Abstract

The reef-flat facies reservoirs in carbonate are dominantly developed along the Eastern Edge of the Pre-Caspian Basin. Due to the influences of salt domes and strong heterogeneity, the pre-salt stratigraphy-controlled traps cannot be well imaged with the conventional source, geometry, and processing methods. The narrow-azimuth and low-fold geometry cannot provide high S/N data and image salt domes and pre-salt reef-flat bodies distinctively; the lack of low frequencies and the loss of high frequencies severely affect the resolution of seismic data and inversion quality. The broadband vibrator, LFV3 that enhances low frequency energy from 3Hz, has been developed and was deployed in AMG 3D project, Kazakhstan in 2013. A Wide-azimuth, Broadband, and High-density (WBH) data volume was acquired. Following the acquisition, a WBH processing and inversion flow was set up, and the imaging accuracy of the salt dome boundaries and pre-salt reflections and resolution were greatly improved.

Reference Cited

Applications of Broadband Land Seismology

Zhang, Rujie

26-27, October, 2016. Muscat, Oman
Motif of this workshop

Keywords:

ACQ: WAZ, Low-frequency, Broadband, High-density, Long-offset
High-productivity, Nodal system, Point source/sensor;

PROC: Statics, De-noise, De-multiples, Low-frequency recovery,
Q-compensation, Accurate velocity, Anisotropy, PSTM/PSDM.
15-20 August 2010
Review the value and challenges of frequencies below what is normally captured in seismic operations. In particular, we will focus on the following:

- **Sourcing Low Frequencies both actively and passively**
- **Capturing Low Frequencies in acquisition**
- **Preserving signal and suppressing noise in processing**
- Complementing Low Frequency content with other geophysical measurements
- Utilizing Low Frequencies in imaging and inversion
- Applying Low Frequencies and making a difference
- Looking at the Road Ahead in Low Frequencies
Introduction to this special section: Offshore and onshore broadband seismology, BILL GOODWAY, SHUKI RONEN

……Despite a proliferation of broadband solutions employing combinations of equipment, acquisition techniques, and processing, the full potential of broadband has not been achieved in the authors’ opinion. They go on to describe and conclude that the best broadband results come from the solutions which have tackled both the receiver and source ghost notches to extend the seismic bandwidth to “over six octaves”,……

There are no quantitative definitions to many ACQ terms mentioned above.
Contents

1. Overview
2. Broadband sources
3. Applications
4. Conclusions
Vibrator manufacturing started in 1978:

- KZ-7, peak force 16,000 lbs
- KZ-13, peak force 28,000 lbs
- KZ-20, peak force 42,000 lbs
- KZ-23/2000, peak force 51,000 lbs
- KZ-28, peak force 62,000 lbs
- LFV3, peak force 62,000 lbs
- EV-56, peak force 56,000 lbs
What is low frequency vibrator?

The “low frequency vibrator” refers to the vibrator that can start shooting at a frequency less than 5Hz with full-drive-force.

<table>
<thead>
<tr>
<th>Model</th>
<th>Peak Force (N)</th>
<th>RM Weight (kg)</th>
<th>Usable stroke (m)</th>
<th>Piston Area (m²)</th>
<th>Pump flow rating m³/s</th>
<th>lowest limited freq. (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>KZ28</td>
<td>282000</td>
<td>4600</td>
<td>0.076</td>
<td>0.01378</td>
<td>0.00680</td>
<td>6.4</td>
</tr>
<tr>
<td>KZ34</td>
<td>390000</td>
<td>6800</td>
<td>0.076</td>
<td>0.0168</td>
<td>0.0078</td>
<td>6.2</td>
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<tr>
<td>Vibrator A</td>
<td>266900</td>
<td>5696</td>
<td>0.102</td>
<td>0.01329</td>
<td>0.01009</td>
<td>5.3</td>
</tr>
<tr>
<td>Vibrator B</td>
<td>278000</td>
<td>4082</td>
<td>0.076</td>
<td>0.01334</td>
<td>0.00763</td>
<td>6.7</td>
</tr>
<tr>
<td>Vibrator C</td>
<td>400300</td>
<td>7000</td>
<td>0.102</td>
<td>0.0157</td>
<td></td>
<td>5.0</td>
</tr>
</tbody>
</table>
KZ28LF vibrator (Prototype)

1.5Hz signal was recorded by conventional geophones (10Hz) in both downhole and the surface (long-offset (30km) 2D acquisition trials).

