

Speed of operations is also an important consideration. Thus data is stored and processed in data base systems utilising random access files. These data bases can have restricted access for processing to ensure the integrity of the stored data.

Interpretation

The interpreter can improve the confidence level of interpretation by employing multiple techniques or by multiple presentation of a single technique. For example, in the latter case, the use of the fast Fourier transform technique on gridded data sets can provide: spectral plots; low, high or band pass filtered data; derivative maps; upward and downward continuations; reduction to pole.

These maps can all be created on today's minicomputers and even on some microcomputers. Thus where the data warrants the effort, these maps can be available for the interpreter or created by him.

The eventual aim of the interpreter is a geological interpretation. Structural interpretation is a necessary element, and features such as trends and faults can also be added to relevant data sets during the gridding process to enhance the presentation.

Conclusions

Contour maps can be a vital feature of an interpreter's array of tools if the gridded data set is created to represent the entire spectrum of the geophysical signal. Two important parameters will ensure that the gridded data reflects the full spectrum: (1) as small a mesh size, consistent with data spacing, that data distribution will allow; and (2) a minimum contour interval consistent with the accuracy of the data.

A correct grid will then allow the interpreter to utilise other techniques, such as fast Fourier transform operations, to provide other perspective views of the data set.

First break refraction methods to calculate statics

Thomas L. C. Goh Bond Corporation, 26 St George's Terrace, Perth, WA 6000

The methods which calculate weathering statics from first break refraction data often involve the determination of the intercept time T_i and an estimate of the velocity of the consolidated formation V_1 , with the weathering velocity obtained from an uphole or Low Velocity Layer (LVL) survey. It is erroneous to extract the intercept time T_i on the x - t graph for determination of the delay time T_d (from $T_d = 1/2 T_i$), or to estimate the consolidated formation velocity V_1 from the gradient of the line of best fit through the x , t points, on the basis of refraction first breaks obtained from individual seismic shot records. However, the iterative method minimises the error in estimation of the intercept time T_i for the calculation of weathering statics, and obtains the consolidated formation velocity as a by-product, which is then used to compute the elevation statics.

The determination of weathering statics using the redundant refraction data from reflection seismic records has the inherent advantage of deriving the statics and

applying the corrections on the same data set, and therefore under identical physical conditions (cf. statics calculated from an LVL survey and applied on seismic data). In a typical 12-fold or 24-fold coverage survey using a 96 trace split-spread configuration with 50-70 m station interval, the relevant refraction first breaks achieve at least fourfold redundancy at each station. This statistical advantage is the primary basis on which the iterative process can provide effective statics control.

Description of the iterative process

Only those first break arrivals which pertain to refraction energy from beneath the weathered layer are included for computation in the iterative process. The first break picks, within a defined offset interval of typically from 200 to 800 m, are ordered into common shot and common receiver sets, and a preliminary refraction velocity V_1 is determined by a linear regression algorithm.

In each iteration, the V_1 values from each station are smoothed with a broad triangular filter of 100-150 points, i.e. approximately 1-1.5 times the cable spread length. Each smoothed V_1 is then fitted through the corresponding mean point (\bar{x}, \bar{t}) of the ordered first break picks to obtain the intercept time T_i at $x = 0$. Half the intercept time, i.e. the delay time T_d , is assigned to the respective shot or receiver station; the total time delay from shot and receiver is then computed and subtracted from each first break pick corresponding to that relevant shot and receiver combination.

The entire procedure is repeated for three iterations, updating V_1 and then obtaining the intercept time T_i with each iteration. The standard deviation of the linear regression fit of the picks will decrease as the estimation improves with each iteration. After the final corrections the intercept time for the line of best fit should be zero.

At the end of the last iteration, the consolidated formation velocity V_1 is accepted for subsequent calculation. The delay time T_d at each station is obtained by summing the intermediate values of each iteration.

Finally, the datum static at each station is calculated from the usual formula:

$$T_g = T_e + T_w = -\frac{E}{V_1} - k T_d, \text{ where } E = \text{elevation above datum, and } k = [(V_1 - V_0)/(V_1 + V_0)]^{1/2}$$

The Gardner-Leclerc method of computing static corrections using a desk-top computer*

P. Leclerc and **A. Bennett** Compagnie Francaise de Prospection Sismique, Sophia Antipolis, BP 16, 06565 Valbonne Cedex, France

and **C. Rowson** Seismograph Service Ltd, PO Box 287, Glenside, SA 5065

Introduction

Since the introduction of surface and near-surface sources, there has been difficulty in obtaining information about the vertical velocity through the weathering, so accurate static corrections have been difficult to estimate.

