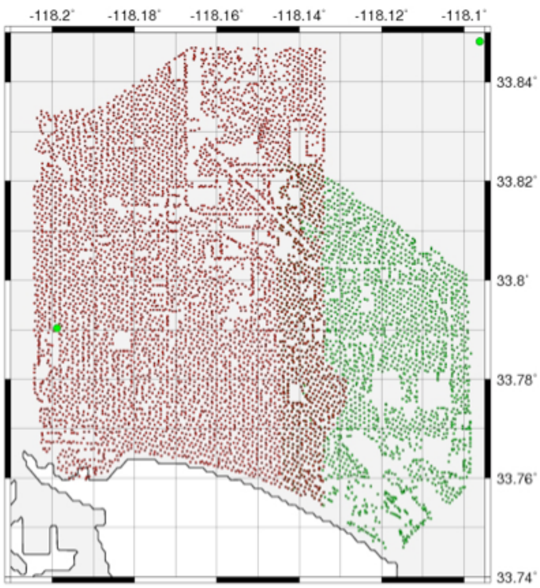
GRID OF RECEIVER POINTS



Long Beach 3D seismic survey covered 38 sq. miles. Red dots are phase one, green dots phase two. Large green dots are Southern California Seismic Network (SCSN) stations.
Source: NodalSeismic

This field has the distinction of the highest recovery of oil per producing acre of any field in the world. SHPI estimates that as much as 2 billion bbl of oil is still in place with a vertical section of stacked reservoirs up to 10,000 ft thick.

Due to its historic recovery and relatively small producing area, some consider Long Beach field, sometimes referred to as Long Beach/Signal Hill oil field, to be "an outlier of the outliers" in reference to its global significance. Its recovery rate is even more impressive when you consider the obstacles both above and below ground.

Roughly 80% of the field's producing area is in the city of Signal Hill. At 2 sq miles in size, the city is home to 11,000 residents and is completely surrounded by the city of Long Beach. Long Beach contains the remaining producing area, and at 50 sq miles with roughly 9,191-people/sq mile, it is a busy metropolis and the second largest city in Los Angeles County.

The field produces from the porous and rich oil bearing Pliocene-age Repetto and Miocene Puente formations in complex combinations of stratigraphic and structural traps.

The City of Signal Hill is actually a prominent topographical high that is the surface expression of an anticlinal and overthrust structure that parallels the fault zone, a defining characteristic of the field. Its complex geological formations and dense cultural environment make for a formidable drilling environment, and make seismic a necessity.

Breaking through the challenges

Prior to NodalSeismic's survey, Long Beach field had never been successfully imaged with 3D. 2D seismic data acquired in the early 1970s were available but provided only small slices of the picture that were impossible to interpret due to the complex geology of the area.

Before the successful completion of the Long Beach 3D, there had been two 3D seismic attempts in the Los Angles basin that proved to be ineffective. In one case, the seismic crew was not matched for the dense urban environment, and the other resulted in expensive and unreliable data.

To be successful, a seismic contractor needed to get the dense urban formula right.

After several years of testing new technologies, and geophysical and operational approaches, NodalSeismic defined the dense urban formula. The new methodology consisted of a completely redesigned operations approach, a local government and community education strategy, a never-before-used cable-free recording system, and innovative techniques for operating both new and old equipment.

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Instead of trying to make the environment fit the operation, they tailored the survey to the dense urban environment and discovered a more streamlined and efficient seismic operation.

The survey

NodalSeismic spent months prior to the survey to produce educational material for civic officials and residents that explained what a seismic survey was, and how it would look, feel, and sound.

Operationally, the crew executed a strategic and streamlined deployment of thousands of cable-free geophone sensors, also known as nodes. The combination of approach and cable-free advantage immediately decreased the survey's footprint within the city, eliminated troubleshooting, and made the project easier and quicker to permit.

Long Beach 3D data were acquired in two phases over 38 sq miles. Phase one began in early 2011 and consisted of a 6-month deployment of roughly 5,400 sensors. The second phase began in early 2012 with 2,500 sensors deployed for 3 months.

A two-phase, 3D seismic survey for Signal Hill Petroleum Inc. over and around Long Beach oil field involved seismic trucks sourcing in residential areas of Long Beach. Image courtesy of NodalSeismic.

NodalSeimsic's unique approach to its cable-free system led to a breakthrough in survey design. With a cable system, positioning of receiver locations is constrained by accessible locations, length between geophone takeouts in the cable, and acceptable and safe cable traverse between receiver positions.

Without the constraints of cable, they were able to orient the receiver lines diagonal to the existing street system. This maximized the use of major streets for sourcing and minimized the use of smaller residential streets.

The nominal receiver design was a 330 by 330-ft uniform receiver grid, resulting in a novel fold distribution that allowed for a flexible common midpoint bin size. The receiver density was approximately 256 sensors/sq mile.

NodalSeismic also developed new active sourcing parameters using 30-ton seismic vibrator trucks. The contractor used a group of four vibrators on major city streets and a single vibrator on smaller residential streets. The parameters were designed to balance the public's experience of the vibrations while maintaining optimal drivel levels to ensure data quality.

The trucks sourced every 55 ft along city streets with constantly varying drive and sweep parameters that were predesigned based on source location. The parameters took into account the localized shallow geology, topography, and building type and proximity. This unique and detailed source engineering allowed the project to successfully conduct source operations in immediate proximity to a major regional medical center.

In total, the project successfully completed 80,000 source sweeps and achieved a 99.7% rate of data recovery with no public safety incident, timetable delays, and maintained positive community reaction to the project.

The results

Prior to the Long Beach survey, the field's average well depth ranged from 5,000 ft to around 10,000 ft. The bottom of the producing zone was a mystery.

The 3D data are still being analyzed but have already begun to illuminate the fault structures, revealing a much more complex picture than previous literature indicated. SHPI is now beginning to understand the relationship between the traditional flower structure model and the particular faulted-fold complex for the area.

The results have already warranted SHPI's purchase of a new, all electric top-drive drilling rig. The rotary has a depth capacity of 14,000 ft and has horizontal drilling capability.

The rig, which is now the largest piece of drilling equipment owned by the company, was custom built specifically for urban operations and is currently drilling a deep test well based on the survey results to formations below 13,000 ft.

Shared benefits

The Los Angeles basin is both an extraordinary petroleum basin and a seismically active area in terms of naturally occurring earthquakes. Due to its location in the basin, Long Beach served as NodalSeismic's initial study in developing a technique that uses passive earthquake data to enhance active-source data.

During the Long Beach survey, NodalSeismic recorded more than 20,000 local microearthquakes in the 6 months the geophones were deployed in phase one. The system also captured the Mar. 11, 2011, Japan M9.0 earthquake more than 5,000 miles away. By simultaneously recording and preserving passive earthquake data, the company has been able to use seismic interferometry analyses to improve shallow velocity models. Teleseismic events in the form of large earthquakes greater than M5.5 2,000-6,000 miles away can be analyzed to develop velocity models using seismic travel-time tomography.

It should be noted that being in an earthquake-prone area is not a requirement. These image-enhancing techniques can be used in any geographic area and in any terrain.

NodalSeismic and SHPI have created shared value with the academic community by allowing access to the survey's passive data for prominent academic institutions such as Caltech and Stanford University. Analyses from the data have already begun to form a new understanding of earthquakes.

The authors

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