SBGf00199

Survey design for vertical cable seismic acquisition

Carlos Rodriguez-Suarez and Robert R. Stewart

The CREWES Project, University of Calgary

ABSTRACT

The vertical cable recording geometry has shown considerable promise as a seismic acquisition technique. It is especially suitable for marine areas where any of the following are present: 1) obstacles (e.g. platforms or buoys) for a vessel towing streamers, 2) deep to very deep water, 3) a complex subsurface geology, 4) pipelines on the sea bottom, and 5) a hard (e.g., carbonate or basalt) sea floor. The last two situations may prohibit the use of ocean bottom cables (OBC). On land, it can be seen as a 3D-VSP with one or more wells (cables).

If we are to acquire vertical cable data, we need to be able to design the surveys to best image the target geology in the most economic way. Thus, we are interested in questions of source and receiver distribution and the resultant target coverage.

Analysis of fold for regular grids of bins in vertical-cable acquisition was done for a straightforward, still realistic, 2.5-D synthetic case. It describes a passive continental margin environment in a Mesozoic basin. Acquisition geometries with a different numbers of vertical cables, hydrophones per cable, numbers of shot points and water depths were analyzed. Three-dimensional ray tracing was used to obtain the reflection point from a target layer. Converted (P- to S-) waves, and a land case were also analyzed.

The results show that good coverage can be obtained using only a single cable, a reasonable number of hydrophones per cable and a fair shot point spacing. Deeper water acquisition shows better fold homogeneity than shallow water when several cables are used on an optimized configuration.

OVERVIEW OF THE VERTICAL-CABLE TECHNIQUE

The basic idea on this technique is to use the receivers in a vertical configuration, instead of horizontal, which is the usual case in marine seismic acquisition. On land, the possible use of 3-C receivers is an additional benefit. The cables are kept in the vertical position by buoys at their tops and an anchor at their bottoms. In comparison to conventional acquisition, the vertical-cable advantages reported by Krail (1991, 1993, 1994, 1997), Anderson et al. (1997) and Leach (1997) are:

- less background noise (which also turns the acquisition less susceptible to weather conditions)
- up- and down-going waves separation
- a less rigid and easier to reconfigure acquisition geometry (interesting for 3-D pre-stack migration)
- as several azimuths are sampled, true 3-D imaging is possible
- no common mid-point assumption is used, as the data is 3-D pre-stack migrated
- on small 3-Ds, costs are considerably reduced, as smaller boats can pull the source, eliminating the large distances required for turning a vessel pulling long streamers
- the coverage is better as the boats can get closer to any obstruction
- 3-D pre-stack depth migration is much cheaper than on streamer data
- for complex geologic structures, a uniform distribution of reflection points from an interface can be obtained.

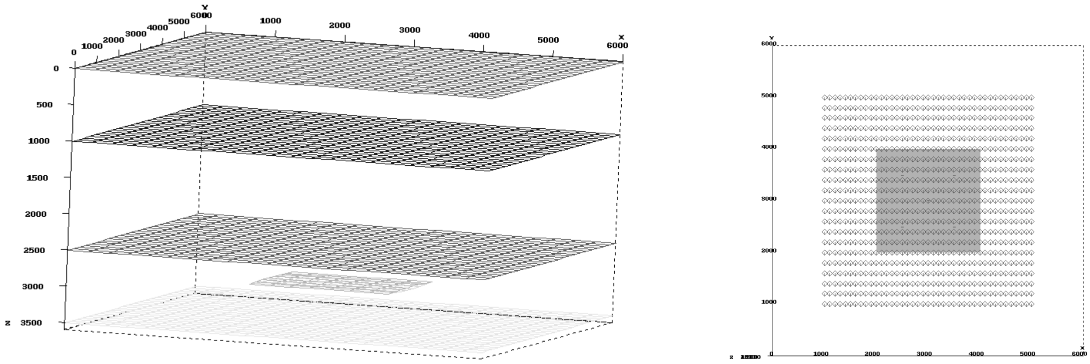
Another potential advantage is for 4-D seismic, as a closer to constant receiver positioning and response can be obtained on time-lapse surveys, without the coupling concern that may be present for ocean bottom receivers.

