Over 40,000 VPs per day – with real-time quality control: Opportunities and Challenges

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Summary

In order to evaluate high density source and receiver land seismic acquisition designs, two sets of simultaneous high-productivity field tests were performed in a relatively flat terrain area with good signal-to-noise ratio. These included distance separated simultaneous sweeping (DSSS) (Bouska, 2009), slip-sweep (Rozemond, 1996), distance separated simultaneous slip-sweep (dynamic slip-sweep) and independent simultaneous sources (ISS) (Howe et al., 2008) with unique sweeps and real-time QC – we were not sweeping blind. The second dynamic slip-sweep field test used a 29Km active fixed super-spread (12 receiver lines separated by 300m) with 20 point vibrator fleets on a 25m x 25m source grid. Ten point vibrators were oriented orthogonal to the receiver spread in the North and ten in the South direction with a lateral separation distance of 14.5Km. This method achieved 30,346 vibration points (VPs) in a 24 hour period. The same fixed active receiver spread was reduced to continuously record the unconstrained simultaneous sources (micro-seismic mode) in 18 quadrants (3x6). Each quadrant was 1.8Km x 1.8Km with 4,320 VPs on a 25m x 25m source grid (77,760 total VPs). The unconstrained stakeless productivity test was first acquired with 18 unique 12s pseudorandom sweeps (Sallas et al., 2008) and repeated with 18 unique linear upsweeps (14.5s average sweep length). These tests achieved optimum productivity rates of 45,501 and 44,793 VPs per 24 hours, respectively, with real-time QC. Even higher rates could have been achieved with stakeless guidance training of the vibrator drivers. In these field test cases, without any training, high productivity rates were achieved with 72 drivers organized in three 8-hour shifts. Four vibrator pushers were used per shift. Three helped with fleet management and one for TDMA real-time communication between the vibrators and the recorder.

Introduction

In recent years, many oil and gas companies have used new high-channel count recording systems equipped with new vibrator control systems to acquire densely sampled symmetric seismic surveys. From these seismic surveys, decimation studies have shown that a balanced increase in receiver and source density improves the resolution of seismic images at all target depths (Bianchi et al., 2009). Although we have seen a steady improvement in seismic image quality, we are far from acquiring a true uncommitted 3D stack array acquisition design. The main challenge is how to QC and process mega-channel, continuously recorded seismic data in the field and how to reconfigure in-house processing centers (Denis and Sauzedde, 2009). One method used to compensate for recording channel limitations is to position the vibriseis fleets outside the receiver spread. This increases the cross-line offset, at the cost of reoccupying VPs. Combining this method with high-productivity source methods, will allow us to acquire densely sampled wide-azimuth seismic survey designs.

The most common simultaneous source high-productivity methods are constrained by distance only, time only, or a combination of both time and distance (Table 1). The important question we need to ask is – “What is the most productive vibroseis acquisition method that preserves data quality?” (Baguini, 2010). DSSS is the lowest risk method, because each vibroseis record can be treated independently without noise interference given sufficient distance separation. The upper limit in terms of productivity is the unconstrained simultaneous source method. As the distance between independent unconstrained vibroseis fleets is reduced, the increased level of cross-talk interference must be removed in seismic processing without removing prestack signal.

<table>
<thead>
<tr>
<th>Simultaneous Methods</th>
<th>Distance only</th>
<th>Time only</th>
<th>Distance and Time</th>
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<tbody>
<tr>
<td>DSSS</td>
<td>X</td>
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<tr>
<td>Slip-Sweeps</td>
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<td>Dynamic Slip-Sweeps</td>
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<td>Unconstrained simultaneous sources</td>
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Table 1. High-productivity distance and time classification.

The productivity of each of these methods can be simply improved by increasing the number of vibrator fleets and recording channels. This provides the option to either increase the distance and/or time separation between simultaneous sources.

