In land seismic operations, there is a strong drive to improve both quality and performance to meet the increasing demand for high-density and wide-azimuth recording.

The shift to a point-source, point-receiver acquisition model that reduces the size of conventional source and receiver arrays has advanced the improvement in image quality. The goal is geophysical. Source and receiver arrays improve the signal-to-noise ratio of the recorded data with the summed energy of multiple sources and the summed response of receiver arrays. However, this crude method of improving signal amplitude can cause undesirable side effects, such as intra-array statics and residual normal moveout across the array. These shortcomings vanish progressively as the array size decreases. For the receiver array, modern seismic recording equipment lets us deploy more channels and reduce the array size continuously below any desired threshold and even use single digital geophones as point receivers.

The real challenge lies in reducing the source array size in vibroseis operations. The size of a vibroseis array is dictated by the size of the vibrator trucks and how close they can operate, so that even with a small array of two vibrators the component sources will be 5–10 m apart. Therefore, for the source array, the obvious answer is single-vibrator acquisition where each vibrator is used as an independent source. Not only does single-vibrator acquisition give us the geophysical benefit of a point source, it can also bring huge gains in acquisition performance and seismic image quality.

CGGVeritas’ high-productivity vibroseis acquisition (HPVA) technology is an exclusive technique based on slip-sweep vibrator operations where several vibroseis source arrays (typically a fleet of 3–4 vibrators) overlap their source sweeps, speeding up operations. HPVA refines the slip-sweep technique by removing the harmonic interference between the concurrent vibrator fleet sweeps. This allows three or more fleets to be deployed and overlap their sweeps to record high-quality, high-density, wide-azimuth data with higher productivity. HPVA has enjoyed considerable success in North Africa and the Middle East, providing improved productivity and enhancing image quality. HPVA crews operating in this region have achieved productivity records of more than 300 source positions per hour.

V-1 single vibrator acquisition. CGGVeritas developed V1 as a practical solution to both high-performance and single-vibrator acquisition, overcoming significant technical and operational hurdles in the process.

The first priority is to maintain source power and signal amplitude. This can be done by increasing the sweep length of the single vibrator to partially compensate for the reduction of the number of vibrators per fleet and by increasing the density of the shot points. For a given bin size, the increase in shot density will increase the fold of the recorded data set, giving greater stacking power (and thus, signal amplitude) during the processing. This opens the way to improved data quality via better illumination, better multiple suppression, and better azimuthal amplitude and velocity information.

With the deployment of a large number of vibrator sources, a robust and efficient operation is the key to success. Figure 1 shows a 12-vibrator shooting schedule with the long sweeps that would typically be used. At any given time, up to eight vibrators are sweeping concurrently, while four are moving to the next shot points and preparing to fire. To meet this tight schedule, a new concept in vibrator fleet management has been introduced. The vibrators are now automatically allocated slots in a shooting schedule and move independently on their designated shot lines. If a vibrator falls behind and misses its slot, it waits for the next available slot. As the vibrators are all operating independently, this will not slow the progress of the other sources. This system also is flexible enough to quickly modify the shooting schedule and redeploy the individual units. This could be done to cover for a source failure or add additional effort on source lines with more difficult terrain where transit times from shot point to shot point are longer.

The final challenge is recording the data set. With long sweeps, short slip times, and multiple sources firing on an intensive schedule, a continuous stream of data flows from the receivers. The data therefore have to be recorded continuously along with accurately synchronized source information and shooting “time stamps.”

The short slip times and large number of concurrent sweeps could also result in harmonic noise contamination. This is where the patented HPVA technology plays an important role, modeling and subtracting the harmonic noise to ensure the data quality is unaffected.

V1 pilot projects. Three pilot projects have been completed recently in Egypt and Saudi Arabia to assess V1 operations...
and data quality. In all cases, V1 improved image quality while achieving production rates equivalent to, or better than, conventional slip-sweep operations.

The first case illustrated is from the western desert in Egypt. The production source configuration consisted of four fleets of four vibrators operating in slip-sweep mode, while the V1 configuration was 14 single vibrators operating in slip-sweep mode. Table 1 compares the average acquisition statistics of the two configurations. The four-fleet operation achieves very high productivity (340 shot points per hour), but V1 doubles the total. For this trial, the additional productivity has been used to double the shot-point density while maintaining the high production rate (km² per hour).