GEOLOGICAL MODEL AND 3-D RAY TRACING

A straightforward 2.5-D geological model was created using a numerical modeling program. No multiple reflections were considered for the ray tracing. The model intends to represent an area of passive continental margin. It consists of four layers, including a target (Figure 1). The shallowest layer is the water or a weathering layer. Below it, there are two layers of Tertiary age, representing sand and shales deposited in a shallow to deep-water environment. They are separated by an unconformity. The target, inside the lower Tertiary layer, has top and bottom slightly curved. It petrophysically represents an unconsolidated sandstone turbidite.

Only the reflection points from the top of target interface were used for analysis. On some models, a 6% dip on X direction was applied to all layers. The total area of the model is 4 x 4 km^2, and the target has 2 x 2 km^2. All media are perfectly elastic. All layers but water, weathering and target have a constant linear increase of velocity with depth. Density was obtained using Gardner's relationship (except for water) and shear wave velocities using Poissons' ratio.

Two shot points configurations were used: 1) 100 m shot point distance (along X-axis) and 200 m shooting line spacing (along Y-axis, Figure 1.B); and 2) 50 m for shot point distance and 100 m shooting line spacing. The later, although more realistic, was in general avoided due to the long computer time. Both shooting configurations are 3 x 3 km^2, so there is a 1-km aperture to all sides off the target. A bin size of 100 x 100 m was used on all analysis.



(a) (b)

Figure 1 – (a) 3-D view of the geological model (1,000 m water depth). Target is the fourth layer from top, around 3,000 m. Five cables are also shown; (b) map view of shot point grid (outer square, from 1,000 to 5,000 m) and target (inner square, 2,000 to 4,000 m). Distance in meters.

TARGET IMAGING: RESULTS AND COMMENTS

Figure 2 shows the fold results for 500 m water depth. The top of the picture presents coverage distribution when one cable is used at the center of the model (3.0 km for X and Y coordinates). The four different situations analyzed are (from left to right): 16 hydrophones (from 30 to 480 m at 30 m interval) with a 100 x 200 m shot point (SP) grid (100 m on X direction), 32 hydrophones (15 to 480 m at 15 m interval) and 100 x 200 m SP grid, 16 hydrophones with 50 x 100 m SP grid and diagonal SP grid (45^0 to X and Y axis, 100 x 200 m), 1 cable and 16 hydros.
The fold for the first case (16 hydros) has a very homogeneous and smooth distribution over the target, except for some increase as it gets closer to the cable. The average values for fold (around 30) can be considered only modest for a marine 3-D. When twice the number of receivers (32 hydros) are used, the average fold more than duplicates (from around 30 to around 80), which shows how important the use of shorter hydrophone distance may be. Another very effective way to increase the coverage is to reduce by two the shot point and shooting line intervals (SP grid 50x100m, instead of 100x200m on the two previous examples), as when the number of shot increases by four, the average fold roughly increases by the same amount (from 30 to around 140). Besides a more homogeneous fold distribution, the use of more shot points has two other advantages over the use of more receivers: 1) less receivers per cable are necessary; and, 2) the closest shot point grid used here (50 x 100 m) is still wide on a real marine acquisition. If a diagonal SP grid is used, remarkable acquisition footprints are present (top right on Figure 2).

