Technical Advances in Onshore High-density Seismic Acquisition

Lieqian Dong, Min Li, Xinquan Wang, Yang Yang, BGP Inc., CNPC.

Summary

High-density seismic can significantly improve imaging quality of subsurface targets and has been widely applied in different regions across the world. However, onshore high-density seismic acquisition still faces some challenges. To address these challenges, BGP has developed the up-to-date techniques in survey design, shooting, receiving and operational management to achieve cost-effective high-density and high channel count acquisition. Application shows that the new techniques further complete the comprehensive onshore high-density seismic acquisition solution, improving data quality and acquisition efficiency.

Introduction

With the growing demand for energy, hydrocarbon exploration has increased significantly. Survey trace-density has been following an exponential trend of ten-fold increase each decade (Manning et al., 2019). Conventional acquisition techniques have not been able to meet exploration challenges in terms of acquisition size and cost. However, high-density acquisition solutions can well deal with the above-mentioned difficulties by applying a large amount of source and receiver equipment at a reasonable cost (Nabil K. Yazami et al., 2019). It is well established that data quality is strongly correlated to trace-density (Pecholc et al., 2010). The benefits of high-density surveys go well beyond the increase in S/N of the stack. It has been demonstrated that a significant uplift is to be expected on AVO and AVOZ attributes (Ourabah et al, 2015), with the latter becoming valuable products in defining fractures and detecting sweet-spot in complex reservoirs. High-density acquisition has helped to improve the spatial resolution of seismic data (Figure 1).

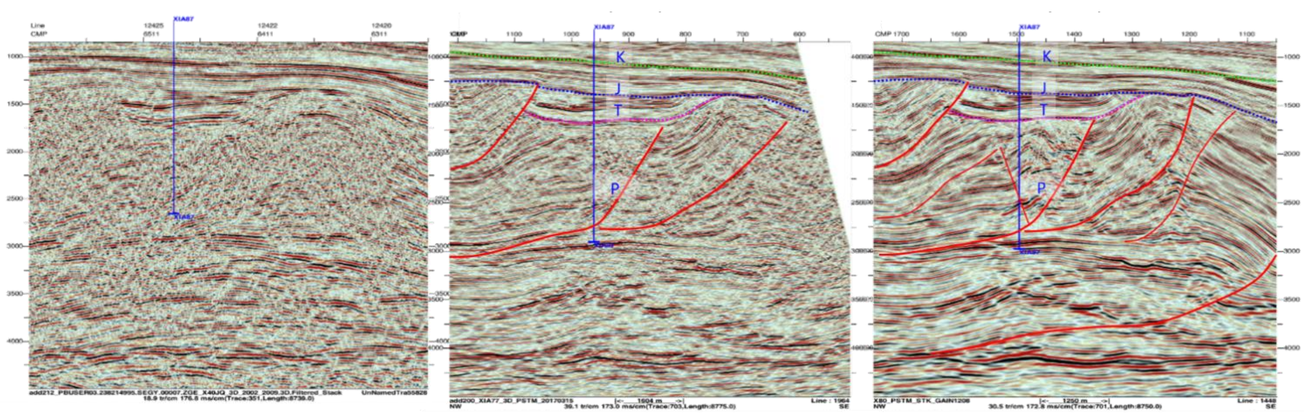

Figure 1. Comparison between seismic imaging with different trace density: (left) 50000, (middle) 850000, (right) 3830000

High-density acquisition will inevitably result in high cost which also limits its application. BGP's high productivity acquisition and nodal technique provides a cost-effective solution to achieve high-quality data. However, when trace density increases to a scale of 100 million traces /km^2, it brings new challenges for survey design and implementation. Also, seismic acquisition is still restricted in some areas because of safety or environmental concerns. In the paper, we present some latest technical advances in survey design, shooting, receiving and operational management aspects to achieve high-quality and high-density seismic data.