The effect of the increase in the shot-point density on the final images is significant. Using a typical land-processing sequence (including prestack time migration) and the same bin size for both data sets, there is a marked improvement in the coherency of the V1 image (Figure 2). The most noticeable improvement is the reduction in the acquisition footprint. As a result of this and the inherent benefits of the point source, the V1 image exhibits better signal-to-noise ratio.

A second pilot project data set allows further comparison. Here V1 acquisition that used 12 single vibrators was compared to a production configuration of three fleets of four vibrators operating in slip-sweep mode. As before, the extra productivity of the V1 operation has been used to increase shot-point density. In this case, the original shot line spacing was 300 m and the shot interval was 50 m. V1 data was acquired at four times this density (150 m lines and 25 m interval).

Table 1. Acquisition statistics for a V1 pilot project in an open desert environment.

<table>
<thead>
<tr>
<th></th>
<th>Production</th>
<th>V1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vibrators</td>
<td>4 fleets x 4 vibs</td>
<td>14 fleets x 1 vibs</td>
</tr>
<tr>
<td>Sweep length</td>
<td>16 s</td>
<td>42 s</td>
</tr>
<tr>
<td>Slip time</td>
<td>10 s</td>
<td>5 s</td>
</tr>
<tr>
<td>Shot line interval</td>
<td>300 m</td>
<td>150 m</td>
</tr>
<tr>
<td>Shot point interval</td>
<td>25 m</td>
<td>25 m</td>
</tr>
<tr>
<td>Receiver line interval</td>
<td>200 m</td>
<td>200 m</td>
</tr>
<tr>
<td>Receiver group interval</td>
<td>50 m</td>
<td>50 m</td>
</tr>
<tr>
<td>SP/km²</td>
<td>266</td>
<td>533</td>
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<tr>
<td>Productivity (SP/hr)</td>
<td>340</td>
<td>680</td>
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<tr>
<td>Production rate (km²/hr)</td>
<td>2.5</td>
<td>2.5</td>
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</tbody>
</table>

Figure 2. Time slice from data acquired with four fleets of four vibrators (left) is compared to V1 data using 14 single-vibrators (right) acquired with double the shot-point density. V1 has produced a more coherent image with greatly reduced acquisition footprint (vertical striping), and at an equivalent production rate. Data courtesy of Apache.
Figure 3 compares the images from this example. A more rudimentary processing sequence was used in this case; the same bin size was used for comparison.

The “high-density” panel shows the result using the full V1 data set with four times the shot density (the shot line spacing and the shot interval have been halved). There is a marked improvement in the coherency and resolution of the image when compared to the production result. The production rate for V1 was 1.1 km²/hr, which compares favorably to the three fleet slip-sweep configuration rate of 1.4 km²/hr (at standard shot-point density). For comparison, a notional two-fleet flip-flop configuration at the standard shot-point density would achieve 0.9 km²/hr.

The “high production” panel shows a result using half of the V1 shot points, i.e. two times the production shot density (the shot line spacing has been halved). We still see an improvement in the image quality compared to the production data set, and, at the same time, the production rate has increased to 2.2 km²/hr.

The pilot projects have demonstrated that dense single-vibrator acquisition can provide better image quality and better production rates than current vibrator fleet acquisition by using the available vibrators more effectively, which boosts crew performance. They also show that V1 is a practical solution for high-performance vibrator acquisition, which can offer scalable options to meet production rate and image-quality objectives.

For a V1 crew, the actual productivity that can be achieved is determined by the required record length, given that the number of vibrators available is consistent with the requirements of the geometry and shooting parameters. In the second example, the 12 vibrators reached a maximum rate of 700 shots per hour, compared to the theoretical maximum of 720. This demonstrates the efficiency of V1 and its new fleet management system, which is nicely illustrated by the actual recording sequence for the second example data set in Figure 4. With some vibrators experiencing problems, and some source lines proving to be slower than others, the shooting plan was modified to maximize source utilization and optimize the operational efficiency.

Benefits. V1’s advanced productivity makes it a valuable tool for wide-azimuth land acquisition. The intrinsic point-source nature and increased shot-point density of V1 data also make it ideal for superior high-resolution imaging, with high-fold or smaller CMP bin size. Complementing this with a small receiver group interval gives dense wavefield sampling to record unaliased noise and signal, allowing more effective noise attenuation and improved signal processing. By adding the wide-azimuth aspect, V1 data sets provide optimum illumination and energy recovery from the point source, optimum multiple attenuation, and valuable azimuthal information.

