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Image Improvement of Indian Offshore by Single-Sensor Seismic

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Summary

ONGC has deployed Q-Marine Vessels of WesternGeco in west and east coast of India since November'2005 for high resolution 3D data acquisition. The Q-Marine single-sensor technology is focused primarily on minimizing the noise content of recorded seismic data and improving survey repeatability. The pilot processed sections show that Q-Marine single-sensor acquisition and processing techniques could improve seismic imaging of Indian offshore. The key to success was the ability to effectively remove noise and preserve signal fidelity and high frequencies in the pre- stack data. In towed streamer surveys, a key phenomenon influencing the recordable frequency range is ghosting. The amplitude spectrum of the ghost filter possesses notches at zero Hz and at regular intervals along the frequency axis depending upon the depths of the source and streamers. The first non-zero notch is typically considered to be the upper limit of useful bandwidth. Forcing that first non-zero notch to occur as high on the frequency axis as possible is often a key objective in survey design. If the sea state is such that swell noise is present, the severity of recorded swell noise worsens with shallower depths of streamer tow. Single- sensor sampling has enabled the swell noise problem to be addressed more effectively. With single-sensor technology, the trace interval is sufficiently dense to allow adaptive velocity filters to be effective in data processing.

The implication is that single-sensor technology can tolerate the recording of more swell noise, thereby enabling the streamers to be towed at a shallower depth, resulting in better resolution. This high-resolution implementation of technology has been the key strategy for these surveys.

Introduction

The seismic resolution and imaging quality is determined by the frequency content and signal-to-noise ratio content in the data. A popular thrust in the seismic method has been the pursuit of resolution, which requires high frequencies. In towed streamer surveys, a key phenomenon influencing the recordable frequency range is ghosting. Ghosting is caused by interference of the upgoing wave field with a polarity-reversed copy of itself that is sent back in the downgoing direction after scattering off the air/water interface. The amplitude spectrum of the ghost filter possesses notches at zero Hz and at regular intervals along the frequency axis. The locations of those notches depend on the depths of the source and streamers- the shallower the source streamers, the higher the frequencies where the notches occur.

The first non-zero notch is typically considered to be the upper limit of useful bandwidth. Forcing that first non-zero notch to occur as high on the frequency axis as possible is often a key objective in survey design. With this in mind the source and streamers is towed at shallow depths about 5m to 6m. However, there is problem associated with this. If the sea state is such that swell noise is present, the severity of swell noise worsens with shallower depths of streamer tow.

Therefore, the best way to keep the signal–to-swell-noise ratio at an acceptably good level is to tow the streamers a little deeper than would otherwise be desired.

Recently, single-sensor sampling has enabled the swell noise problem to be addressed more effectively. Swell noise actually propagates as a coherent train across the seismic record. However, propagation velocity is extremely slow, meaning that in conventional records, where the group center trace interval is 12.5 m or so , the noise train is too aliased to be suppressed by velocity filters. However, with single-sensor technology, the trace interval is 3.125m. This interval is sufficiently dense to allow adaptive velocity filters to be effective in data processing.

The implication is that single-sensor technology can tolerate the recording of more swell noise, thereby enabling the streamers to be towed at a shallower depth, resulting in better resolution. This high-resolution implementation of technology has been the key strategy for these surveys.

Traditional Marine Data Acquisition

Marine seismic surveys are acquired by ships towing streamers, or instrumented cables, to record signals from shots fired as the vessel maneuvers across the target. A typical streamer is 3000 to 8000 m long and, in conventional acquisition, carries hundreds of receiver groups of 12 to 24 hydrophones feeding to a single recording channel. In principle, summing the detected signals before recording—a step called array forming— enhances signal-to-noise ratio. However, array forming can irreparably damage signal fidelity and reduce the effectiveness of subsequent processing steps aimed at attenuating noise traveling down the streamer. To minimize sea-surface wave noise, streamers are towed at a depth specified in the survey-planning stage, usually 6 to 10 m. Towing at shallower depths can increase the high- frequency content of the recorded signal, but usually increases noise level also.

