Some notes on Special Section: Seismic Survey Design in TLE, October 2004

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It was a great pleasure to read the papers in the Special Section on seismic survey design in TLE, October 2004. In this note I would like to make some comments to two of those papers.

First some comments to the paper by Thomas and Neff on teepee technology for C-wave acquisition design. I would like to point out that the "hybrid gather" referred to by the authors is the same as a "cross-spread," a more familiar term coined at Exxon in the late 1960's.

The authors make a very interesting recommendation for regularizing (illumination) fold. (I am adding "illumination" here to underline the distinction between fold-of-coverage or midpoint fold which is the same for P-wave and C-wave data and illumination fold being discussed here; it is the illumination that is strongly different between the two types of waves. Note that the discussion in Thomas and Neff is about illumination fold in horizontal geology; in complex geology it will be more complicated but I will also make the assumption of horizontal geology.) They observe that irregular illumination fold can be regularized by taking only that part of the illumination area of each cross-spread that can be covered by complete unit cells (the area between two adjacent receiver lines and two adjacent shot lines). The outer parts of the illumination area are discarded. This procedure leads to regular illumination fold at all levels deeper than the time where the mute function meets maximum offset.

Figure 1 illustrates the method using a square cross-spread with midpoint area of 2000 x 2000 m. The outline of the corresponding single-fold C-wave illumination area is indicated with a heavy line. It has been computed for Vp / Vs = 2 for a horizontal reflector at 2000 m in a constant velocity medium. The outline is not exactly rectangular because my program does not use an asymptotic assumption. The shot line interval and the receiver line interval have been selected equal to 250 m. Thus the fold-of-coverage of this geometry equals 2000 / 250 x 2000 / 250 = 64. This means that the unit cell of 250 x 250 m fits 64 times on the midpoint area of the cross-spread. The gray area in Figure 1 indicates the way an integer number of unit cells can be fitted on the C-wave illumination area. This area consists of 11 x 4 = 44 unit cells. This means that everywhere (except along the edges of the survey area) there are 44 overlapping illumination areas. Therefore, in this case the regularization procedure of Thomas and Neff leads to an illumination fold of 44.

It is interesting that this technique for fold regularization can be expanded to shallower levels in a similar way as described for P-waves in my book "3D seismic survey design". This is illustrated in Figure 2 for the same illumination area as in Figure 1. The oval shaped curves represent constant absolute offset contours with a contour interval of 500 m. The quarter-unit-cell-sized black squares represent illumination by traces with a small range of absolute offsets. Four such squares taken together represent an illumination fold count of 1. Not including these traces reduces the illumination fold by 1. The way to regularize fold for all levels is to assign the same mute time to all traces in each group of four little squares.

The four black squares are just lying outside a heavy-line polygon. There are 44 squares inside the polygon corresponding to an illumination fold of 11. The centers of the little squares inside the polygon all correspond to traces with absolute offset smaller than the traces in the center of the four black squares (which have absolute offset of about 1000 m). Hence all squares inside this polygon will be assigned a smaller mute time than the four black ones. With this procedure illumination fold above the mute time of the black squares will be at most 11, whereas below that mute time illumination fold will be at least 12. At all levels the fold will be integer.

In situations with relatively small dips, application of this mute procedure (offset-vector oriented muting) may lead to more regular amplitudes in the C-wave section and less acquisition footprint.

My other comments pertain to Nyland's paper on Alaska survey design. Especially the first part of this paper is very interesting and instructive. The false-color thermal image of his Figure 5 is yet another (and what a great one!) illustration of the message of Laake and Insley in the same issue of TLE.

The second part of the paper discusses the actual choice of acquisition parameters. Nyland, generously, shares his survey design technique with the reader and that allows comparing his technique with other approaches to survey design. I would like to focus on two aspects of Nyland's approach, the derivation of group interval and the selection of a multi-line roll geometry.

In the derivation of group interval the author makes use of average velocity V_{ave}. Other designers make the same choice, but perhaps it is better to use interval velocity V_{int}. In a horizontally layered medium Snell's law tells us that apparent velocity is preserved and is equal to $V_{int} / \sin \alpha$. This means that a normal-incidence ray starting at target level with angle α and interval velocity V_{int} will be recorded with apparent velocity $V_{int} / \sin \alpha$ and that is the apparent velocity on the corresponding zero-offset section. In practice, there will not be horizontal layering, but if anything, V_{int} should be used in the formula rather than V_{ave}. (It is easier and more accurate just to measure apparent velocity on a zero-offset section.)

The use of dip angle in the derivation of apparent velocity to be sampled properly is quite dangerous for low dip situations. It may lead to the choice of too large sampling intervals. Because the required migration aperture (in degrees) is always larger than the maximum dip angle, I recommend selecting the angle α as the required migration aperture with a minimum of 30°. For small dips, sampling will be based on a migration aperture angle of at least 30°, an angle for which most diffraction energy will be caught in the migration process.

Nyland recommends selecting a sampling interval that produces 3 samples per wavelength. Of course that is an excellent recommendation, but why recommend this for the dominant frequency? For high resolution, the maximum frequency in the data should be sampled properly. Assuming that maximum frequency is at least 1.5 times dominant frequency, it is not just a “good idea to obtain at least three samples per (dominant) wavelength”, it is essential.

