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COMPUTATION OF FULLY INTERPRETED *SH* SEISMOGRAMS FOR COAL SEAMS BY THE RAY-REFLECTIVITY METHOD

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ABSTRACT

The conventional ray methods are not well suited for an efficient computation of synthetic traces representing a seismic response of the so-called laminated structures consisting of very thin layers. This is due to the fact that quite a large number of rays reverberating inside thin layers must be summed up to produce individual wavelets seen on the synthetic trace. Such computational difficulty can be avoided if the so-called ray-reflectivity method is employed instead for the laminated structures. This hybrid method, which has been developed in a series of our earlier papers (Daley and Hron, 1982, 1990, 1992), accounts correctly for the reflection from and *transmission through the stacks of thin layers by employing the* concept of matrix propagators while computing the pertinent traveltime and the amplitude loss due to the geometrical divergence of wavefronts in the thick layers according to standard ray methods.

INTRODUCTION

In a previous paper published in this journal (Pascoe et al., 1988), the Alekseev-Mikhailenko method (Alekseev and Mikhailenko, 1980) was employed in the computation of *SH* traces for a simplified geological model (Figure 1). This model consisted of two horizontal coal seams, each of 2 m thickness, located at depths of 200 m and 250 m. The authors of the earlier paper were able to identify arrivals in the synthetic traces representing the total wave field recorded at the surface. These arrivals included not only the primary reflections but, also, intrabed multiples and other arrivals with complex raypaths. The positive identification of individual arrivals was aided by computing another set of synthetic traces for the same model with the receivers in this second case located along a vertical profile. These are known as vertical seismic profile (VSP) seismograms.

When accuracy is the prime consideration in computing synthetic traces, the Alekseev-Mikhailenko method (AMM) *has few viable contenders. The price for this high accuracy is* the large amount of computer resources required together with the necessity of computing the additional VSP synthetic traces for arrival identification purposes. The heavy expenditure of computer resources demanded by the AMM would discourage *many potential users from implementing this program type.*

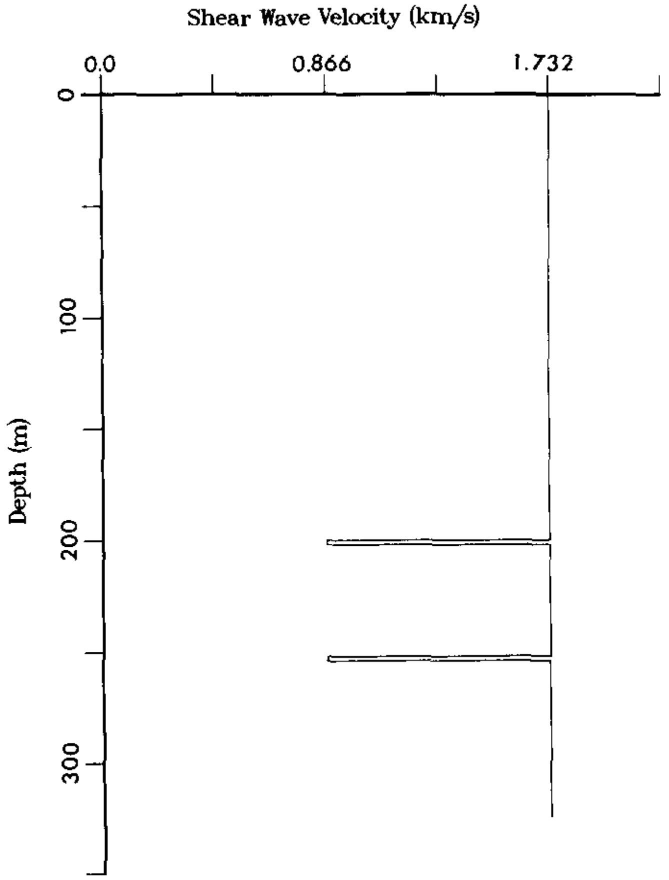

Fig. 1. The velocity-depth model used for the computation of *SH* synthetic seismograms. Two coal seams of 2 m thickness are located at depths of 200 m and 250 m, respectively.

In this paper, it is demonstrated that a computationally reasonable alternative for the generation of synthetic seismograms in thinly layered (laminated) media exists in the form of the ray-reflectivity method referred to in what follows as RRM (Daley and Hron, 1982, 1990, 1992). This method has been developed over a number of years specifically for such

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geological structural types. A demonstration is presented here, which entails the recomputation using the AMM, of the original model studied by Pascoe et al. (1988), augmented by utilizing the RRM for the synthetic trace calculations for the same model. These traces are displayed in Figure 2 with identical amplitude and time scaling parameters to facilitate comparison.