High-performance acquisition vessels can tow 12 to 16 streamers spaced 50 to 100 m apart. Deflectors based on Monowing multistreamer towing technology are deployed at the front of the streamer to help maintain streamer spacing. While the Monowing devices control streamer separation at the front, what happens behind that point is subject to nature. Currents, tides and other forces can cause streamers to feather, or drift laterally from programmed positions, and in extreme cases, tangling can occur.

Any application of seismic data requires accurate position information, and some uses, such as time-lapse seismic monitoring, demand repeatable positioning. To ensure that the acquisition arrangement is accurately documented, positioning sensors are used to determine the position of every source and receiver at every shot point as the vessel moves. Global Positioning System (GPS) measurements use satellites to pinpoint the vessel position to within three meters. With traditional systems, positions of seismic sources and receivers relative to the vessel are calculated using information from acoustic and streamer-mounted heading sensors in networks at the front and tail of the streamer. The front and tail positions of the streamers are known accurately. However, the positions of individual sensors are estimated from a streamer shape that is calculated by use of streamer-mounted heading sensors placed at a few locations along the streamer, which can introduce significant errors.

The typical seismic source is an array composed of subarrays each containing up to six air guns separated by about 3 m. Like streamers, air-gun arrays also are towed at a depth of 6 to 10 m. Arrays that are towed too shallow produce insufficient output; instead of the air-gun burst traveling downward, it produces only bubbles at the sea surface because there is not enough hydrostatic pressure to form them properly. Sources produce signals that are altered by destructive interference between the direct sound waves that travel downward and those that travel up first and reflect off the sea surface—ghosts—just a few milliseconds later. Receivers similarly suffer from interference between the upcoming reflections and downgoing ghosts reflected off the sea surface. The shallower the source or streamer, the more the high-frequency content in the recorded signal, but the greater the loss of deeply penetrating low frequencies and the higher the noise. The deeper the source or streamer, the greater the low-frequency content and the lower the noise, but at the cost of losing high-frequency signal. The signature of a source array can vary from shot to shot depending on variations in individual gun firing times, gun-chamber pressure, array geometry and drop-out—failure of a gun to fire. These shot-to-shot variations can reduce the accuracy and repeatability of seismic surveys.

Improved Q-Marine Data Acquisition

Q-Marine technology is fully calibrated; point receiver marine seismic acquisition system, providing the technology needed for locating, defining, and actively managing offshore reservoirs throughout field life. Q can be applied during the life of the field, from exploration to the stage of improved oil recovery. Q-Marine technology is the result of detailed analysis to identify the key sources of noise and error that impact seismic data quality and repeatability. Q-Marine technology has four main components**.**

Calibrated sources:

Q-Marine system utilizes TRISOR as source controller. The signature of any air-gun source varies from shot-to- shot for a multitude of reasons, including gun dropouts and array movement; this variation reduces the accuracy and repeatability of seismic data. These factors are reduced drastically by TRISOR.

Source-control electronics on the air-gun subarrays synchronize and fire each gun based on its acoustic output. Fiber-optic lines communicate with the vessel, replacing conventional two-way systems that can mistime gun firing as they send signals to and from the vessel.

Calibrated positioning:

Positioning knowledge is crucial for time-lapse and high- resolution reservoir seismic data. Q-Marine has a positioning system for the in-sea seismic equipment that uses a fully braced acoustic positioning network from the front to the tail of the streamers, independent of streamer length, bringing seismic positioning accuracy to a new level.

The new acquisition system carries an acoustic ranging system along the full length of the streamer. Distinctive acoustic sources spaced every 800 m along the streamers emit signals that can be recorded at any seismic hydrophone. The relative timing of each arrival allows a set of ranges, or distances between source and hydrophone, to be computed across the entire network. The acoustic ranges are used as input to a ranging-network adjustment that extends between GPS readings. The result is an absolute positioning accuracy to within 4 m anywhere along the streamers.

Calibrated single sensors:

Streamer sensitivity variations introduce perturbations into the seismic data. Q-Marine single sensors enable automatic calibration and "cleaning" of this footprint. Fully flexible spatial sampling will optimize specific survey objectives. Additionally, the single-sensor sampling enables powerful new filtering techniques to remove noise.

