Increasing both resolution and productivity of Vibroseis methods with enhanced sweeps and simultaneous acquisition by the standard 3D cabled seismic crew

Ilya Korotkov, Alexander Zhukov, Radiy Gafarov, and Ilnur Siraev.

Introduction

The 3D seismic vibroseis method is a key way to conduct large-scale land exploration work in vast territories of licensed blocks, the area of which can exceed thousands of square kilometers. The possibility of multiple increases in the productivity of such work will lead to seismic survey coverage of a larger area in one field season and, if necessary, an increase in the density of observations to obtain more detailed seismic images. The practice of condua cting vibroseismic survey shows that the actual sweeping and listening time together with the movement of the vibrator groups occupies a significant part of the total survey time.
A well-known Slip-sweep method (Rozemond, 1996) increases the number of source groups that work together with a given overlap in sweep time. In this method, the overlap is fundamentally limited by the listening time to minimize the mutual influence of different groups, but no more than half of the sweep length is often chosen. Shuffle method (Zhukov et al., 2017) uses pseudo-random sweep signals that are not correlate with each other for synchronously vibrating several vibrator groups simultaneously. In this case, an entirely blended response is recorded – a single vibrogram, which then de-blended by it individual correlation with the each of differently seeded Suffle sweep pilots. These methods can be carried out using standard cabled recording systems such as Sercel (428,528). The ISS method (Howe, et al., 2008) removes all restrictions on vibration start times overlap between jointly working groups of vibrators without any synchronization between them. The work is carried out in the so-called source-starting mode, and synchronization is performed only within a group, or it is assumed that group will work as simultaneously operating dispersed source (Berkhout, 2012). In the case of ISS, recording of responses from independent vibrations is possible only in a continuous mode with subsequent transcription of individual vibrograms according to the start times of each individual vibration, stored by the vibrator controller. The continuous recording mode requires the use of autonomous (nodal) recording systems, which, despite their potential advantages, have not yet been widely used in the practice of standard land seismic crews. We managed to find a technical solution for using the Sercel 528XL cable system in one of the standard modes for piecewise continuous recording in the source-starting mode driven by the GDS-II controller, which made us possible to carry out experimental surveys by the ISS method with cabled recording.

Data acquisition

The 3D experimental surveys were carried out at an area of 18 square kilometers as a part of a production survey, which was shot using the Slip-sweep method. The main goals of the experiment included productivity increase tests and comparison of seismic images obtained from different sweep signals.

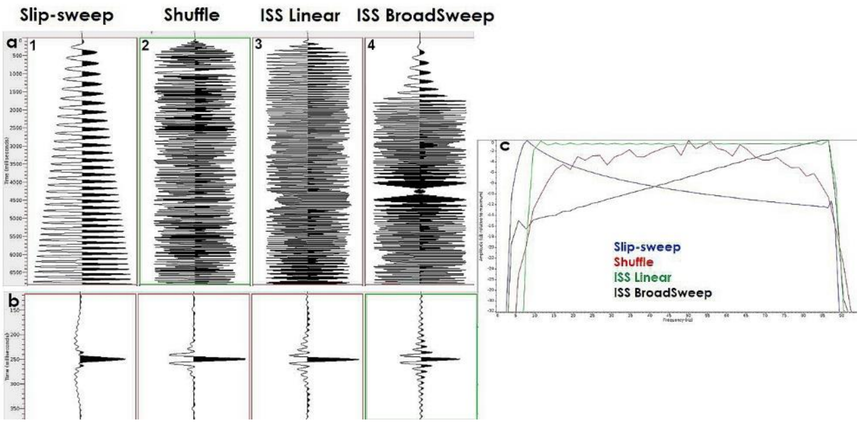

Figure 1 *(a) First 7 seconds of different sweeps used in experiment surveys, (b) their autocorrelations, and (c) spectra.*

There was also feasibility test of the vibroseis acquisition in continuous mode with a standard cabled recording system included in standard 3D crew equipment. Figure 1 shows reference sweeps for the different surveys, where the Slip-sweep is a non-linear sweep that has lowered force characteristics at low frequencies but longer taper (Figure 1a, 1) and negative nonlinearity at higher frequencies which is visible on its spectrum (Figure 1c, blue colour). Shuffle (Figure 1a, 2) is one seed of a pseudorandom sweep. The ISS linear (Figure 1a, 3) is a standard linear sweep with flat spectrum (Figure 1c, green colour), and the Broadsweep (Figure 1a, 4) uses dwell regime at lower frequencies from 3 to 9 Hz and positive nonlinearity at higher frequencies (Galikeev et al., 2019) as seen on its spectrum (Figure 1c, black colour).
Table 1 shows four different survey methods, sweeps, and parameters. The two of them (the Slip-sweep and the Shuffle) were acquired in standard recording mode and the others (the ISS Linear and Broadsweep) required a quasi-continuous recording regime that use recorded data splitting into 99 seconds time portions before writing them to the storage drive in SEG-D format.