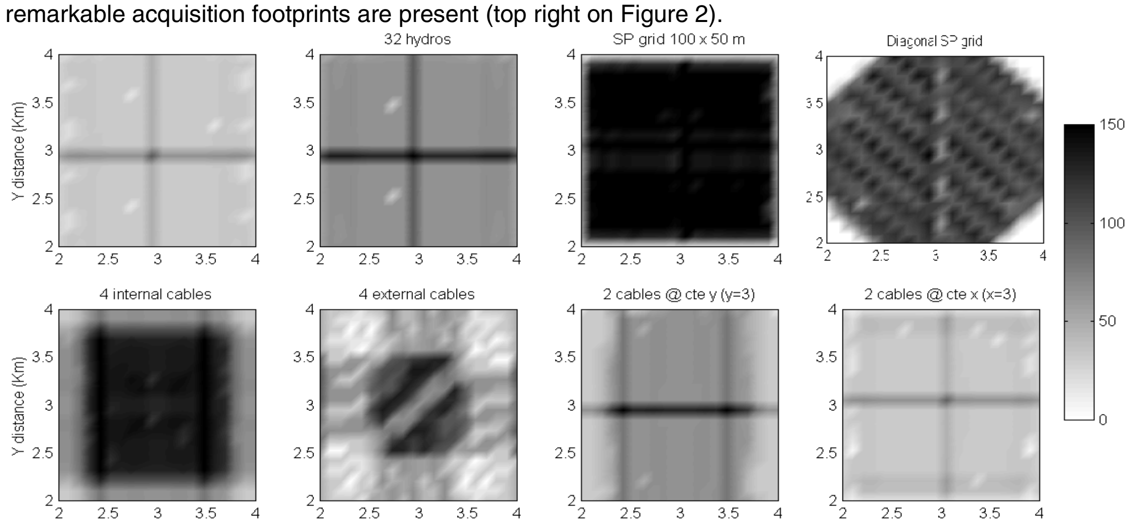


Figure 2 – Coverage for 500 m water depth. Top: 1 cable at target center (X=Y=3.0 Km); from left to right: 16 hydros, SP 100X200 m; 32 hydros, SP 100X200 m; 16 hydros, SP 50x100 m; 16 hydros, SP 100x200 m, diagonal SP grid. Bottom: 16 hydros/cable and 100x200 m shot point grid; from left to right: 4 “internal” cables; 4 “external” cables; 2 cables along X-axis (constant Y); 2 cables along Y-axis (constant X).

The results for more cables are presented on the bottom of Figure 2. A realistic number of receivers per cable (16) and a larger than realistic shot point – due to computer time – grid (100 x 200 m) were used. A centered and equally-spaced 4-cables (“internal”) geometry – cables coordinates (2.5,2.5), (2.5,3.5), (3.5,2.5) and (3.5,3.5) – shows a high (over 120)

and relatively homogenous fold over most of the target (4 internal cables on Figure 2). The fold decreases on both directions from the center, this being more drastically at corners. When the same number of cables is used on an "external" configuration – cables positioned on target corner limits, coordinates (2,2), (2,4), (4,2) and (4,4) – the fold both decreases and looses homogeneity in the distribution. Therefore, we see that to deploy the cables in an "internal" configuration is better than an "external".
As the top target is slightly curved (10 m depth difference on 1,000 m distance along Y direction), when 2 cables are used on orthogonal alignments, some differences will occur. When 2 cables (1 km apart) are along Y center (coordinates (2.5,3.0) and (3.5,3.0)), a fair fold (around 80) is obtained for most of the target (2 cables @ cte y on Figure 2). However, if the 2 cables are used along a constant X (coordinates (3.0,2.5) and (3.0,3.5)), the average fold has a strong decrease (less than 50). The conclusion is when curved interfaces are present, the cables should be aligned on the longitudinal axis of the structure rather than the transversal.