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A dense uphole survey provides this information, but as it is slow and costly, the most often used method is the shallow refraction survey. This method has a major drawback in that it measures *horizontal* velocities which are used to determine *vertical* time through the weathering. These horizontal velocities can be very different from the vertical velocity, so bad static corrections can result.

The object of this paper is to present an alternative field static method which is accurate and inexpensive. The method is based on that devised by L. W. Gardner (1939), who used it to determine the structural form of the refractor, whereas, as a static correction method, it is used to determine differences of travel time through the weathering.

The computation of these time differences, or *relative static corrections*, relies on measurements of time taken from the very traces to which the resulting static correction will be applied.

Since the 1960s considerable experience has been acquired by LeClerc in applying the method. The advent of the desktop computer with digitiser and plotter has eliminated the tedious manual computations that were previously necessary.

Input data

The system requires: the field monitors or processing centre records of each shot-point, elevations and co-ordinates, uphole or Low Velocity Layer (LVL) information (although this is not always needed) and observer's reports.

The reflection spread data can be from various sources — dynamite, Vibroseis* or Mini-Sosie. Lines can be of any shape or length and records can have any number of traces.

Digitising

The refraction arrivals (first breaks) of the reflection records are digitised. The computer is programmed to plot out the time-distance (T-x) curves representing the picked arrivals. A refractor that is continuous throughout the whole survey area is preferable but not essential. The software allows the refractor to have moderate dip and a variable propagation velocity. For a split-spread configuration T-x curves are plotted for both forward and reverse directions.

Removal of slope

The slope of the T-x curves is removed by computing an average refraction velocity along the profile and plotting the intercept curve. The best mean curve through this family of curves is computed and plotted. This is called the Relative Intercept Curve. The intercepts are shifted by a tie-constant so that their vertical positions correspond to their surface station positions.

Intercept curves

For split spread configurations Direct and Reverse Relative Intercept Curves are plotted. These two curves are averaged to produce the Average Relative Intercept Curve.

The Delay Times are plotted. These represent the difference between the intercept and the sum of the tie-constants, and are used to assign an origin to the Average Intercept Curve to transform it into a Relative Static Correction Curve.

Shot-point compensation

If the average value of the shot-point delay times is taken as the origin, then the variations of the relative static correc-

tion curve are representative of the variations of delay times at the geophones only. In order to compensate for 'long period' variations of the shot-point delay times, the curve of best fit through the shot point delays is used as a baseline origin, thus obtaining a shot-point compensated static correction curve.

The discrepancy between a particular shot-point delay time and the curve of best fit drawn through the shot delays is applied to the geophone arrivals from that particular shot before the receiver delays are averaged, so that the resultant set of relative geophone statics is compensated for any discrepancy between the positions of the shot and receiver at the same station. The output at this stage is a set of relative statics which refers each surface station to its neighbour.

The Gardner-LeClerc method is now complete, and it remains to calibrate the statics to the chosen refractor (usually either by the intercept or summation methods, performed every 50 or so stations), and then to perform an elevation correction to a chosen datum. This is best done using values obtained from direct vertical velocity measurements, i.e. from uphole surveys. The density of these upholes need not be very onerous, e.g. every 5 km of profile.

Two important points are noticed.

- (1) Computations all take place in the time domain, so a complex velocity structure above the refractor is no problem.
- (2) Elevation data is not used in the calculation so any differences between source or receiver stations and the survey peg are of no consequence.

Results

Statics are output as:

- (a) a graph plotted with an elevation profile.
- (b) tables of values.

Conclusions

The Gardner-LeClerc computation method is a useful tool where static corrections are of vital importance, particularly in such cases as:

- (1) Sand dune areas, where low near surface velocity coupled with elevation changes means that the reaction centre of the shot and geophone patterns may be significantly different to the survey stake position.
- (2) Areas where there are invisible anomalies in the weathering, impossible to detect and correct for with other methods.
- (3) Areas where there are high velocity stringers which give false high velocities on shallow refraction recordings.

Other advantages of this method are:

- (a) Quick handling of a lot of data, with extensive user interaction.
- (b) Multifold coverage allows statistical methods to be used to reduce noise.
- (c) Accurate refractor velocities are known all along the line.
- (d) Sensitivity to high frequency static changes.
- (e) Only a few LVL or uphole shots are needed to give calibration for low frequency statics. If the data quality is

*Trademark of Continental Oil Company.

good enough all the calibration could come from the reflection records.

