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The common-reflecting-element (CRE) method revisited

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ABSTRACT

The common-reflecting-element (CRE) method is a useful alternative to the familiar common-midpoint (CMP) stack or migration to zero offset (MZO). Like these two methods, the CRE method aims at constructing a stacked zero-offset section from a set of common-offset sections. It requires no more than the near surface values of the velocity field to be known. The CRE method deserves more attention as it appears to be one of the best tools to construct a stacked zero-offset section and simultaneously derive a laterally inhomogeneous macro velocity model with a minimum a priori knowledge. The macro velocity model can then be used in a post-stack or pre-stack migration. Another advantage of the CRE method over both the CMP stack and MZO is that it does not suffer from pulse stretch. In the one-dimensional case, it reduces to the CMP optical stack. Finally, the CRE method also provides important insight into the conventional MZO process, which is commonly implemented with a normal-moveout correction followed by a dip-moveout correction applied to the original common-offset section.

INTRODUCTION

The ultimate goal of all seismic reflection-imaging methods consists of providing a depth-migrated image of the subsurface reflectors and of possibly deriving their lithological attributes from the signals distributed along the reflector images. It is well accepted that the success with which this task can be achieved highly depends on the accuracy of the macro velocity model. Different imaging techniques, including the common-midpoint (CMP) stack (Yilmaz, 1987), migration to zero offset (MZO) (Dietrich and Cohen, 1993; Tygel et al., 1996), post-stack migration (Stolt, 1978; Schneider, 1978) and pre-stack true-amplitude migration (Bleistein, 1987; Schleicher et al., 1993) require different degrees of accuracy of the macro velocity model in order to construct the respective image in either the time or depth domains. Therefore, one of the key issues to be addressed in seismic reflection imaging is: What is the best imaging technique for an insufficiently known macro velocity model and how can the original estimate of the macro velocity model be refined as part of the imaging procedure? To this end, we revisit Gelchinsky's (1988) common-reflecting-element (CRE) method.

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Given a set of common-offset (CO) sections, the CRE method is designed to construct a stacked zero-offset (SZO) section for a two-dimensional isotropic inhomogeneous earth model. This SZO section can then be subjected to a post-stack time or depth migration with the macro velocity model that is obtained as a byproduct of the CRE method. Other, better known, schemes to achieve the same goal are the CMP stack and migration to zero offset (MZO). MZO is either realized as a single, direct transformation using a given macro velocity model (which we call direct MZO) or, under a constant-velocity assumption, as the sequence of normal-moveout (NMO) and dip-moveout (DMO) corrections (which we call NMO+DMO).

The CRE method differs from direct MZO and NMO + DMO in the following sense. Firstly, it suffers from only minor residual reflection-point dispersal, thus falling somewhere between the MZO method (no dispersal) and the NMO method (full dispersal). Secondly, unlike direct MZO or NMO, the CRE method does not stretch the seismic pulse, i.e., each reflection in the SZO section has the same pulse length as a true ZO reflections. One of the most important features of the CRE method when compared to an MZO stack is that it *does not require* a macro-velocity model, but only the near-surface velocity (that is assumed to be constant in the vicinity of each point under investigation along the seismic line). Its principal and probably most useful advantage in comparison to the CMP and MZO stacks is that it provides, in addition to the SZO section, important parameters for the construction of a macro velocity model that may even be laterally inhomogeneous. These parameters are given in the form of two specific *wavefront attributes* that can be assigned to each obtained primary SZO reflection event, namely the *radius of curvature* R_o and the *emergence angle* β_o of a fictitious wavefront emerging at the earth's surface. This wavefront belongs to the fictitious wave that is assumed to originate at the so-called normal-incidence point (NIP), C_o, on the target reflector Σ_D. This fictitious wave is referred to as the NIP wave (Hubral, 1983) and its path of propagation C_oX_o as the normal ray. Both the radius of curvature and emergence angle of the emerging NIP wave, once assigned to each primary reflection in the SZO section, define what is called the *radiusgram* and *anglegram* sections (Berkovitch and Gelchinsky, 1989; Berkovitch et al., 1991; Keydar et al., 1995). These two auxiliary sections, in addition to the SZO section, are input to either generalized Dix-type formulas or more general traveltime or tomography inversion schemes (Hubral and Krey, 1980; Goldin, 1986; Keydar et al., 1995) generate an accurate macro velocity model.

