Refined field static corrections in near-surface reflection profiling across rugged terrain

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Deriving effective static (elevation and weathering) corrections is more difficult for near-surface high resolution seismic reflection surveys than for deeper profiling investigations; reflections tend to be less continuous and frequencies much higher in the former. In his three-part tutorial series on static corrections (*TLE,* January-March 1993), Dave Marsden provides a comprehensive account of problems associated with computing land-based static corrections and proposes various methods for resolving them. In particular, he stresses the importance of using intermediate floating datums in regions of floating topography in order to keep field static corrections as small as possible before the calculation and application of NMO corrections. Furthermore, he suggests a running average of receiver elevations over the active spread length as an appropriate intermediate floating datum. After application of NMO, further time shifts to bring the data from the floating datums to final flat datums may be applied; these latter corrections will be referred to as the final elevation corrections.

Many processing packages, affordable to groups working on engineering-scale problems, provide facilities for computing field static corrections based on either a predefined near-surface model or a statistical analysis of first breaks without generating a subsurface model. Derivation of a single source and a single receiver field static correction (with reference to the intermediate floating datum) is common to these schemes.

Here, it is demonstrated that across very rugged terrains and in regions where target depth is of the same order-of-magnitude as relief variations over the active spread length, improved results may be obtained when individual source and receiver field static corrections are computed for each trace of each CMP gather. These individual static corrections are calculated with respect to the intermediate floating datum level beneath each CMP. Although the problem of dip moveout is recognized in the situations presented, it will not be discussed here.

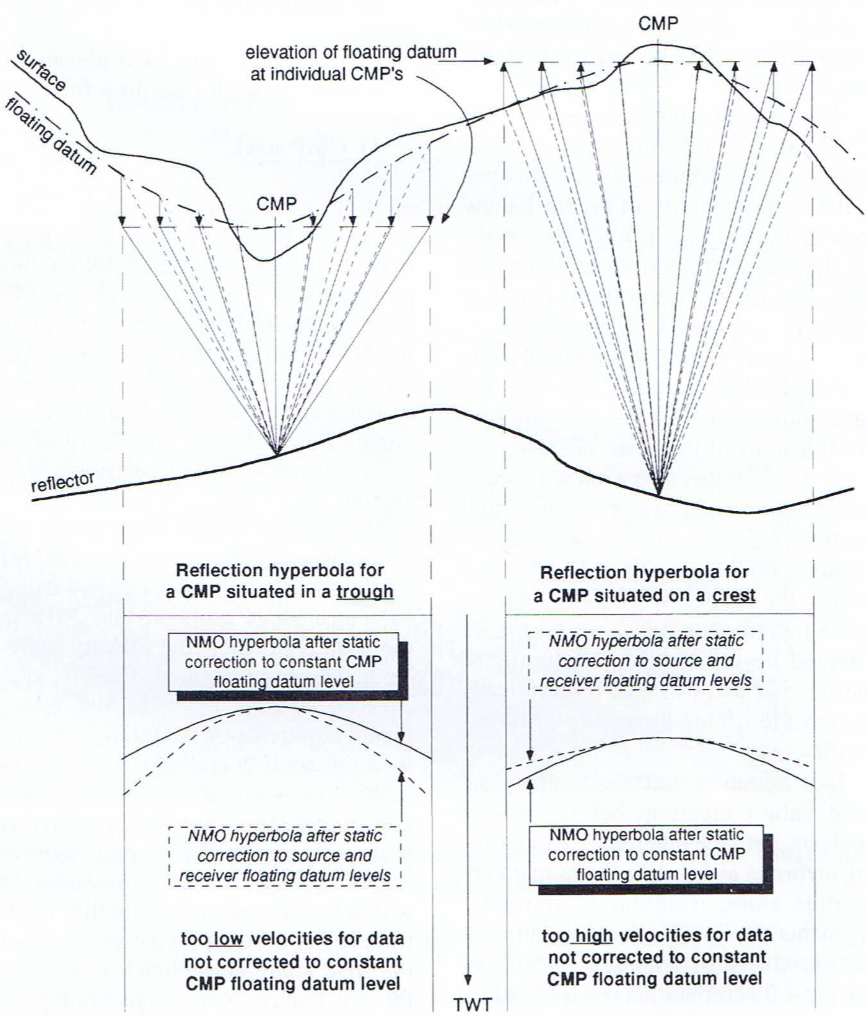

Figure 1. NMO velocity errors resulting from use of single source and receiver field static corrections.