To solve the problem of receiver sensitivity variation, manufacturing engineers stipulated new high-fidelity tubular hydrophones with tight and stable sensitivity specifications. The new hydrophones have much higher survival-depth tolerances and more stable sensitivities because they are pre-aged in the manufacturing process and perform consistently thereafter. Each hydrophone has its own calibration certificate, and all sensitivity values are stored in the streamer front-end electronics for automatic data calibration.

Steerable streamers:

Q-Marine streamers contain the unique Q-Fin steering devices. These are remote controlled wings, integral to the streamer for reduced noise, which enable both precise depth control and horizontal steering. Horizontal streamer steering provides feather correction, safe streamer separation control, active steering for optimal coverage, and 4D repeatability.

While all traditional acquisition systems allow control of streamer depth, only the Q-Marine approach enables active horizontal steering in addition to depth control. Streamer orientation can be modified laterally for optimal coverage, allowing streamers to be towed at separations as close as 25 m with greatly reduced risk of tangling. Narrow streamer separation allows higher resolution sampling for improved imaging, and in-sea equipment can be steered safely near potential hazards such as surface installations. Steerable streamers are ideal for reservoir surveys because they allow significantly faster vessel turns, a major timesaving in relatively small-acreage surveys. Steering control improves logistics involved in streamer deployment and retrieval, making the back deck safer.

Steering devices are located every 400 to 800 m along the streamer. The WesternGeco Q-Fin steering system has independently controllable wings to steer streamers up, down, and side to side.

Digital Group Forming:

Digital Group Forming is another advantage of Q-Marine technology. The removal of the analog grouping process and the use of high over-sampling so that noise captured is unaliased and can be removed are the key reasons for the improved measurement delivered by the Q system. Digital Group Forming enables full flexibility regarding receiver array response.

By recording signals at every receiver position digitally, the properly sampled incoming wave-field, containing both signal and noise, can be processed using sophisticated algorithms. This signal-processing step, which improves upon the noise-suppression capability of a hard-wired array, is called digital group forming. Digital group forming can make use of processing techniques more powerful than simple linear summation.

The result is significantly improved, broader band signal- to-noise ratio. Typically, there is an improvement of 40% or more in vertical resolution, compared with conventional technology. As vertical resolution is linked to horizontal resolution, new and much denser configurations are usually required. In marine applications, not only are tighter configurations and denser spreads being used but also shallower tow.

The higher levels of low-end external noise caused by proximity to the surface in shallow tows can only be effectively removed using the Q single- sensor acquisition approach. Even solid or gel-filled streamers cannot eliminate this noise very effectively, as it does not generate in-line flow, which these remove quite effectively, but axial, often turbulent, flow that is transferred very effectively to the hydrophones regardless of streamer design. This axial flow also generates significant levels of sub-20Hz aliased noise. Traditionally, this is what has severely damaged the signal-to-noise ratio at the low end. In the end, resolution is about broad bandwidth and not just high frequencies.

Application of the technology in Indian Offshore:

All the Q-Marine data acquired during 2005-06 field- season have been processed and handed over to the respective basin for interpretation. The data acquired during 2006-07 field-season is under final processing at data processing center, Mumbai. Q-marine data was acquired in east coast blocks falling in Mahanadi, KG, and Cauvery basins and west coast blocks falling in Kerala-Konkan and Bombay Offshore basins. Improvement in the data quality of all the basins can be assessed from following examples. Comparison of digitally formed array results, with those from hard-wired arrays shows how well the new technique works. A shot record acquired with conventionally grouped hydrophones displays high residual levels of weather related noise that appears incoherent, and thus difficult to filter out. At the same time, a Q-Marine streamer, with closely spaced digital traces, recorded the same shots. The noise, properly sampled, is coherent and can be filtered out through processing without affecting the signal. The digitally array-formed data, output with one channel every 12.5 m, have significantly reduced levels of the residual noise that dominated the conventional shot record. The imaging power and resolution seen in Q-Marine survey data may become the new benchmarks for data quality.