Methods/Techniques

Survey design

In order to lower the pressure of computation for geometry design and analysis of hundreds of millions of traces, BGP develops an ultra high-density geometry analysis technique that combines vector kernel, multidimensional spatial associated index and CPU+GPU. The time required for attribute analysis over 3820 km² (Trace Density:1,105,920,000; active channel: 921600) has been reduced from 118 hours to 22 minutes (Figure 2).

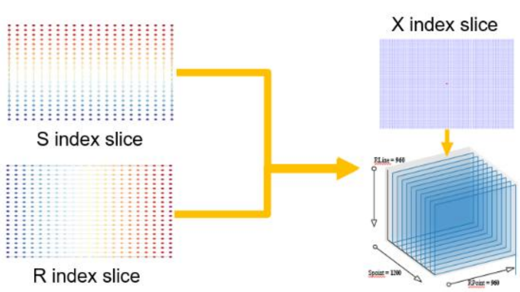

Figure 2. Multidimensional spatial index

Taking advantage of AI techniques, BGP develops the AI-aided identification of obstacles technique that makes the identification rate of obstacle exceed 90%. Fast optimization technique of SP & RP reduces the workload and ensures a custom fold of target layers (Figure 3).

Figure 3a. SP & RP distribution map after conventional offset (left) and AI offset (right)

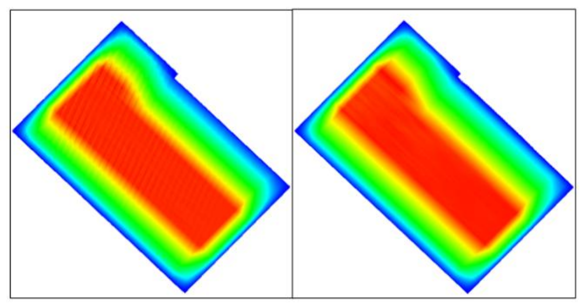

Figure 3b. Fold map after conventional offset (left) and AI offset (right)

Source

Presently, the acquisition projects usually adopt conventional vibrators, and BGP has about 700 conventional vibratos in overseas production. The adoption of conventional vibrators with specified low frequency shooting technique is a cost-saving and economical solution for exploration of deep reservoirs. However, this solution faces strong low frequency distortion. To solve this problem, BGP has developed a low distortion sweep (LDS) technique which addressed two major problems including mutation of harmonic distortion and low frequency harmonics. It can reduce distortion by more than 20% on average, and more than 40% in the transition zone of the sweep signal (Figure 4).

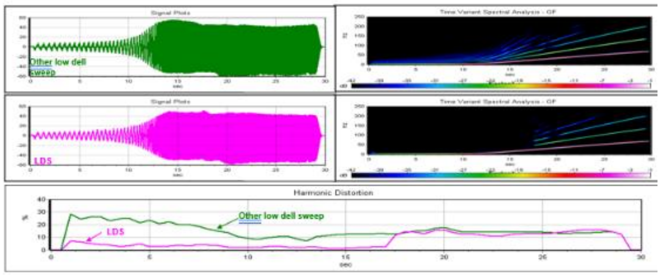

Figure 4. Comparison between the low frequency signals design by LDS and other conventional methods

In dynamite-prohibited areas, BGP develops Gi-source technique which has high controllability and enables custom energy output & energy release direction. Comparing with the data acquired with vibrators, Gi-source data is comparable with vibrator data (Figure 5).