The minor differences in the two traces in Figure 2 suggest that the accuracy of the RRM is comparable to that of the Alekseev-Mikhailenko method for this geological structural type. The significant difference when comparing the two methods occurs when the computing times are examined. On a CDC Cyber 205 supercomputer (maximum speed 200 MFLOPS), with vectorization and highly optimized code, 900 s were required for the AMM run, while the RRM trace was obtained in 4 s on an Amdahl 6800 (maximum speed 5 MFLOPS).

In addition to the speed of the RRM in the computation of synthetics, the main advantage – in comparison to the Alekseev-Mikhailenko and other strictly numerical methods of synthetic seismogram production based on finite-difference or finite-element techniques – is the ability of the RRM to provide a full and automatic interpretation of the arrivals seen on the computed traces. This facility is shown in Figure 3, where an alternate mode of displaying the RRM synthetic seismic traces was used.

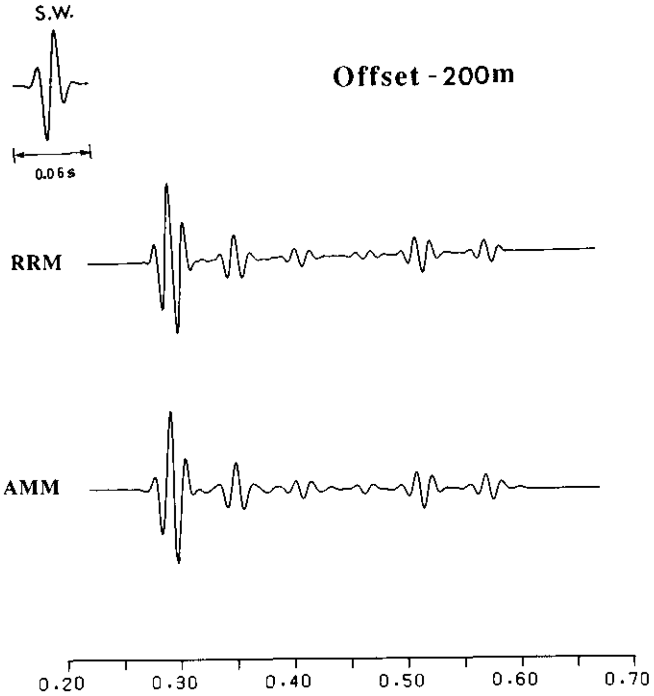

Fig. 2. Two synthetic traces representing the particle motion at the surface of the model described in Figure 1 at an offset of 200 m. The source wavelet, shown in the top left corner, is radiated from a point torque source located at the surface of the medium. Both the ray-reflectivity trace (RRM) and the Alekseev-Mikhailenko trace (AMM) are displayed at the same scale.

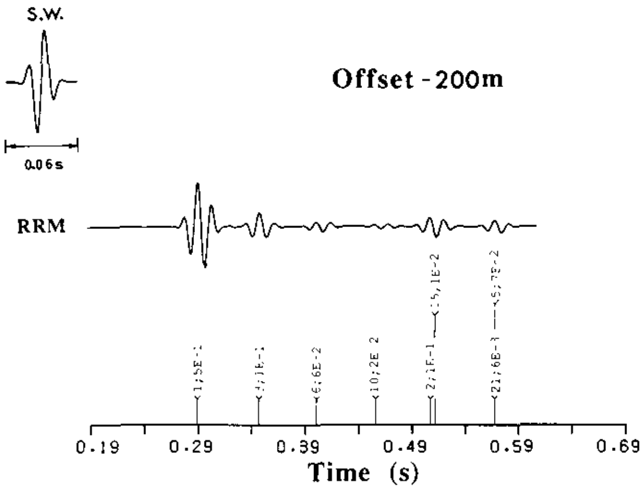

Fig. 3. The fully interpreted RRM trace of Figure 2 displayed in an alternate mode in which each arrival is associated with a specific ray-path in the thick layers. The first number following the "-<" symbol above the time axis gives the catalogued number by which the ray is identified in Figure 4. The second number, written in FORTRAN E-format, characterizes the relative amplitude of the arrival. Note that the relative amplitude of event no. 5, whose centre is arriving at 0.57 s, is twice that of ray no. 5a or no. 5b, as they both arrive at exactly the same time and interfere constructively.