Traditionally, the high-productivity vibroseis acquisition (HPVA) slip-sweep method is designed with point vibrator fleets and organized as a single or multiple salvos. In this case, when the fleets are closely positioned to one another, the slip-time can be increased to mitigate harmonic noise interference or the noise attenuated with special processing
algorithms. The same harmonic noise can be avoided in super-spread configuration. If the same receiver spread is reduced by one-half in the cross-line direction, the extra channels can be used to form a super-spread. This allows the fleets to be separated in distance and time and limit the harmonic noise interference to the far offsets. Further improvements in productivity can be gained by using the CGGVeritas fleet management system, where for each fleet specific GPS coordinates and time slots are allocated (Postel, et. al., 2008).

In October, 2009 and February, 2010 Saudi Aramco, Argas, and CGGVeritas were given the unique opportunity to test these high-productivity methods with an existing 9,000 channel production seismic crew with 24 point vibrators (Figure 1). This paper reviews these recent dynamic slip-sweep and unconstrained simultaneous source methods using unique pseudorandom and linear sweeps.

The high-productivity field test methods

Dynamic slip-sweep method

The first dynamic slip-sweep field test used 6 fleets (two vibrators per fleet), 12s linear upsweep, 6s slip-time and the minimum simultaneous separation distance was set to 6.5 Km. Thirteen swaths were recorded into a fixed spread of 24 receiver lines (Figure 2). The combination of slip-time and distance minimized the interference of harmonic noise (Figure 3 – top) and proved to have no impact on the final processing results. The production and dynamic slip-sweep results were equivalent (Figure 3 - bottom). During this field test we achieved a maximum productivity of 6,000 VPs per day as compared to conventional flip-flop productivity of 3,000 VPs with three fleets.

Figure 2. The first dynamic slip-sweep survey design.

The second dynamic slip-sweep field test (February, 2010) was repeated in a new location with 20 vibrator trucks (4 spares) on a 25m x 25m source grid. Two salvos with 10 point vibrators per salvo were horizontally separated by 14.5Km along a 29Km super-spread (Figure 4 – top). We used a 6s linear upsweep, 3s slip-time and the minimum simultaneous distance was set to 3Km. We achieved 30,346 VPs per 24 hour period after two swaths of acquisition time. As the vibroseis drivers became more familiar with the stakeless guidance monitor, the number of VPs per hour increased (Figure 9). With this steady increase in VPs per hour, achieving greater than 40,000 VPs per 24 hours, may have been possible, if additional test time had been available.

Unconstrained simultaneous source methods

The unconstrained simultaneous source field tests acquired in February, 2010, used a reduced active receiver spread with point vibrators isolated in 3 x 6 quadrants, where each quadrant was 1.8Km by 1.8Km with 4,320 VPs on a 25m x 25m source grid (Figure 4 – bottom). The unconstrained simultaneous source field test was acquired with 18 unique pseudo-random and linear upsweeps, along with real-time QC. Both sweep designs were designed to reduce the cross-talk noise by 20dB or greater. These field tests were acquired with real-time QC. We were no longer sweeping blind. Both the seismic data and vibrator attributes could be quality controlled in real time.

Figure 3. Dynamic slip sweep (upper). Note the lack of harmonic noise contamination. The production (left) and dynamic slip-sweep stack (right) are equivalent.

Figure 4. Dynamic slip-sweep super-spread with vibroseis salvos shown in red (top) and unconstrained simultaneous source (bottom) field test designs.

Unique linear sweeps

The selection of 18 unique linear sweeps was based on the analysis of the maximum amplitude from the cross-correlation matrix of linear sweeps ranging from 6 to 23s.
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Cross-correlating any sweep along the diagonal with an adjacent linear sweep with only a one second difference in sweep rate reduces the cross-talk noise by 20dB or more (Figure 5). For this reason, we chose a simple approach and organized the 18 linear sweeps as shown in Table 2.

![Figure 5. Linear sweep cross-correlation matrix from 6s to 23s. Note with only 1 s difference, the cross-talk is reduced by approximately 20dB.](image)

<table>
<thead>
<tr>
<th>Optimized linear sweep lengths per quadrant in seconds</th>
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<tr>
<td>6 → 23</td>
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<tr>
<td>7 → 22</td>
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<tr>
<td>8 → 21</td>
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Table 2. After acquiring 50% of the total time to complete the acquisition in quadrant one (1,1), each vibrator changed sweeps from blue to green. The average sweep length for all quadrants was 14.5s.