Ground forces & downhole signals

Theoretical earth response \((\text{iio})\)  
Geophone response

(in 2009)
Low frequency vibrator LFV3

High lights:

- Linear sweep starting from 1.5Hz with only 0.5s taper;
- Symmetrical wave field reducing source anisotropy;
- Computer-aided hydraulic flow summing technique.

Based on KZ 28 vibrator chassis.
EV 56 broad band++ vibrator

Broad band ++ : More accurate modeling w/vibrator, less perturbation of mass, and low distortion force output
**EV-56**

- **Eastern Vibrator**
  - 56,000 Lbs

- EV-56 is a broad band vibrator with the peak force 251KN (or 56,000lbs) from 3Hz to 160Hz. Its fundamental force is comparable with regular 276KN (62,000lbs) vibrator!

- The state-of-art chassis structure supports its reliability in low frequency emitting and accurate control based on John Sallas’s modeling, which improves the output-force distortion in both low and high frequencies.
### Specs of EV56

<table>
<thead>
<tr>
<th>Index</th>
<th>LFV3</th>
<th>EV 56</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAX. HD, kN</td>
<td>281</td>
<td>310</td>
</tr>
<tr>
<td>Peak Force, kN</td>
<td>276</td>
<td>251</td>
</tr>
<tr>
<td>Limited LF, Hz</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Max. Stroke, mm</td>
<td>178</td>
<td>210</td>
</tr>
<tr>
<td>Areas of BP, m²</td>
<td>3.35</td>
<td>3.35</td>
</tr>
<tr>
<td>Mass Weights, kg</td>
<td>5250</td>
<td>5900</td>
</tr>
<tr>
<td>BP Weights, kg</td>
<td>1920</td>
<td>2032</td>
</tr>
<tr>
<td>MASS/BP Ratio</td>
<td>2.66</td>
<td>2.9</td>
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<tr>
<td>MAX frequency, Hz</td>
<td>100</td>
<td>160</td>
</tr>
<tr>
<td>Vibration HP, Mpa</td>
<td>21</td>
<td>21</td>
</tr>
</tbody>
</table>
Highlights of broadband source

1. A linear sweep starts at 3 Hz with full-drive force.
2. A linear sweep can start at 1.5 Hz with full-drive force using only a 0.5 second taper.
3. Broadband sweep is from 1.5-160 Hz.

Notice: Strong harmonic distortion appears at the transition point from non-linear to linear sweep, referencing to the paper by Claudio Bagaini.
Sweep type comparison

Data1: 1.5-96Hz*65% linear
Data2: 1.5-96Hz*65% non-linear
Comparison with different sweep types

Linear 1.5-96Hz*65%  
PSTM  
Non-linear 1.5-96Hz*65%
3D Seismic Survey in Kazakhstan

<table>
<thead>
<tr>
<th>Item</th>
<th>Pre-planned</th>
<th>Acquired</th>
<th>Overlapped</th>
</tr>
</thead>
<tbody>
<tr>
<td>Num. of SPs</td>
<td>182,880</td>
<td>233,549</td>
<td>5,0669</td>
</tr>
<tr>
<td>Num. of RPs</td>
<td>9,0216</td>
<td>109,872</td>
<td>1,9656</td>
</tr>
<tr>
<td>Survey area</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>454km²</td>
</tr>
</tbody>
</table>
Challenges

• Large salt domes in this area
• Low resolution of conventional seismic data
• Poor image of pre-salt strata with conventional seismic acquisition
• Unclear boundary of reef-shoal
• Thin carbonate reservoirs with strong heterogeneity
Broadband shooting: Six Octaves