In my paper in the same issue of The Leading Edge, I argue that the use of multi-line roll geometries is to be discouraged because it “produces higher production at the expense of quality”. Although not stated explicitly, it seems that Nyland recommends using a multi-line roll geometry (see his Figure 7) and that gives me a chance to show the serious effect multi-line roll has on the bin attributes of intermediate level data. Figure 3 compares the fold for offsets 0 to 8000 feet of the multi-line roll geometry proposed by Nyland with the corresponding one-line roll geometry. The fold for the one-line roll geometry in Figure 3b varies between 25 and 28, whereas for the multi-line geometry it varies between 22 and 28. Note that the length of the shot salvo is returning in the attribute displays, five distinct strips with the width of a receiver line interval in Figure 3a, only one strip in Figure 3b. The larger variation in bin fold of multi-line roll is more likely to produce a serious acquisition footprint than the smaller variation in fold for one-line roll. Moreover, for the one-line roll geometry it is possible to generate constant stacking fold at all time levels in a similar way as described above for the converted-wave illumination fold. Creating constant fold for multi-line roll data. at all time levels might still be possible, but only with lower constant folds than with the one-line roll geometry. Therefore, multi-line roll is to be avoided in survey design implementations. For higher production there are better ways to implement the desired survey design (cf. “Implementation of the nominal geometry” in my contribution to the October 2004 issue of TLE).

Suggested reading. All papers in the Special Section of the October 2004 issue of The Leading Edge.

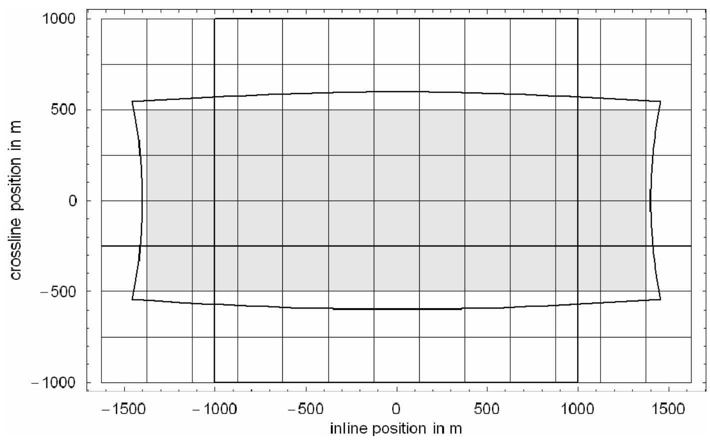

Fig. 1. Regularization of C-wave illumination fold according to method proposed in Thomas and Neff (2004). Square with heavy outline represents midpoint area of single cross-spread. Heavy curved lines describe outline of C-wave illumination area of the same cross-spread for horizontal reflector at 2000 m and Vp/Vs = 2. The small 250 x 250 m squares represent unit cells of the geometry. Regular illumination fold of 44 can be achieved by muting all traces that do not illuminate the grey rectangle.

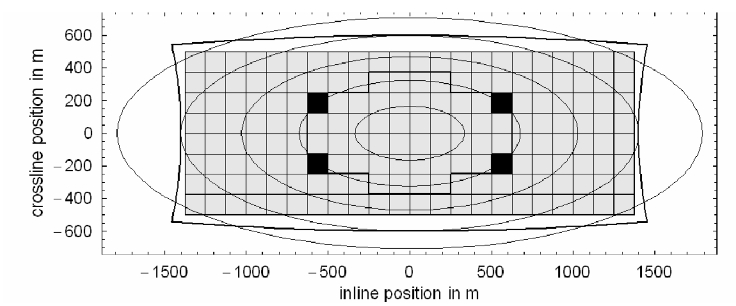

Fig. 2. Regularization of C-wave illumination fold for intermediate levels. Same model as for Figure 1. Oval curves represent contours of constant absolute offset with 500-m contour interval. The area of the small squares equals one quarter of a unit cell. The four black squares contain traces with a small range of offsets. Adding or dropping those traces corresponds to changing the illumination fold count by plus or minus one. Assigning the same mute time to all traces inside a group of four small squares and repeating this for all such groups of four creates integer illumination fold at all time levels.

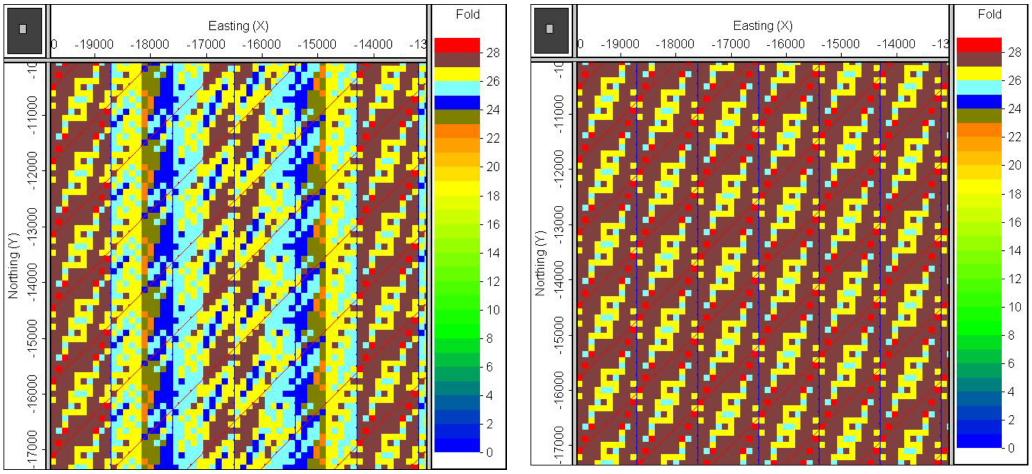

Fig. 3. Comparison of bin fold for offset range 0 – 8000 feet in multi-line roll geometry (a) proposed by Nyland and in corresponding one-line roll geometry (b). Note that fold varies from 22 – 28 in (a) and from 25 – 28 in (b).