The Q-Marine seismic section illuminates more layers and small-scale features than the conventionally acquired section. Reflections that were imperceptible in the older survey are clear and strong in the newer image.

With Q-Marine technology, more high frequency signal is preserved at all depths. Whereas conventional surveys in Mahanadi basin contain usable 62-Hz signals at the target depth, the Q system delivers frequencies up to 105 Hz at the same depth. This improvement in resolution allows more detailed interpretation of subtle features such as lateral stratigraphic changes and time-lapse reservoir variations. The table below shows the comparison between legacy and Q-marine data of all the basins.

Basin	Bandwidth and Frequency	Legacy	Q
Mahanadi	**Bandwidth at -10 dB**	**10 – 62 Hz**	**8 –105 Hz**
	Dominant Frequency	**27 Hz**	**40 Hz**
KG	**Bandwidth at -10 dB**	**13 – 57 Hz**	**15 – 110 Hz**
	Dominant Frequency	**40 Hz**	**57 Hz**
KK	**Bandwidth at -10 dB**		**16 – 95 Hz**
	Dominant Frequency		**58 Hz**
D12/D31	**Bandwidth at -10 dB**	**9- 32 Hz**	**9- 55 Hz**
	Dominant Frequency	**11 Hz**	**27 Hz**
CY1	**Bandwidth at -10 dB**	**6- 38 Hz**	**9- 65 Hz**
	Dominant Frequency	**12 Hz**	**25 Hz**
CY2	**Bandwidth at -10 dB**		**7- 93 Hz**
	Dominant Frequency		**23 Hz**
B142	**Bandwidth at -10 dB**		**9- 78 Hz**
	Dominant Frequency		**33 Hz**

There is an increase of bandwidth in Q-marine data from 66% in KG to 100% D12/D31 block of Mumbai Offshore basin (figure-1).

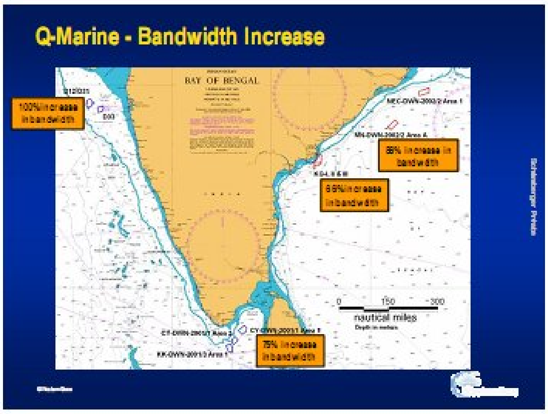

Figure 1: Q-Marine Bandwidth increase in Indian offshore basin.

The figures 2&3 below and the above table show that the interpretable frequency in Krishna-Godavari Basin has increased from 40 Hz (corresponding vertical resolution of 11.5m) in legacy data to 57Hz(corresponding vertical resolution of 8.25m) in Q-marine data.

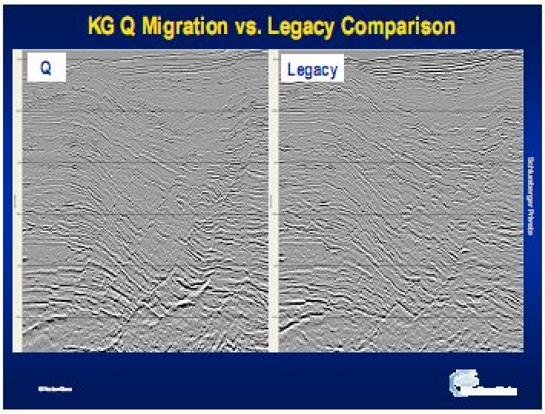

Figure 2: Seismic section with Q-Marine and legacy data of KG Basin.