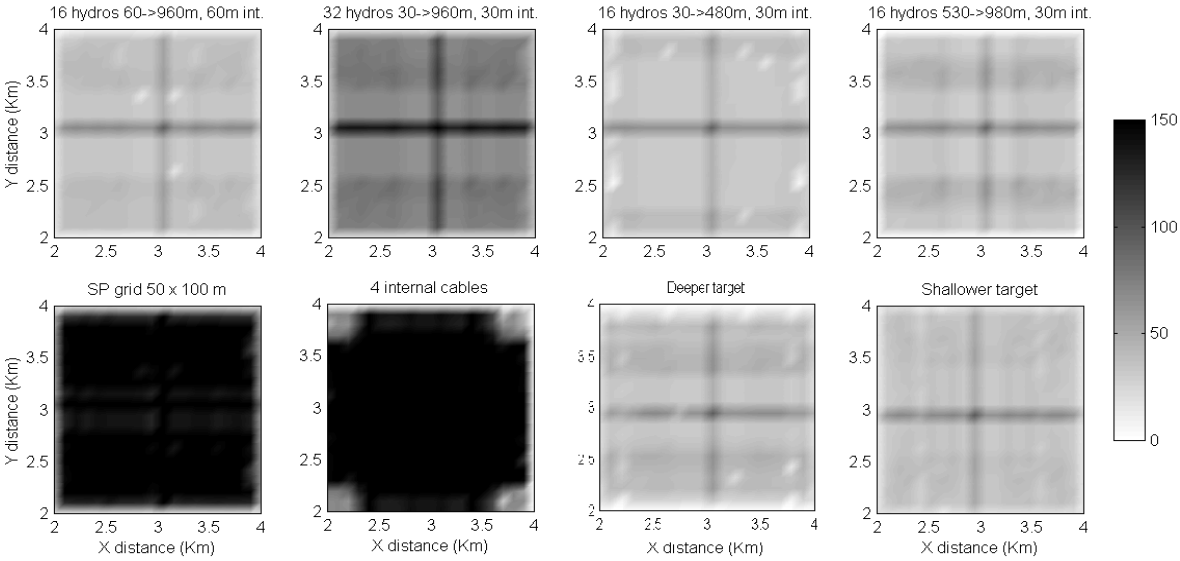


Figure 3 – Fold for 1,000 m water depth. Top (all 1 cable at center, SP grid 100x200m), from left to right: 16 hydros (60m apart) from 60 to 960m; 32 hydros (30m apart) from 30 to 960m; 16 hydros (30 m apart) from 30 to 480m; 16 hydros (30m apart) from 530 to 980m. Bottom (all 16 hydros/cable, 60m apart), left to right: SP grid 50x100m; 4 "internal" cables; target 500 m deeper; target 500 m shallower

The behavior for deeper water (1,000 m) is shown on Figure 3. For 16 hydrophones 60 m apart (from 60 to 960 m depth), shown on upper left, a high fold is not obtained (coverage is under 50) over most of the target. The target top curvature causes less coverage to be present towards the center (along a constant X). Using twice receivers (32 hydros) increases the fold roughly by two, keeping the same imaging distribution.
If we have a limited amount of receivers per cable and a great water depth, we may ask which is the best option: use a regular receiver distribution, or concentrate most hydrophones in the shallow or deep section of the cable? The first choice (regular receiver distribution) has already been presented (16 hydros on Figure 3). Analysis for the second (top, third left to right) and third (top right) are discussed now. When the same number of receivers (16) are placed on the shallow part of the cable (30 to 480 m), a better fold distribution is obtained than if a regular spacing is used along the whole cable, although a small decrease on fold content occurs over some areas. If the receivers are used in the deeper part (530 to 960 m), the fold increases at the price of a less homogeneous fold. One may conclude the best option is this case is to use the receivers at the shallow part of the cable. This result has to be checked in other models and water depths.
As for 500 m water depth, one obtains more homogeneous and higher coverage using smaller grid size on shot point geometry (results on left bottom of Figure 3) than increasing the numbers of receivers (32 hydros on Figure 3). This conclusion may be even more important for deeper waters, where it can be more difficult to handle a bigger number of hydrophones in the cable.
When four cables are used on the same "internal" configuration explained before, the result is an excellent sampling, regarding both fold values and distribution, except for the target corners (4 internal cables on Fig. 3). A comparison to 500 m water depth (4 internal cables on Fig. 2) shows deeper water is favorable for vertical cable use when more than one cable is used on an optimized configuration.
If we had the target 500 m deeper or shallower than on the models analyzed so far, a slightly higher fold would occur (compare bottom right and top left, Fig. 3), but no significant difference is present. Therefore, we see the results obtained here can be extrapolated, to some extent, for shallower and deeper target depths.
Some examples for shallow (50 m) water and land (50 m weathering layer thickness) are shown in Figure 4. One can see a fair coverage and sampling distribution is obtained, what means this technique may work fine in these environments. The use of more cables, though, does not improve the fold values and its distribution in the same extent observed for deeper water (compare with Figures 2 and 3).

Sexto Congresso Internacional da Sociedade Brasileira De Geofisica

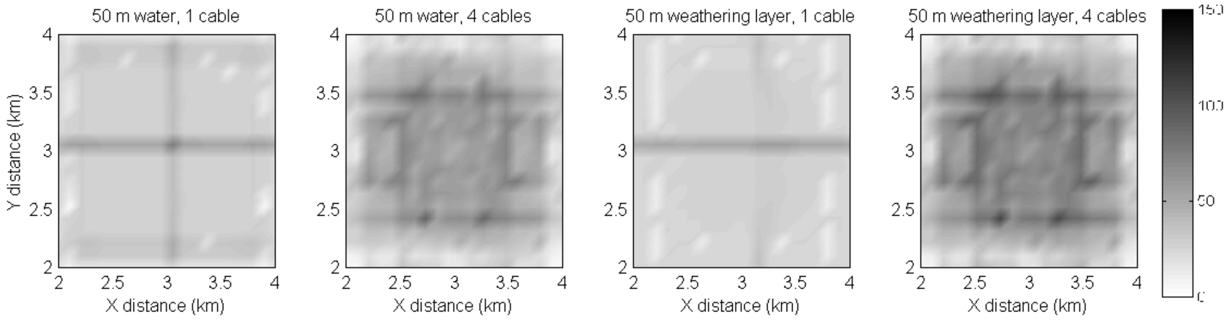


Figure 4 – Fold for shallow (50 m) water and land (50 m weathering layer thickness); 1 and 4 cables. 16 hydros/cable, 100x200 m SP grid.