The fact that the CRE methods needs as an input parameter the near-surface velocity provides no principal difficulty as this is usually available prior to a full velocity analysis. In a marine environment, the water velocity that is generally known can be used. In land seismics, usually some preprocessing like redatuming (assumed to be already done when the CRE method is to be applied) also needs a near-surface velocity field that can be used.

In contrast to the MZO described by Tygel et al. (1996), the CRE method is based on kinematic considerations and is not an amplitude-preserving process. The reader is also to be reminded that the CRE method is only one of a set of so-called *homeomorphic imaging* methods (Berkovitch et al., 1991, Gelchinsky et al., 1993a,b; Keydar, 1994; Cruz, 1994; Keydar et al., 1995), which include, e.g., the *common-evolute-element* (CEE) method and others, by which amplitude aspects may be taken into account (Steentoft and Rabbel, 1995).

The CRE method has seen considerable study over the past decade in the construction of SZO sections (Rabbel et al. 1991; Steentoft and Rabbel, 1992a,b; 1994; Steentoft, 1993; Gelchinsky et al., 1993a,b; Keydar, 1994) and in the estimation of the laterally inhomogeneous macro velocity models (Berkovitch and Gelchinsky, 1989; Berkovitch et al., 1991; Steentoft, 1993; Keydar et al., 1995). From the more practical point of view, the works of Steentoft and Rabbel (1994) and Olalde (1996) provide a variety of synthetic and field data examples with impressive results. Those readers who need to be convinced of the value of the CRE method by looking at its actual implementation are referred to the above publications. For instance, Steentoft and Rabbel (1994) implemented a corresponding algorithm and applied it to the Marmousi data. They came to the following conclusions. The CRE algorithm automatically produces SZO sections the quality of which is at least comparable to standard NMO- and DMO-processed seismograms. High-energy arrivals are successfully processed even in situations where the NMO method fails. The coherency of the CRE-derived image was superior to the CMP stack. Moreover, CRE stacking is very accurate with respect to detecting the directional properties of the reflected wavefields.

Critical to the success of the CRE method is the two-parameter coherency analysis which yields the emergence angle and the radius of curvature as stacking parameters. It turns out that both these parameters possess a significant independency in the CRE moveout expression, so as to allow a stable operation. The examples contained in the above cited papers fully confirm this statement. This fortunate situation is in contrast with the strong instability one encounters, for instance in the conventional CMP stacking, when trying to estimate the stacking velocity by means of a fourth-order Taylor expansion of the NMO traveltime.

The present paper mainly aims at shedding new light on the basic principles underlying this interesting method and at deriving in a simple way the main formulas involved. We find that such a didactical approach is still lacking in the literature and maybe this has been one of the reasons the CRE method has not yet attracted the due attention it deserves as a useful tool of constructing good SZO sections. After reviewing the CRE method, we provide new derivations and new results, in particular regarding the pulse stretch.

Apart from this Introduction and the Conclusions, this paper is composed of six principal sections and one appendix. The first section provides fundamental concepts of the CRE method that will be used throughout this paper. The second section presents the strategy used in the CRE method to construct an SZO section, by means of determining the radiusgram and anglegram, from the complete set of CO sections. In the third section, we describe the three principal implementation steps of the CRE procedure. In the fourth section, the CRE method is tailored to the one-dimensional (1-D) case. There, we will observe that the optical stack proposed by de Bazelaire (1988), which provides a well-known alternative to the standard CMP method, can be looked upon as a special case of the CRE method. The fifth section shows very simply why the SZO reflections obtained by the CRE method suffer from no pulse stretch. In the sixth section, we provide a birds-eye view of the main features of the CMP, CRE, NMO + DMO, and MZO stacks. This we do to better understand the CRE method in the framework of the other existing methods to construct SZO sections. Finally, the Appendix provides a brief review of some original CRE formulas that can be compared with the new ones derived in this paper.