(f) Errors in the data can be detected easily.

Reference

Gardner, L. W. (1939), 'An areal plan of mapping subsurface structure by refraction shooting', *Geophysics* **4**, 247-59.

A post-stack method for 3-D cross-line statics estimation*

Philip S. Schultz and August Lau Digicon Inc., 3701 Kirby Dr, Suite 1144, Houston, TX 77098, USA

A method has been derived for the estimation of cross-line statics in which we perform the best possible stack of the data using whatever statics corrections are needed to optimise the stack response, followed by an estimation of the cross-line statics corrections using the stacked data only. The method makes use of several assumptions regarding the stacked data:

- (1) We have correctly estimated and removed the high wave-number statics in the in-line direction.
- (2) We have remaining the low wave-number statics in the in-line direction, since the low wave-numbers are indeterminate using any of the standard residual statics methods on real data.
- (3) We have remaining much, if not all, of the high wave-number statics in the cross-line direction.
- (4) We cannot separate low wave-number cross-line statics from low wave-number cross-line structure.
- (5) There are no vertical faults parallel to the in-line direction.
- (6) We can adjust the low wave-number statics within any and all lines in the in-line direction to correct for high wave-number statics in the cross-line direction.

The need for such a procedure is seen on a 3-D land survey. All pre-stack information was used to obtain best estimates of statics corrections, but the post-stack cross-line sections show clearly that high wave-number cross-line statics components remain uncorrected in the stacked data. Such remnant static distortions of the stacked data can and should be corrected by some post-stack method, such as the one suggested here.

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Opseis telemetry

H. A. Tims Exploration and Production Group, Phillips Petroleum Company, Bartlesville, Oklahoma 74004, USA.

The elimination of the heavy cumbersome multi-pair cables between the geophone stations and the recording unit has been long awaited. Stepped-up exploration activity for new oil and gas reserves has made the industry more sensitive to this need, primarily since the search leads increasingly toward difficult areas where cable recording systems are less economically feasible. Reliable, high-fidelity two-way radio links were required that would allow command-response

operations. Only as state-of-the-art advancements occurred in digital radio frequency (RF) techniques in the last few years has transmission of seismic data with the dynamic range and resolution qualities demanded by today's needs been possible.

Consider the freedom a wireless recording system offers the user: easier access into jungle, swamp and mountainous terrain; no geometric restrictions on spread configuration, e.g. 3-D or areal coverage; multiple line recording with one source; fewer logistic recording problems with rivers, lakes, highways and no-permit areas. Such a system, named OPSEIS (Tm) 5500, has been developed by the Phillips Petroleum Company of Bartlesville, Oklahoma.

Two-way digital frequency modulation (FM) radio transmission links are used between the spread deployed units called remote telemetry units (RTU) and the central recording station (CRS) located at any convenient point within radio range. A repeatable command-response mode of operation and data error checking techniques ensure data integrity even under poor signal conditions.

The OPSEIS (Tm) 5500 system gives rise to many novel features:

(1) The system utilises high quality, narrow band two-way digital FM radio links for transmission of command and seismic data between the central recording station and the remote telemetry units. The choice of narrow band FM conserves RF spectrum while providing a highly reliable, noise-free data communication medium.

(2) Seismic waveform data is stored in memory at the RTU and is available for re-transmission if transmission errors are sensed by the CRS. Data stacking and editing is performed by the remote units when surface energy source techniques are utilised.

(3) Microprocessor control in both the CRS and the RTU provide for an extremely reliable and flexible system. Only software changes are required to change the mode of operation.

(4) A CRS controls and records data from four seismic lines either simultaneously or one at a time.

(5) Two spread configurations can be used for each of four prospect lines, which permits the use of two shooters on each line for increased productivity.

(6) Up to 200 channels can be recorded on each spread with the standard system. This feature can be expanded to 1016 channels per spread with full dynamic range and resolution qualities.

(7) Spread and equipment parameters are tested prior to data recording to insure system reliability and data integrity.

(8) A full day of shooting can be recorded from a single recording location. The microprocessor controls the spread advance after each shot and is accomplished by simply pushing a button. The operator's roll-along display panel keeps him totally informed of his current spread configuration and status of roll-along capabilities.

(9) There are no geometric restrictions for an RF linked recording system. The standard line shooting technology of today can be easily changed to the simultaneous recording of multi-lines from one energy source. This capability readily lends itself to 3-D coverage.