**Unique pseudorandom sweeps**

Eighteen unique pseudorandom sweeps were defined and applied to point vibrators in each quadrant (3x6 quadrants). As described by Sallas et. al. (2009), the objective of using the pseudorandom sweeps was to reduce the cross-talk noise by greater than 20dB and increase the low frequency energy.

**Unconstrained simultaneous source real-time QC**

In the past, to speed up acquisition, the recording system sent the start command through the radio to the vibrators and the vibrators sent the ready-to-shake command to the recorder. Now, in continuous recording mode, the vibrators will sweep independently of radio communication. Radio communication is where a great percentage of acquisition time is lost. In flip-flop, slip-sweep (HPVA) and high-fidelity vibroseis seismic (HFVS) modes, a loss (or degradation) of radio contact between only one vibrator or more within a fleet can stop or slow down production. In this case, observers would have to consider moving the recorder truck to improve radio communication or implement the use of radio repeaters.

![Figure 6. Unconstrained simultaneous sweeps using pseudorandom (left), unique linear (middle) and the same linear sweep (right). Note the different levels of cross-talk.](image)

![Figure 7. Real-time QC of simultaneous sweeps for pseudorandom (left), unique linear (middle) and the same linear sweeps (right).](image)

![Figure 8. This real-time QC illustrates the vibrator position in each quadrant. The red dots indicate vibrators above predefined distortion threshold.](image)

Using the V1 methodology (Postel et. al., 2008) and unconstrained simultaneous source acquisition modes (enhanced with V1 real-time QC modes) the radio communication is no longer needed for source control. We are no longer dependent on distance or terrain conditions. The QC can be monitored either in the recorder truck or in a V1 equipped vehicle. Production is no longer interrupted when a vibrator is out of specification or when radio communication is lost. The vibrators will continue sweeping. During production, the Tablet PC, within each vibrator, stores all the QC attributes such as vibrator phase, distortion, amplitude, position, sweep parameters, and GPS time. These attributes and more can be retrieved by modem at a later time, or relayed by the other vibrators, or repeaters to the recorder. We are aware of the state of each
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vibrator based upon these QC attributes. These are used to optimize fleet management.

Figure 9. Dynamic slip-sweep productivity per hour.

How the pseudo real-time QC works

The pseudo real-time QC software, can be setup in a light truck in the middle of the vibrator fleets, on a high elevation point, and run by a vibrator pusher. Through repeaters, it can also be monitored in the base camp or other locations. This automatic QC in the vibrator and recorder allows both the vibroseis driver and observer to quickly take decisions about reshoooting a VP. This ensures acquisition compliance within pre-plan specifications at high-productivity rates. If an adequate internet connection were available, the software could be run safely (with access through login and password). This interface is currently under development.

Conclusions

Based on these limited tests, we determined that the use of both distance and time constraints, poses the lowest risk acquisition high-productivity method with our current production seismic crews. Given the opportunity to achieve production levels greater than 40,000 VPs/day, this implies we can finally acquire well sampled wide-azimuth seismic surveys. Currently, we believe the fixed time slot method with both distance and time, can achieve very high-productivity rates with our current production seismic crews.

As noted earlier, the unconstrained simultaneous sources technique offers the highest production rates. Seismic processing algorithms will need to be developed and proven to preserve prestack signals. In all the field test cases, it was clear that the vibroseis drivers require proper training with stakeless guidance systems, as shown by the standard deviation for move-up times on a 25m source grid (Figure 9).

Figure 12. Stakeless guidance monitor (Tablet PC)

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Why are we faster today?

The answer is very simple - point vibrators or fleets of vibrators are sweeping independently with stakeless guidance systems and real time QC. For example, if the vibrator fleet is out of position (tolerance) the driver will know instantly before sweeping by a synthesized voice from the Tablet PC. The driver will be warned to sweep again without any QC radio communication (Figure 10).

Figure 10. Unconstrained pseudorandom (left) and unique linear simultaneous sweep productivity per hour (right). Peak productivity per hour was 2,064 for unconstrained simultaneous sources.

Figure 11. The median, mean and standard-deviation values for the move-up times for unconstrained simultaneous source field tests using a 25m source grid.

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