Spectrum of sweep signals

LF vibrator: 1.5-96Hz
Year 2006: 8-68Hz
Conventional Vibrator: 6-96Hz
WA, Broadband, and HD Vibroseis data processing flow
“Source-wavelet controlled” LF recovery

Conventional

Low pass < 9Hz

LF vibrator
Stacked data comparison (No filtering)
Data-driven self-adaptive ground roll attenuation
Data-driven self-adaptive ground roll attenuation

Before (1-10Hz)  After (1-10Hz)
Data-driven self-adaptive ground roll attenuation

Time: 1600-3000ms

before

after
Comparison of conventional and WHB data

Conventional (8 - 68 Hz)

Low-frequency (1.5 - 96 Hz)
Comparison of legacy and WHB data

Legacy 3D_PSTM (INL7040)
Comparison of legacy and WHB data
Comparison of legacy and WHB data
Comparison of legacy and WHB data

Legacy 3D_PSTM (INL8080)
Comparison of legacy and WHB data
Comparison of legacy and WHB data
Comparison of legacy and WHB data
Comparison of legacy and WBH data

Legacy data

Raw
1.5-3.0Hz
3.0-6.0Hz
6.0-12Hz
12-24Hz
24-48Hz
48-96Hz
65-140Hz
70-150Hz

WBH data
LF model building with logging and seismic data

- **Logging model**: 0-10Hz
- **Seismic model**: 1.5-96Hz

- LF model by logging
- LF model by both data
LF models with logging and seismic data

Logging LF model 0-12Hz

Broadband LF model 0-12Hz
Acoustic impedance inversion with logging & LF seismic data

Conventional AI inversion

LF seismic data AI inversion
Applications in Junggar Basin, Xinjiang

Topography of 3D project

Great sand dune
Striped sand dune
Small sand dune
Geological and geophysical issues

Main issues: Low S/N, hard to delineate the faults and fractures in Triassic and Permian systems, poor imaging the top of Carboniferous system.

2D: 2L1S800, F:400, MO: 7990, 8x3kg-6m(2013)

3D: 2L9S152R, F:3x19=57, bin:25x50, MO:4475m, 10x2kg-6m(2002)
Sources

Vibrator: BV-620LF
Sweep length: 16/20s
Array pattern: 2 Vibs x 1 sweep
Start slop: 0.5s
Sweep type: linear
End slop: 0.25s
Frequency: 1.5-84Hz
Shooting type: slip-sweep
Drive force: 65%
Slip time: 15s

Receivers

Type: 30DX-10
Pattern: rectangle
Num. of phone: 2x20
Element interval: 4m
Array area: 16m × 12m
Frequency contents of dynamite and vibrator

Dynamite: 2L2S800R, 7990-10-20-10-7990, fold 800, 6m × 8hole × 3kg

LFV3: 2sets x 1sweep, bin 25m × 25m, fold 1152

Raw data  (3-6)Hz  (6-12)Hz  (12-24)Hz  (24-48)Hz  (48-84)Hz  (60-120)Hz
Comparison of 2D dynamite and WBH 3D Vibroseis

2D line 14 in 2013

2L1S800R, 7990-10-20-10-7990
Fold: 400
Dynamite: 8holes × 6m × 3kg

WBH 3D in 2014

48L3S288R, 7175-25-50-25-7175
Bin size: 25*25, LI150m
Fold: 1152
Vibroseis (LFV): 1.5-96 Hz
Comparison of legacy 3D and new 3D
Conclusions

• The broadband vibrator can provide the subsurface with a linear sweep 1.5-160 Hz.
• The stability, repeatability, accuracy, and efficiency of low-frequency/broadband vibrator series are tested and verified with both downhole and surface programs.
• WAZ, Broadband, Long-offset, and high-density 3D seismic survey is an optimum selection for prospecting of deep and igneous rocks, as well as pre-salt targets.
• The use of broadband data with FWI demonstrates its powerful ability in velocity model building, imaging, and AI inversion.
Thank you for your attention!