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Advanced Processing of 2D Marine Reflection Seismic Data Using the Common Reflection Surface (CRS) Stack Method with K-L Filter Application

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Abstract

Data processing using the seismic reflection method is an important stage in the exploration of natural resources and minerals. This research was conducted to determine the effective and efficient stacking and filtering methods in reconstructing the subsurface geological structure of the earth from the results of data processing using ProMAX software. The data processing method used is the conventional stack and the Common Reflection Surface (CRS) stack. Aperture values of 0 ms – 50 m and 3000 ms – 150 m in the CRS stack process produce the most optimum seismic sections. Both methods produce a different quality of seismic cross-section display. The 2D cross-section model from the conventional stack method looks noisier than the results from the CRS stack method. In addition, the reflector pattern on the cross-section of the results of the CRS stack method is clearer and visible with a relatively large amplitude compared to the results of the conventional stack method. To maximize the quality of data display, data enhancement is applied, which is the K-L filter. The eigenimages value of 0.10% on the K-L filter with a horizontal window width of 120 is used to reduce random noise. Thus, an increase in the S/N ratio will be obtained in the seismic data so that the 2D cross-sectional model of the seismic reflection method can approach the original conditions of the subsurface geological structure.

Keywords: conventional stack; common reflection surface stack; K-L filter.

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Introduction

The process of searching for natural resources and minerals can be done by utilizing seismic waves. The acquisition of the seismic method utilizes seismic energy sources, including waterguns, dynamite, airguns, vibroseis, and others. Usually, exploration using the seismic method is divided into three stages, which are seismic data acquisition, seismic data processing and seismic data interpretation. Several seismic data processing processes can be grouped into four functions, which are data preparation, data correction, data reduction, and data quality improvement. Each company's workflow in processing seismic data is different. Conventional methods of processing seismic data consume significant time and resources (Desai et al., 2021).

The signal-to-noise ratio in the reflection seismic data is controlled by the seismic data collection stage. Conventional 2D surveys are generally carried out in the acquisition phase of the seismic method which has certain drawbacks. The development of seismic method acquisition techniques has not been able to solve the existing problems. The key to obtaining good interpretation results is that it depends on the quality of the data obtained (Prabowo et al., 2021). One solution to data quality problems can be solved at the data processing stage (Zhu et al., 2015). A low signal-to-noise ratio can degrade the quality of data analysis such as inversion and imaging. Thus, seismic noise must be reduced as well as being a very important step (Chen et al., 2019).

Stacking is part of an important process in processing seismic data because it can produce an initial appearance below the earth's surface before the migration process takes place. Stacking must be applied to increase the signal-to-noise ratio. Several seismic data stacking methods that are commonly used include Common Mid-Point (CMP), Common Reflection Surface (CRS), and Common Reflection Point (CRP). One of the stacking method options used and the direction of measurement of important data is to reduce reflector ambiguity so that it is more efficient in reconstructing complex subsurface geological structures (Dani & Sule, 2021). The results of the conventional method stack depend heavily on the velocity model of the velocity analysis process (Daruartati et al., 2015). The CRS (Common Reflection Surface) method as a zero-offset (ZO) method for the stacking stage does not require a macro-velocity model (Garabito, 2021). With the use of the CRS method, the ambiguity in conducting velocity analysis is not too important to consider.

As for maximizing data quality after the stacking process, it is necessary to carry out a filtering process that aims to reduce the presence of noise. In this study, the eigenvector filter method is used as the main screening method. The eigenvector filter uses the Kahrunen-Loeve theory to decompose trace data into eigenimages using eigenvectors. The use of the Kahrunen-Loeve (K-L) method for seismic signals has been considered by Shukla & Jaiswal (2017), and most recently by Wang et al. (2020). In the field of image processing, the K-L transformation is commonly applied in data transmission and data analysis (Zaharov et al., 2014) as well as digital image enhancement (Sharma et al., 2018).

This research will explain how effective, efficient, and optimal the use of the Common Reflection Surface (CRS) stacking method is compared to conventional methods. The discussion regarding the application of the K-L filter in this study is also important because there is still little literature regarding the creation of this filter in reducing random noise.

Materials and Methods

This research was carried out at the Oil and Gas Testing Center "LEMIGAS". Data processing using ProMAX 2D software.