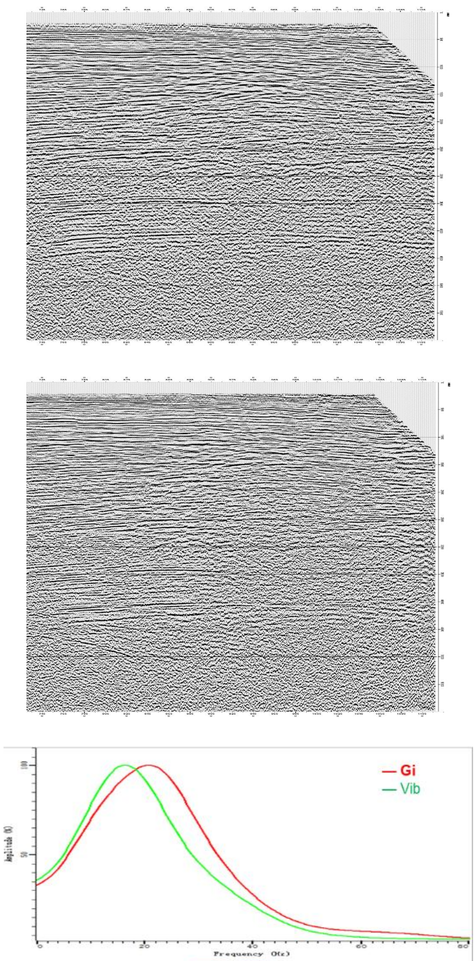

Figure 5. Data comparisons between vibrator (top) and Gi-source (middle) and frequency spectrum (bottom)

Besides, BGP forms the Wi-source technique which provides a solution for acquiring near-offset data in restricted areas. By comparing a 75 kg Wi- Source with an 80,000 lb. vibrator with 7% drive force, Wi- Source can get comparative shallow information (Figure 6).

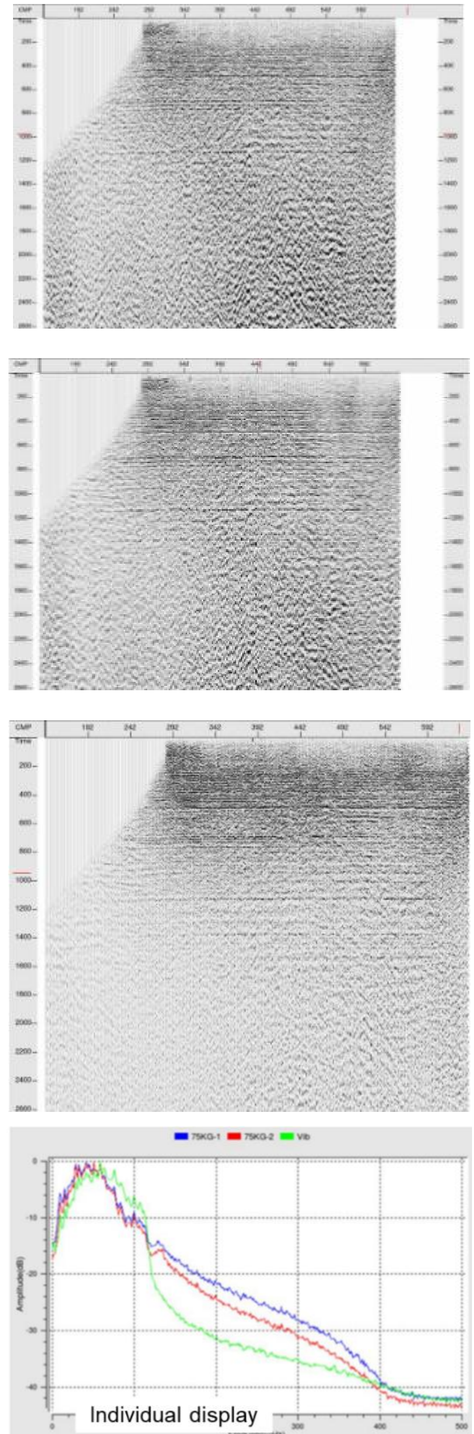

Figure 6. Comparison between data acquired using a 75 kg Wi-Source with 1 shot per SP (top), 75 kg Wi- Source with 2 shots per SP (upper middle) and a vibrator (lower middle), and their frequency spectrum (bottom).

Receiving

In order to monitor the status of nodes and safeguard seismic data quality, nodes with LoRa function are selected. Quantum and eSeis, both developed by BGP, are utilizing this function. LoRa-based fast QC technology is developed to achieve daily full coverage QC of all deployed nodes in land operations. LoRa consumes low power and covers a long range, aiming to harvest at least one QC dataset a day from every node. There are two ways to harvest the node status QC data. One is truck-based gateways to quickly harvest reliable and comprehensive QC data; the other is drone-based gateways to harvest the data from the terrains difficult to access by vehicles (Figure 7).