The imaging for converted wave – P- to S- at target and S- back to P- at water bottom – is presented on Figure 5 for 1,000 and 50 m water depth. We see that a high (over 100) and homogenous fold is obtained, but for a smaller area than the P-P image. This result is expected, as most conversion points are located closer to receiver than source. Some ways to overcome this problem may include: 1) the use of longer source-receiver offsets, 2) spreading of more cables and/or 3) consider downgoing energy reflected from sea surface. The first and second option, although more expensive, may be necessary due to difficulties on receiver ghost identification of P-S-P mode in the data. The use of longer offsets (6x6 km SP grid on Figure 5), although does increase fold values, also causes an undesired heterogeneous distribution. When 4 cables are used, then a very high and homogeneous distribution is obtained for the converted wave. Shallow (50 m) water presents fold less smooth than deep water. This is caused by the rays path difference for each media.

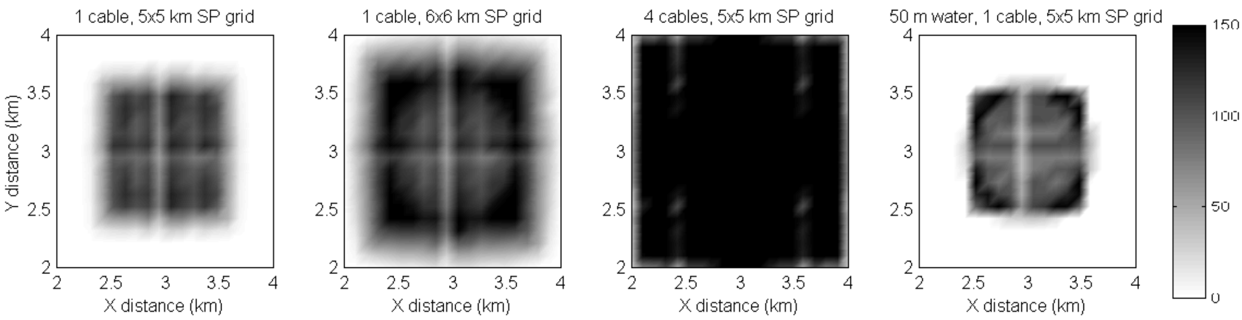


Figure 5 - Fold for converted wave energy (P- to S- at target and S- back to P- at sea bottom); 16 hydros, 1,000 m water depth, SP grid 100x200 m . From left: 1 cable, SP grid 5x5 km; 1 cable, 6x6 SP grid and 4 cables, 5x5 km SP grid; 50 m water depth.

CONCLUSIONS

Using a single cable, a good and well-distributed coverage can be obtained with the use of a reasonable number of receivers per cable and shot point distance. Concentrating receivers on cable shallowest section may give better results than regular receiver distribution along the whole cable. An optimized cable configuration has to be found when more than one cable is used. The results obtained here could be extrapolated for at least 15% depth variation in the target.

Work to be presented in the conference, and not mentioned here, includes: dipping layers; downgoing energy contribution, mainly for converted waves; azimuth and offset analysis for different cable quantity and positioning, and some other acquisition geometries.

ACKNOWLEDGEMENTS

For CREWES sponsors. The first author thanks PETROBRAS for the financial support on his research.

References

Anderson, J., Sukup, D., Boyd, S., Noponen, I., Cai W. and Delome, H., 1997, 3D vertical cable processing to obtain a prestack depth migrated image: Presented in the 59th EAGE Conference and Technical Exhibition, paper A054.

Krail, P.M., 1991, Case history vertical-cable 3D acquisition: Presented in the 53rd EAEG Meeting, paper B052, p. 206.

--, 1993, Sub-salt acquisition with a marine vertical-cable: Presented in the 63rd SEG Meeting, paper WS2.5, p. 1376.

--, 1994, Vertical-cable as a subsalt imaging tool: The Leading Edge, 13(8): 885-887.

--, 1997, Vertical-cable marine seismic acquisition: Presented in the 1997 Offshore Technology Conference, OTC 8315, p. 347-355.

Leach, P., 1997, Strathspey vertical-cable seismic survey: a North-Sea first: Presented on 1997 Offshore Europe Conference (SPE International), Aberdeen, Scotland, 9-12 September 1997, SPE 38508.