Source/receiver and CMP field statics. Figure 1 shows the geometry of two CMP gathers along rugged topography. The CMP to the left is in a minor trough and that to the right on a crest. The dotted lines in the upper diagrams depict hypothetical ray paths to a shallow target reflector after application of intermediate field static corrections to the floating datum. Each source and each receiver location is assigned a single intermediate field static correction regardless of the CMP gather being considered. In the following, this approach is referred to as the source/receiver field static correction method (s/r). Shown as dotted lines in the lower halves of the figure are the appropriate apparent NMO hyperbolae for the target reflector. Since over the length of the cable spread, the shape of the floating datum departs considerably from a horizontal line, erroneous NMO velocities would result; the curvature of the apparent NMO hyperbola changes according to the shape of the local floating datum so that derived velocities would be too low for a CMP in a trough and too high for one on a crest.

A horizontal reference level for each CMP gather is recommended to avoid this effect. The continuous straight lines in the upper diagrams of Figure 1 show hypothetical ray paths after intermediate field static corrections to horizontal reference levels at elevations equal to the floating datums beneath the respective CMPs. Adopting this method leads to individual field static corrections for each source and receiver location that are functions of the CMP positions. In the following, this approach will be referred to as the CMP field static method. As depicted in the lower diagrams of Figure 1, after application of CMP field statics, the shapes of the NMO hyperbolae (continuous lines) are no longer affected by topographic variations of the floating datums; this, in turn, leads to derivation of more accurate NMO velocities.

It is common practice to apply s/r field static corrections before velocity analysis, with the inherent risk of deriving incorrect and poorly constrained velocities along irregular topographic segments of a line. Further, inaccuracies are introduced by adopting the following typical computational sequence:

1) Compute/apply s/r field static corrections to each trace.

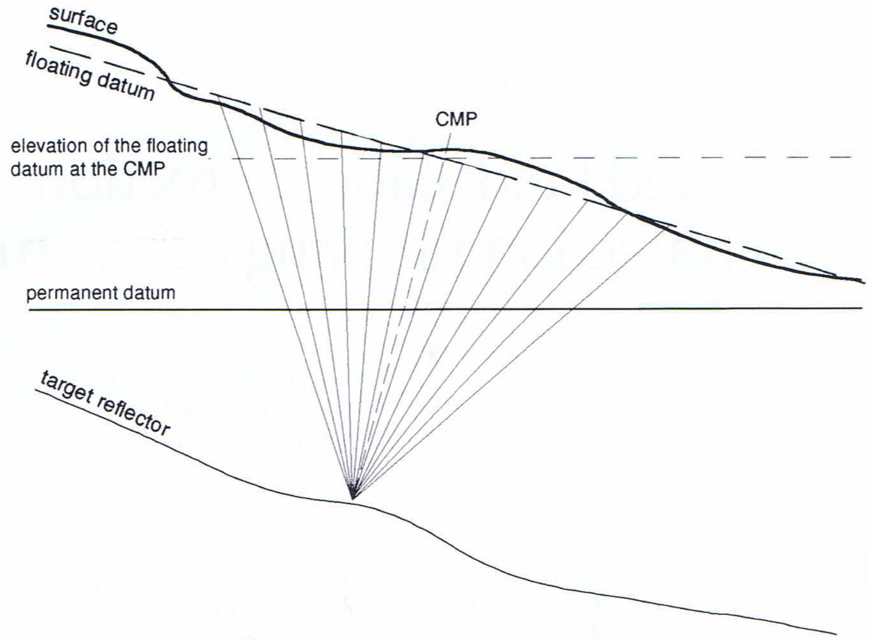

Figure 2. Simpler situation where CMP statics should not be applied.

2) Compute/apply NMO corrections.

3) Compute/apply final elevations corrections to each trace to a final flat datum.

4) CMP stack.

In this situation, the horizontal lineup of reflections achieved by step 2 may be disrupted by step 3. Often, this problem with the s/r method is partly resolved by applying a single common field elevation correction to all traces in a CMP gather. Like the CMP field static method, this common final elevation correction is based on the floating datum elevation of the CMP being considered.

If velocities based on the dotted hyperbolae of Figure 1 were used for NMO, the above sequence may cause no intermediate problems at CMPs in the vicinity of where the velocity analysis had been performed. Clearly, successful application of the procedure would require dense sampling of velocity estimates to account for some topography-related lateral velocity variations; velocity functions would be required at practically every CMP. Application of highly variable velocity functions, in which lateral velocity variability is introduced to account for a component of the field static corrections, is unsatisfactory. Indeed, to avoid generating artificial structures and to better relate the velocities to the geology, it is common practice to choose laterally smoothed velocity functions. In addition, if at step 3 a common field elevation correction is applied to all traces in a CMP gather, a computation inaccuracy creeps into the procedure because of the effect of switching from the s/r domain to the CMP domain; such a final elevation correction should strictly be applied only to CMP traces that have previously been reduced to a common intermediate floating datum.