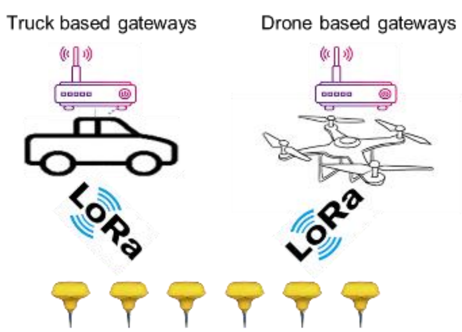

Figure 7. LoRa gateway harvesting node status QC data

For solving the real time monitoring of nodal ambient noise, BGP develops an ambient noise monitoring technique by utilizing star link/4G and cloud services. It has the functions of the real-time ambient noise monitoring, visualization of noise amplitude and displaying the occurrence time and coordinates of noise (Figure 8).

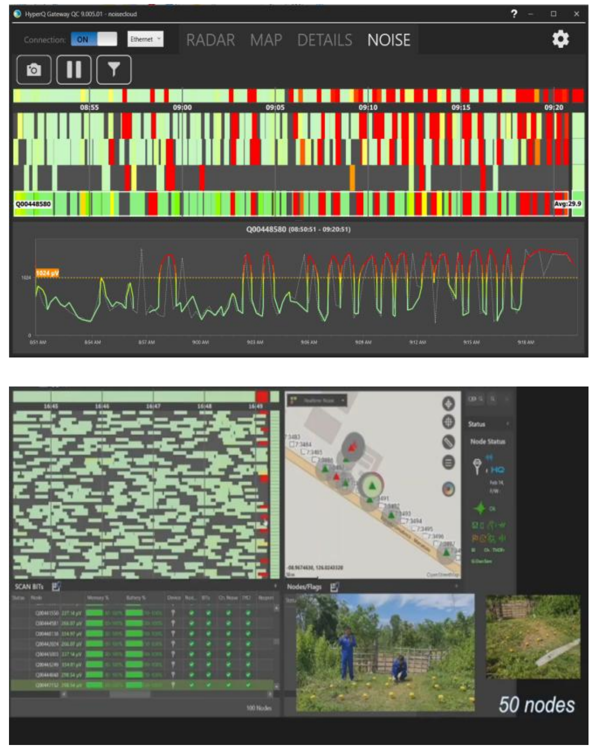

Figure 8. On-site ambient noise monitoring

Operation management

BGP has also developed and improved the DSS system (Figure 8) based on VibPro controller of Inova vibrator, which is a real-time remote control and management system for vibroseis that uses high-speed radio networks and links, multi-global positioning systems and geographic information, and is suitable for both cable and cableless recording systems. This system includes DSC (Digital Seis Controller) and DSG (Digital Seis Guider). It contains a multitude of functions, such as long-distance high-speed communication (≥30km), a digital communication link structure (≥50 vibrators), a real time shooting control with continuous recording, a vibroseis pusher management system, real time wireless job assignment, customized shooting, restricted zone alerting, real-time monitoring, stake-less operation, and production statistics. The high-speed long distance data link solves the challenge of long-distance communication. An advanced digital communication link structure was designed to solve the communication problem of UHP multi-vibrator parallel shooting. In addition, there is a provision if there is no radio signal because of some obstruction. Two special functions have been developed for this situation. One is an offline method based on autonomous mode. Namely the vibrators work with an independent and autonomous mode, does not rely on radio signals. The other is to utilize the function of satellite regional short message communication (RSMC) to exchange command information between DSC and DSG (Figure 9). In this way, even during periods without radio communication, the DSS system can still achieve effective control.