Survey / Parameters	Slip-sweep	Shuffle	ISS Linear	ISS Broadsweep
Recording type	Standard		Continues, 99 sec data blocks	
Controller	VE 464	GDS-II		
Sweep type	Non-linear, -1.8 dB/Oct	Random	Linear	Broadsweep, 0.1 dB/Hz
Frequency range, Hz	3-90	7-90	7-90	3-90
Sweep length, sec	45 (sleep-time 50%)	60	12, 14, 16, 18	12, 14, 16, 18
Groups	3	4	4	4
Vibrators	3	2	2	2
Vertical stack	1	1	4	4

Table 1 *Surveys and parameters*

Acquisition spread consisted of 29 receiver lines with 204 channels each, 300 m distance between lines, nominal 300 m between source lines, and 50 m between shot and receiver points. The maximum CMP fold was 340. A group of 30 tons Batyr vibrators equipped with a GDS-II controller served as the seismic source and Sercel 528 XL served as a seismic recorder. Figure 1 shows the full production survey layout (a) containing the experimental area (a, blue and red colours). The zoomed part of the experimental survey is shown on Figure 2 (b).

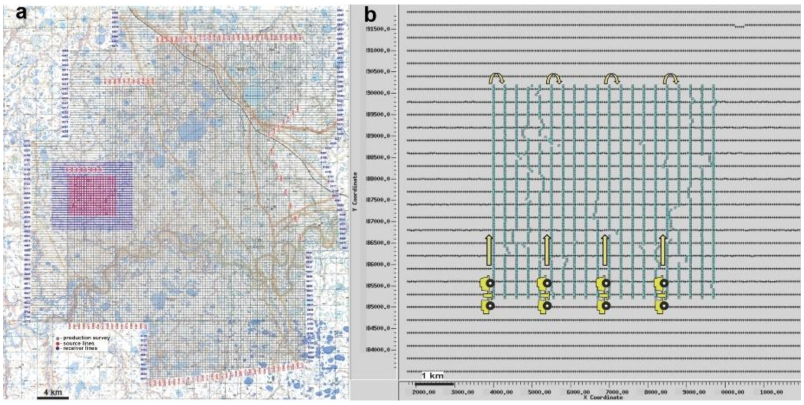

Figure 2 (a) 3D production survey map (grey lines) and experimental survey layout (red and blue lines). (b) Vibrator groups moving (yellow figures and arrows) in the experimental Shuffle and ISS surveys.

There are three vibrator groups were located successively in the Slip-sweep survey and moved along each source line vibrating 45-second sweeps with 22.5 seconds of slip time between them.
For the Shuffle and ISS surveys, four vibrator groups moved along parallel lines at a distance of 1500 m, shooting the experimental area simultaneously. After the turns, the groups shifted by 300 m and moved in the backward direction (Figure 2, b). There are five passes were made that covered 20 source lines while maintaining a predetermined distance of 300 m between them. In the case of the Shuffle survey, we recorded data in the standard regime after the synchronous start of four simultaneous vibrations, each emitting an individual pseudorandom sweep. Thus, four vibrator groups produced one fully blended Shuffle vibrogram. For the ISS survey, the Sercel 508XL recording unit was used in a special micro seismic regime, which provided 99-second portions of a continuous recording, while vibrator groups worked completely independently.

Data processing and results

Specially created software transcribed raw ISS records to individual vibrogarms before the data processing stage and de-blended Shuffle correlograms were extracted and assigned to their real vibration points.
The fieldwork of various methods was passed through a single processing graph, including gathers pre-processing, amplitude normalization, impulse deconvolution, velocity analysis, two iterations of residual statics, random and coherent noise removal, stacking, 3D post-stack migration, and coherent filtering. Figure 3 shows a comparison of the inlines from migrated volumes for different field methods and signals from Table 1.