These points may be of only minor concern for deeper probing surveys, since the introduced errors may be close to negligible and rectified through routine computation/application of residual static corrections. For high-resolution surveys, on the other hand, inaccuracies as small as 4 ms may cause "fatal" cycle skips when using schemes based on correlation for the derivation of residual static corrections.

The CMP field static approach is more robust and, if final datum elevation correction can be applied at any point in the processing procedure after stack, offers advantages for poststack migration of data from areas with high relief. For a velocity model based on stacking velocities alone, it is imperative that poststack migration be computed from the same reference level as that used to determine the stacking velocities. This means that final elevation corrections should be constant in the CMP domain, so that single corrections can be "attached" to the stacked traces during poststack processing and finally

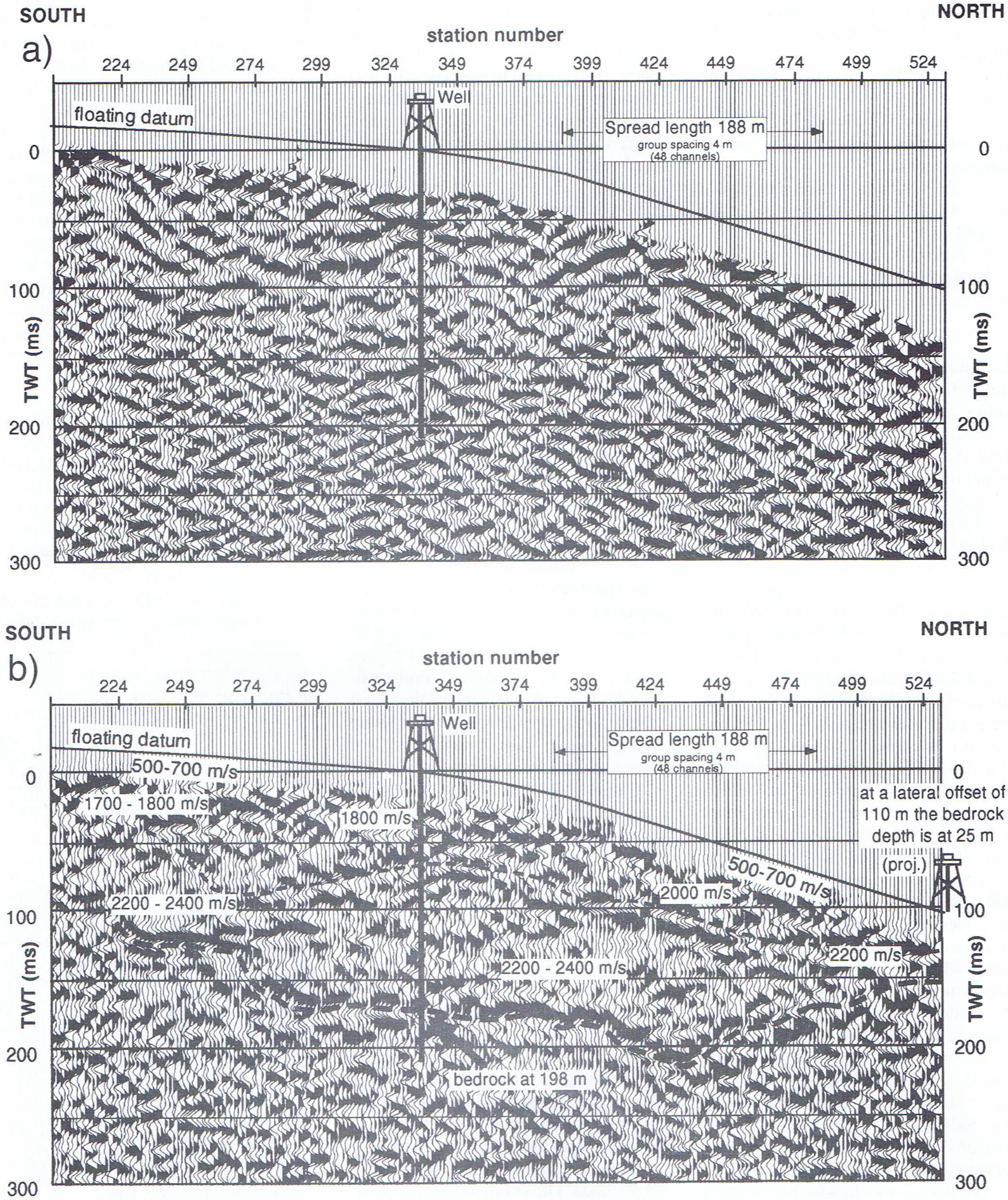

Figure 3. (a) Stacked section with conventional field statics (i.e., using a constant floating datum for each source and receiver location). (b) Stacked section with individual CMP referenced floating datum statics.

applied after migration. If the final elevation correction is large and applied before stack, severe focusing and positioning errors may result when migration is performed from a reference level different from that used for velocity analysis. Final elevation corrections are probably best applied as the last step before display of both unmigrated and migrated stacks.