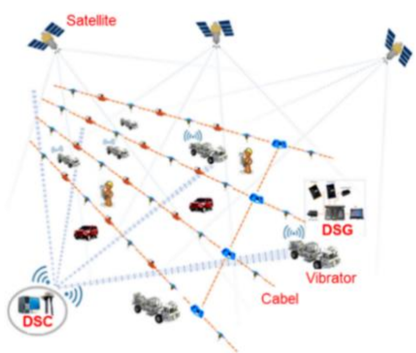

Figure 8. DSS system

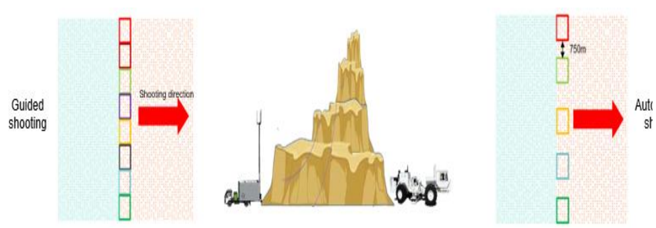

Figure 9. Vibroseis autonomous shooting in shadow area

For dynamite efficient shooting management, BGP carries out a quantitative analysis of the seismic wave dynamic characteristics based on the energy of single-shot seismic data, calculates the energy attenuation variations in the time-space domain, and conducts scientific and quantitative design. As a result, the T-D (time-depth) rule-based synchronous acquisition technique is developed for dynamite seismic surveys in loess mountainous areas. The acquisition efficiency has been steadily improved, with the average daily productivity reaching 3,843 shots (Figure 10).

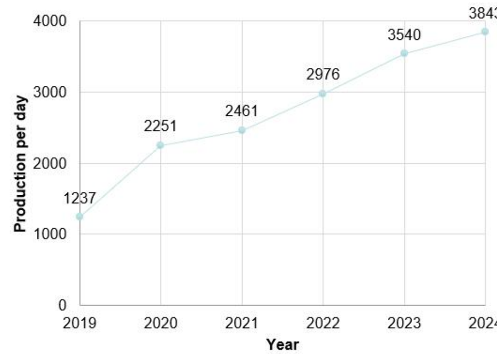

Figure 10. Average productivity with dynamite

Application

Recently, five typical UHP 3D projects have been completed in recent years. The case in this paper is in Oman. The geometry parameters (Table 1) and T-D rules (Figure 10) are shown below. A total of 50,000 Quantum nodes were used, as well as 10 units of TITAN 480 vibrators and 3 spare units, and 12 sets of DSS system.

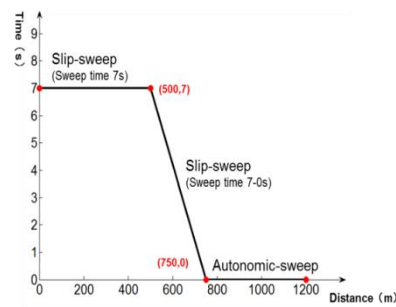

Figure 10. Time-distance Rules

Table 1. Geometry Parameters

Template	120L*3S*202R
Bin (m)	12.5*12.5
Fold	6060
Active Spread	24240
Receiver grid (m)	75*75
Source grid (m)	25*25
Inline Offset (m)	7537.5
Maximum Offset (m)	8772.2
Source Density (vp/km^2)	1600
Trace Density (million/km^2)	38. 78

Starting from March 2021, UHP nodal acquisition has been applied in the complex Gobi desert area in Oman.

Fast QC using LoRa plays a significant role in the project. Truck-based gateways collect the status QC of 1600 nodes per hour. When drone-based gateways are permitted they collect the status QC of 10 thousand nodes in just one hour. All deployed nodes are monitored, and their status QC data are efficiently and correctly collected.

When nodes are used for recording, the vibroseis control system and the recording system are separate. If it is not handled well, the spread may be wrongly picked up or there may be an issue with the spread while vibrators are still working. To solve these issues and for the benefit of field operations management, after preliminary research, BGP has summarized a set of methods suitable for the DSS management system and nodal acquisition. Nodal status data is harvested by a vehicle or a drone-based gateway and is sent to the nodeQM software. This software can manage the spread using the information obtained. It will send the active spread information to DSS system. The DSS can manage the vibroseis units based on this information about the spread. The DSS also sends a report to nodeQM, after which nodeQM can calculate the pickup spread information and inform the back crew to harvest. (Figure 11).