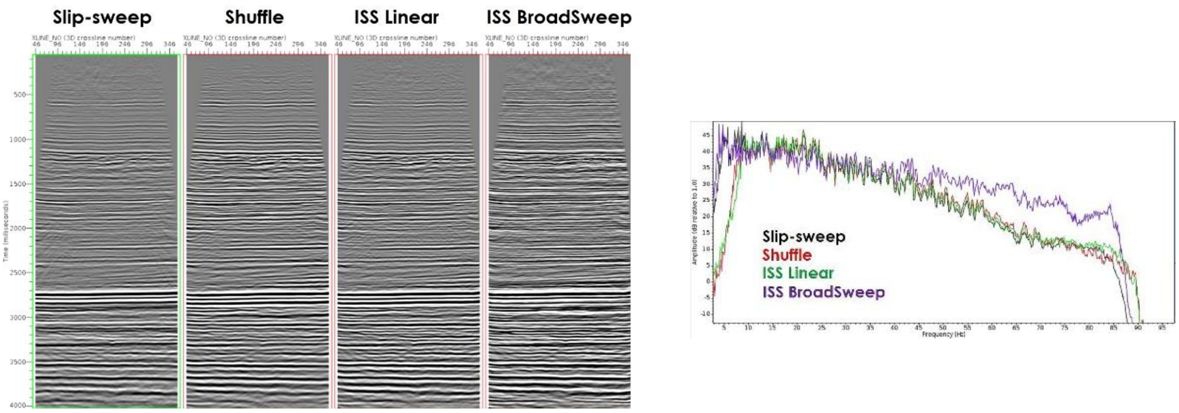

Figure 3 Migrated time section obtained from different acquisition methods and sweeps (at the left), and their amplitude spectra (at the right).

A comparison of the processing results (Figure 3, at the left) and their amplitude spectra (Figure 3, at the right) shows that the differences in the obtained resulting images are mainly related to the frequency range and characteristics of the emitted sweeps, i.e. productivity increase methods themselves do not affect the quality of the resulting images.
Figure 4 shows a detailed image of a geological object in the Jurassic deposits on vertical (a) and horizontal (b) sections extracted from cubes of different methods.

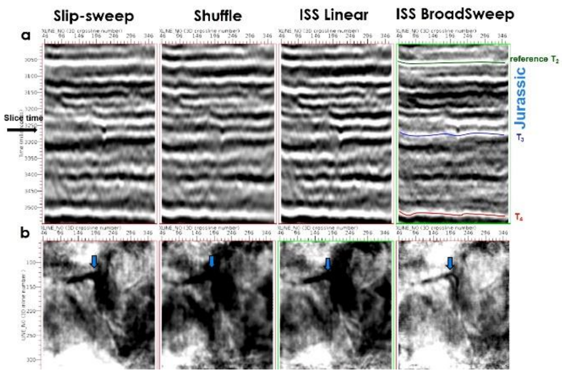

Figure 4 *(a) Fragments of time sections in the Jurassic interval and (b) time slices through the meandering channel (blue arrow).*

One can see that the meandering channel (Figure 4b, blue arrows) is much better delineated on the ISS Broadsweep volume (Figure 4b, rightmost).

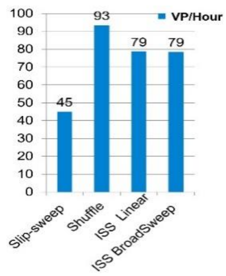

Figure 5 *Productivity comparison diagram (in vibration points per hour).*

We used detailed survey information from 2000 operator reports of each survey to compare the productivity of the four methods. The diagram (Figure 5) shows the productivity indicators of the methods in their pure form, without taking into account time losses due to weather conditions, refueling, etc. The productivity increase of the ISS method is about 1.75 times and the Shuffle method is 2 times faster than the Slip-sweep survey. It should be noted, that we did not set the goal of achieving the highest possible productivity, therefore, all tested methods were brought to approximately equal conditions for the production Slip-sweep survey in terms of the number of vibrators utilized and total times spent for sweeping (Table 1). We did that not to alter acquisition standards established for the particular license area.

Conclusions

We found a technical solution, which combines an enhanced vibrator controller with cabled recording systems in the source-starting mode for continuous recording. That allows the practical possibility of standard cabled crew productivity increase by applying ISS – like methodologies. From the four sweeps tested, the Broadsweep signal ISS survey was able both increase productivity and real geological objects resolution.

Acknowledgments

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