The geophysical benefits of V1 can be seen in the superior quality of the V1 images in Figures 2 and 3. There are clear improvements in both the time slices and the sections. The shallow images benefit especially from the increased shot-point density, with reduced acquisition footprint, stronger signal content, and more coherent events. Faults are defined more clearly, and the thinner events are more coherent, providing more detail in the time-slices. In the deeper section, there also is improved resolution and signal-to-noise ratio, providing a clearer image.

There are other imaging benefits for surveys in obstructed areas, such as producing fields. A prime example is heavy oil production facilities, which can create large obstacles for the repeat 4D surveys used to monitor them. The dense source grid, higher fold, and wide-azimuth content help minimize the effect of the gaps on the image, either directly or by providing a data set more suitable for multidimensional interpolation.

Health, safety, and environment. CGGVeritas, and the industry as a whole, is committed to continually improving HSE
performance. Assuring a safe workplace and minimizing the environmental impact are key HSE objectives. In this context, the new mode of single-vibrator operations that V1 introduces brings significant advantages.

With the elimination of vibrator source arrays, we avoid the close maneuvering of vibrators in a source array fleet as they transit between shot points and park in formation. This reduces the risk of vehicle collision, one of the key concerns for HSE crews.

Single-vibrator operations decrease the footprint of the

Figure 4. Actual recording sequence during a V1 field trial with 12 vibrators. The receiver lines are blue, and the source lines are grey. Progress of the vibrators along the lines is red, and their direction is indicated by the black arrow. Some shot lines proved to be slower than others, so the shooting program is adapted toward the end of the survey to compensate. The redistribution of the vibrator effort ensured they were optimally utilized and the survey was completed as efficiently as possible. Operations were limited to daylight hours.
source array, reducing environmental impact and promoting environmental best practices. This is particularly important in sensitive areas such as Arctic tundra. Depending on the local environmental regime, a strategy that uses dense shot lines or sparse shot lines can be adopted, both of which benefit from V1 operations. The dense shot-line strategy would use a single vibrator on each line, reducing tire damage per line and effectively diluting the environmental impact more evenly over the survey area. For sparse shot lines, fleets of single vibrators would roll along acquiring sets of dense shot points. The result is more data acquired more quickly and with the same impact as conventional operations.

The sparse shot-line model is also applicable to other scenarios where the terrain is difficult or access lines must be cut, such as foothills with ground conditions that prevent drilling of dynamite shot holes. Here, the single vibrators are more maneuverable and better suited to tight shot point locations than vibrator fleets.

Another potentially important environmental benefit is that less energy emitted at each shot point lessens the risk of damage to the infrastructure. This can be an important factor in mature fields where there are extensive surface facilities.

Fast turnaround. There are certain economic scenarios, such as short-term exploration leases or land sales where time becomes the critical factor for acquisition. V1 operations provide not only higher production rates to reduce the survey time, but also improved imaging, which could reduce the burden of time spent for interpretation. Both of these factors will aid more rapid seismic evaluation of prospects to meet strict deadlines.

Adaptable acquisition. With the flexibility that single-vibrator operations bring, it is now possible to develop a more adaptive approach to acquisition. For example, in areas where the surface or near-surface conditions are particularly problematic for vibroseis acquisition, adaptively increasing the shot density and allocating more vibrators to these source lines can increase the source effort. This could be done ahead of time by utilizing LIDAR and other remote sensing techniques to identify features such as gravel pits where the shot point density could be increased to overcome the dispersive effect. It is also possible to adapt the survey on-the-fly using available vibroseis QC data such as ground force, which the V1 system makes available in real time. As V1 uses accurate onboard GPS vibrator navigation, modifications to the shooting plan can be made easily without the need to resurvey the shot points.

Open technology. The recording and QC of V1 operations use industry-standard tools and remain completely open to the client. The demultiplexing of the continuous recording and the HPVA processing are performed in the field, allowing real-time QC of the data and delivery of field data that are fit for the purpose and require no postprocessing.

Conclusion. V1 can improve land-seismic image quality through high-performance, high-density, wide-azimuth acquisition. In addition, undesirable source array effects are removed, resulting in a data set more suitable for sensitive applications such as high-resolution imaging and reservoir characterization.

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