A general procedure for high-resolution surveys in rugged terrain is:

1) Compute/apply CMP field static corrections to each trace.

2) Compute final elevation statics (constant for all traces in a CMP gather).

3) Compute/apply NMO corrections.

4) Compute/apply surface consistent and/or trim residual static corrections (optional).

5) CMP stack and store the correction derived in step 2 in the header of the stacked trace.

6) Poststack migrate (optional).

7) Apply final elevation static corrections and display.

Limitations of the CMP field static method. As shown in Figure 1, s/r field statics are always smaller than CMP field statics. To some extent, the CMP field static method thus violates the guidelines that pre-NMO corrections be as small as possible. The theoretical considerations outlined above and the field example below demonstrate that in rugged terrains the advantages of this method amply justify larger pre-NMO static shifts. The CMP field static approach, however, should not be applied indiscriminately when working in mountainous areas. Figure 2 is an example of where it should not be applied. Here a plane dipping surface, displaying only minor short wavelength irregularities, departs very little from the intermediate floating datum and a nearly plane target reflector runs more or less parallel to the surface. Application of CMP field statics in this situation would probably cause more harm than good since their values, especially for far-offset traces, would be large. On the other hand, as the surface nearly coincides with the intermediate floating datum, magnitudes of the s/r field statics would be close to zero. In this case, it would be advisable to initially view the overall situation as if it were horizontal; i.e., derive and apply s/r field statics before NMO, followed by stacking. Subsequently, final elevation corrections that compensate for the topographic tilt could be applied.

The decision as to whether to apply s/r or CMP field statics methods is influenced by the topographic setting and by trial runs. Critical parameters are either the magnitude ratio of the CMP field statics versus s/r field statics for large offsets or the rms value of the deviations of the surface elevation from the floating datum elevation at all stations along a line segment. Since local acquisition and geologic considerations have considerable impact on this parameter, the processing geophysicist and the interpreter must derive a cutoff magnitude specific for a certain region rather than rely on some fixed predefined value.

Field example. The CMP field static method has been tested on a seismic reflection profile recorded across a mountain slope with small knolls that produce numerous short wavelength topographic irregularities. An objective of the survey was to map the limestone bedrock surface for a planned road tunnel. The bedrock is at a depth of 198 m in a well within and about 260 m north of the southern end of the profile and at the much shallower depth of 25 m in a well 100 m off the northern end of the line. Overburden in the region is comprised of a chaotic interfingering of landslide material and glacial deposits.

A 48-channel acquisition system was used to record data from an asymmetrical split spread (alternating between a 36 geophones-shot-12 geophones configuration and a 12 geophones-shot-36 geophones configuration). Source and receiver spacing was 4 m, and total spread length was 188 m. Energy sources were dynamite (35% of locations) and weight drop (65%).

Initial processing involved generation of a near-surface velocity model using a GRM-based reflection algorithm. The weathering layer, displaying velocities of 300-500 m/s, extends to depths of 3-6 m. Velocities below this layer increased from 1500 to around 2400 m/s with appreciable lateral variations along the line.

Figure 3a shows the stacked section resulting from the conventional s/r procedure and application of final field elevation corrections after stack. Figure 3b shows the stacked section resulting from the CMP method. Except for the floating datum static corrections, the computational sequence was identical.

Note the appreciable difference in appearance. The strong reflection package in Figure 3b matches the depth to bedrock in the borehole drilled along the line and shallows significantly northward in agreement with the offset borehole. Velocities employed for time-do-depth conversion were derived from refraction analysis and from well information.

Conclusions. For high-resolution seismic profiling across rugged terrain, the proposed technique for deriving intermediate field static corrections based on CMP floating datums should be routine. Although this method results in larger intermediate field static corrections before NMO, the disadvantages are often outweighed by improved velocity analyses and by the constant field elevation correction that may be applied to all traces in a CMP gather. The latter allows for application of final elevation corrections after poststack migration, thus avoiding positioning and focusing errors associated with data collected along profiles with significant short wavelength elevation variations. It is recommended that the method not be employed on data acquired on regular sloping surfaces with plane reflecting interfaces running nearly parallel to the surface. Such situations should be treated similarly to a flat horizontal layered medium, until poststack migration. As the final step before plotting, final elevation correction tilts the section back to its correct orientation in space. LE

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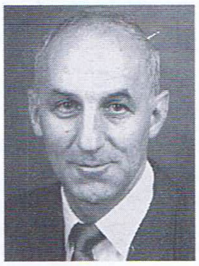

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