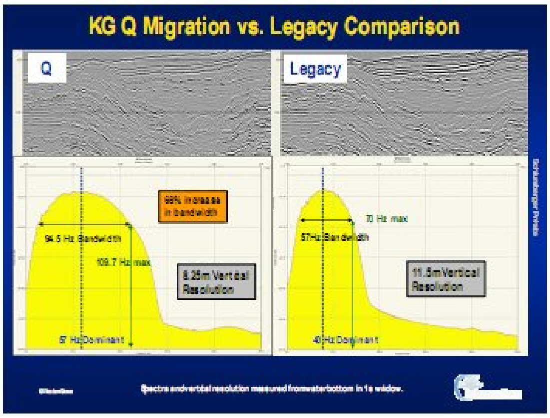

Figure 3: Bandwidth and dominant frequency comparision between Q-Marine and legacy data of KG Basin.

The figures 4&5 below show that the peak frequency in D12/D31 block of Mumbai offshore Basin has increased from 11 Hz in legacy data to 27Hz in Q-marine data.

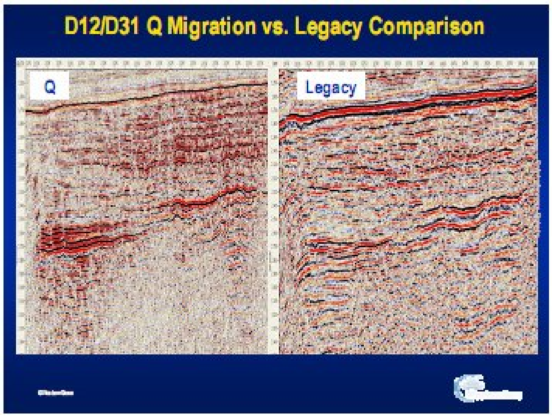

Figure 4: Seismic section with Q-Marine and legacy data of D12/D31 block of Mumbai Offshore Basin

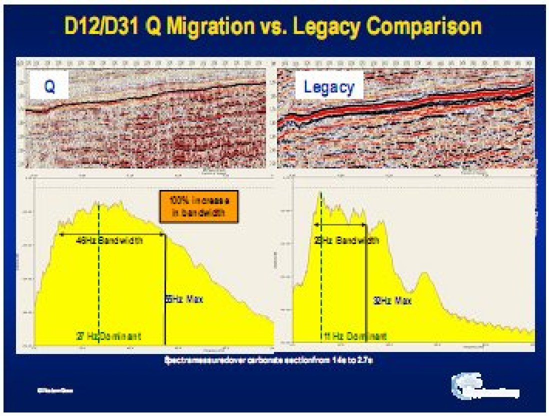

Figure 5: Bandwidth and dominant frequency comparision between Q-Marine and legacy data of D12/D31 block of Mumbai Offshore Basin.

Figure-6 below show that the peak frequency in CY1 block of Cauvery offshore Basin has increased from 12 Hz in legacy data to 25Hz in Q-marine data.

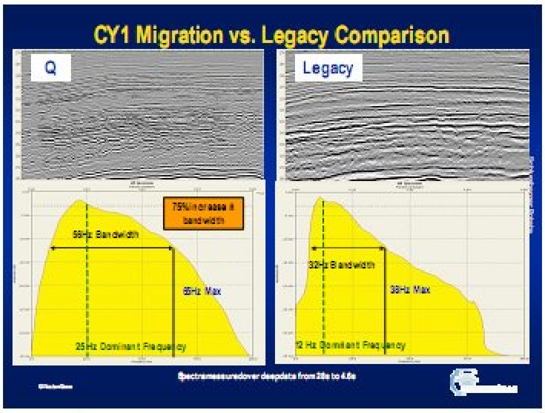

Figure 6: Bandwidth and dominant frequency comparision between Q-Marine and legacy data of CY1 block of Cauvery Basin.

Conclusions:

Single-sensor technology can tolerate the recording of more swell noise, thereby enabling the streamers to be towed at a shallower depth, resulting in better resolution. This high- resolution implementation of technology along with broader bandwidth has been the key strategy for these surveys. Examples from Mahanadi, KG, Cauvery, Kerala- Konkan, and Mumbai offshore basins show the improvements in signal quality and resolution. High resolution Q seismic technology combined with Controlled Source Electro-Magnetic (CSEM) is a real winner in exploration and can make a step change in exploration.

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