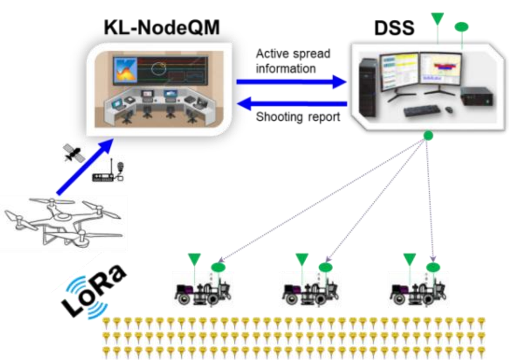

Figure 11. Real-time operation management and QC

The data quality is also improved (Figure 12, Jack JW Levell et al, 2022). Compared with cabled systems, the nodal data is of higher density. Shallow imaging was improved, with a higher signal to noise ratio and more consistent reflections. Productivity was also improved. The average daily production reached more than 25,000 VPs (Figure 13). In addition, manpower was reduced by 45% and HSE driving exposure by more than 35%.

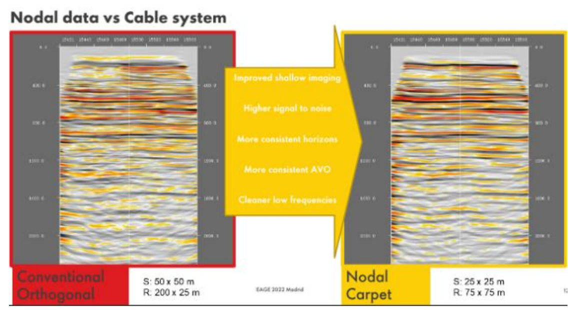

Figure 12. Imaging quality comparison between cable and node systems (Jack et al., 2022)

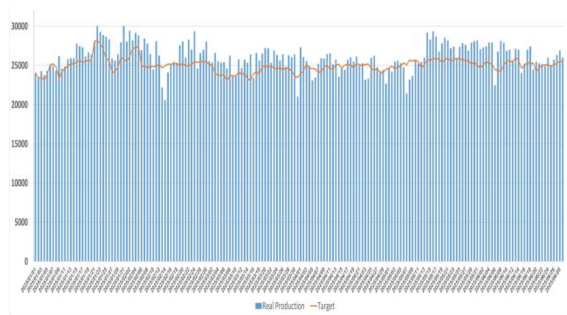

Figure 13. Daily production reaches more than 25,000 VPs (12 Vibrators)

Conclusions

1. A comprehensive acquisition solution of high-density and high channel count has been developed and successfully implemented.

2. The T-D rule based shooting of dynamite source and its integration with the improved DSS system for vibrators which enables independent shooting in shadow areas significantly improve the shooting efficiency of high-density seismic acquisition.

3. The comprehensive solution covers all terrain with the newly developed Gi-source and Wi-source and enables near-real-time noise monitoring and node QC.

References

1. PI Pecholc, Y Zhang, et al., Distance Separated Custom Slip-Sweep - A New High-Productivity Method, EAGE workshop on Developments in Land Seismic Acquisition for Exploration, May 2010.
2. Ourabah, A., J. Bradley, et al., Impact of acquisition geometry on AVO/AVOA attributes quality – A decimation study onshore Jordan: 77th Conference & Exhibition, EAGE, Extended Abstracts, 2015.
3. Nabil K. Yazami, et al., Land seismic survey design for High Channel Counts crews, SEG workshop on New Advances in Land Geophysical Acquisition, Oman 2019.Samuel Valla, et.al, What do we expect from a Land Acquisition System, SEG workshop on New Advances in Land Geophysical Acquisition, Oman 2019.
4. Manning, T., Brooks, C., et al., The case for a nimble node, towards a new land seismic receiver system with unlimited channels. SEG Technical Program Expanded Abstracts 2018: pp. 21-25.
5. Jack JW Levell et al, Carpet Sources and Recievers for Nodal Land Seismic, EAGE Madrid, June 2022.