CONCLUSION

The principal features of the CRE method, about which - so we hope - the reader has now gained a better understanding and new insight, consist of **(a)** the construction of a stacked zero-offset (SZO) section from a set of CO sections with only an estimate of the near-surface velocity, and **(b)** the computation of two wavefront attributes (the radius of curvature and emergence angle) for each ZO reflection in the SZO section. Both wavefront attributes are fundamental for traveltime inversion techniques (e.g., based on generalized Dix-type formulas) in order to estimate an accurate macro-velocity model. Simulating SZO sections by an MZO plus a subsequent stack has definitely found a much broader practical application than the CRE method. The two main reasons seem to be the lack of a more didactical explanation of the CRE method together with the absence of significant synthetic and real data examples. With this paper, we hope to have provided a contribution to the former reason, as well as indicated more recent work where such examples have been carried out.

We also suggest an alternative scheme to construct an optimal CRE gather and its corresponding radiusgram and anglegram. The somewhat complicated formulas found in the original formulation of the CRE method considering source-receiver coordinates (Gelchinsky, 1988) have been replaced by simpler expressions in terms of midpoint and half-offset coordinates.

We have shown that in the 1-D case the CRE stack reduces to the optical stack (de Bazelaire, 1988). Even in the case of horizontal reflectors below a 1-D velocity model, where even the CMP stack suffers from no reflector-point dispersal, the CRE stack can be advantageous for constructing SZO sections. The CRE stacking curves can then be better approximations of the primary reflection trajectories than the RMS-velocity based CMP-stacking hyperbolas (de Bazelaire, 1988). In addition, we have shown that

a) the seismic pulses of the ZO reflections constructed by the CRE method are not stretched when compared to true ZO reflections, (i.e., the frequency of a pulse is not altered by constructing a ZO reflection in the final SZO section from a given CO reflection).

b) the CRE method, unlike the CMP stack, suffers from some residual reflector-point dispersal only. Like the CMP stack, it selects only specular primary reflections along optimally specified stacking lines.

c) a CRE gather can be constructed from a set of CO sections in a parallel way as this is conventionally done from a set of CS records. All that is needed is to transform the source-receiver coordinates into midpoint–half-offset coordinates.

The following remarks about the implementation of the CRE method seem to be in order. The first remark is that one should, in principle, be suspicious of the actual implementation of the two-parameter estimation involved in the CRE method, in particular with the stability of the process. The meaningful synthetic and real data examples described in the literature attest that this is a robust process. The reason might be that both parameters, namely the angle and curvature radius, contribute to the CRE traveltime moveout with significant independence. Although a sound theoretical measure has not yet been provided, the fact is that in all applications, the parameter selection were carried out successfully without any sophisticated coherency analysis being developed. The second remark is that the two-parameter CRE moveout expression is expected, in most situations, to resolve or minimize the so-called conflicting-dip problems, that may be particularly when dealing with two-dimensional data. In fact, the emergence angle and wavefront curvature radius are fundamental physical and geometrical characterizations of the reflection arrivals, certainly better suited to the separation of the reflections than, for example the coefficients of the NMO traveltimes in the conventional CMP stack. Concerning the effectiveness of the CRE method in reducing the reflection-point dispersal, it would be very desirable to be able to quantify this reduction, in terms of the medium inhomogeneity (e.g., values of velocity gradients). Although this is still an open question, it is rather clear that the ray-theoretical foundations of the CRE method should lead to good results for those media where the zero-order ray description is valid. This includes most of the situations encountered in practice. Where it definitely fails, all other stacking methods based on the same principles should also fail.

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PUBLICATIONS

Detailed results were submitted to Geophysics (Cruz et al., 1997)