It may be seen in Figure 3 that each major individual arrival in the synthetic trace can be associated with a distinct raypath in the "thick" layers, which determines not only the proper traveltime but also the geometrical spreading (spherical divergence). This accounts for the decrease in amplitude due to the diverging wavefronts (for details see Daley and Hron 1982, 1990 or 1992, where a complete theoretical background is provided). The RRM treats the stacks of thin layers (layers whose thickness is less than one half of the predominant wavelength) embedded between two neighbouring thick layers (thicknesses of which are greater than one half of the predominant wavelength) as a single laminated boundary. This allows for the expression of the partitioning of seismic energy due to reflections from and transmissions through such composite boundaries by the theory of propagators (Aki and Richards, 1980).

As every major arrival on the RRM trace may be associated with a pertinent raypath in the thick layers, all existing interpretive techniques based on any ray method could be applied to the RRM synthetics. Computationally, it also means that each RRM trace can be displayed with all of its major events interpreted in terms of constitutive raypaths as is done in Figure 3.

It should be noted that the catalogued number, used as an identifying label for each ray in Figures 3 and 4, actually corresponds to the sequential number indicating the order in which the ray was produced by an automatic ray generation scheme during the computation. In our ray generation scheme described by Hron (1971), the wavelet of the first primary (catalogued number 1) was computed first, followed by those corresponding to the first multiple (catalogued number 2) and to the second primary (catalogued number 3), respectively. Even though altogether all 78 existing rays with up to 12 ray segments in both thick layers were generated and their

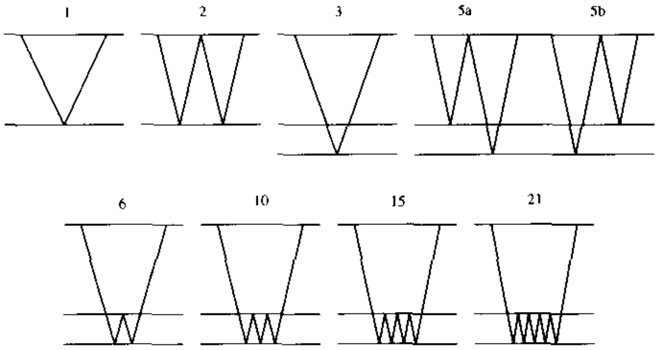

Fig. 4. A schematic representation of all the rays used in the identification of individual events seen on the RRM trace in Figure 3. The number identifying each ray corresponds to the catalogued number seen in the original computer display of the trace in Figure 3.

contribution to the synthetic trace examined, only 9 rays shown in Figure 4 arrived at the offset of 200 m with the traveltime less than 0.6 s. The remaining 69 rays exhibited traveltimes larger than 0.6 s, which was set as the length of the computed seismic trace, and therefore their wavelets cannot be seen on the trace.

One should be aware that in horizontally stratified media there are, with the exception of a few unconverted primaries and higher order multiples, several different raypaths with identical traveltimes from the source to the receiver. They constitute what are called groups of kinematic analogues (Hron, 1971; Hron and Kanasewich, 1971). The contribution of these to the seismic trace is in the form of a single wavelet, the amplitude of which is obtained by the superposition principle. This is the case of the rays labelled number 5a and number 5b in Figure 4. They arrive at the offset of 200 m with the same traveltime of 0.57 s. Since both rays also arrive at the receiver with the same phase, they interfere constructively, producing a single wavelet whose amplitude is double that of one of them taken separately. (See the combined arrival number 5 in Figure 3.)

In conclusion, it should be stated that the present version of our ray-reflectivity program can facilitate laminated structures composed of more than 150 thin layers interspersed between 10 thick layers. In addition, it may also be modified for the numerical emulation of the seismic response of thinly layered geological structures inferred from acoustic log data. There are no formal difficulties in extending the ray-reflectivity theory to the *P-SV* problem.

CONCLUSION

We have demonstrated the usefulness and the speed of the ray-reflectivity method by computing a synthetic *SH* trace for a simplified geological model with two thin horizontal coal seams 2 m thick and located at depths of 200 m and 250 m, respectively. The high degree of accuracy of the RRM in the computation of amplitudes and shapes of the composite wavelets characterizing the reflection of seismic energy from laminated structures can be inferred when comparing the RRM trace with that produced by a highly accurate Alekseev-Mikhailenko method in Figure 3. The main advantage of the RRM method is to be seen, however, in its intrinsic ability to associate each individual wavelet with a distinct raypath in the thick layers, thereby providing a complete interpretation of all major arrivals seen on the synthetic trace.

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