Data Preparation

The research data used is 2D reflection seismic data as a result of measurements in the Nias Sea by the Research and Development Institute for Oil and Gas Technology "LEMIGAS".

Table 1. Acquisition Parameters.

Acquisition Parameters	GM3-BIO-NIAS-L10.1
Source Interval	25 m
Group Interval	12.5 m
Total source	548
Total channel	96
Minimum Offset	50 m
Maximum Offset	1237.5 m
CDP Interval	6.25 m
Maximum Fold	24
Line Length	13.675 m
Line Azimuth	40°

Data processing

Seismic data processing is carried out using two different methods, which are the conventional method and the Common Reflection Surface (CRS) method. The use of two methods to compare the level of the ratio to the signal in order to obtain a subsurface model that matches the original conditions. This data processing consists of various steps arranged in a flow workspace. The flow consists of several processes, including data input, geometry setting, editing, filtering, True Amplitude Recovery (TAR), deconvolution, velocity analysis, stacking, and data enhancement.

1. Conventional Stack

The conventional stack method is performed by averaging the NMO-corrected data or migrated data sets (Jang & Lee, 2022). This method is only optimal when the noise components in all traces are unrelated, normally distributed, stationary, and with the same magnitude (Mandal et al., 2014; Pussak et al., 2014). Common-midpoint stacking (CMP) is a method commonly used in data processing because it can separate signals from the noise that has the same frequency.

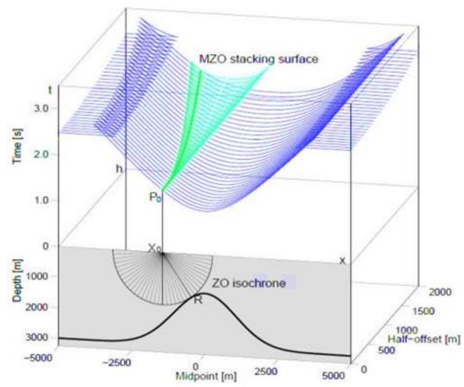

Figure 1. Operators of NMO/DMO stacks (Jäger, 1999).

In Figure 1 there is a symbol h as the offset distance, t is the time, and x is the CDP (Common Depth Point). Different rays can be reflected by a single CDP point. The sum along the multi-coverage data line indicated by the blue line is done to accumulate the different number of rays. After that, it is accumulated in one trace that represents the Po point. Between the time axis and the offset distance axis, there is a hyperbolic curve caused by the offset factor. Thus, a velocity analysis is needed so that the gather becomes straight. The CMP Stack operator is represented by a light green line. The conventional method stack stages are shown along the line in bold green.

2. *Common Reflection Surface* (CRS) *Stack*

The Common Reflection Surface (CRS) method introduced by Muller in 1998 is a zero-offset (ZO) simulation method based on 2-D data that does not require explicit knowledge of macro-velocity models (Pahlavanloo et al., 2017). The CRS method stack operator has several parameters using three attributes of the kinematic wave field which represent the curvature and coincident direction of propagation of the two wavefronts that appear on the acquisition surface, which are the normal incidence point (NIP) wavefront and the normal wavefront (Hubral, 1983).

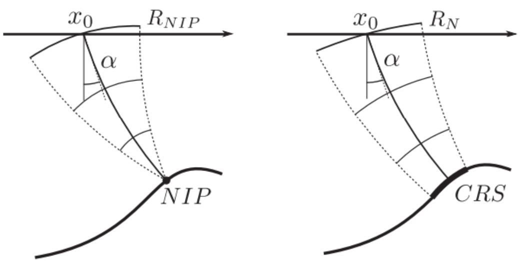

Figure 2. Normal incidence point (NIP), RNIP radius of curvature of a wavefront, and α is incidence angle (Rad & Macelloni, 2020).

The NIP wave radius or R_{NIP} parameter is a wave that propagates from the surface to the reflector and then returns to the surface. NIP waves shrink to a point on the reflector assuming that energy is not lost during wave propagation. The source of the new wave, which is the NIP wave, appears after the wave arrives at a reflector point so that the distance from the reflector to point x_0 can be determined. The waves that propagate in the normal direction or the R_N parameter are created from the area source around the point of occurrence. The R_N parameter contains information about the reflector curvature. The critical angle between the surface and the normal beam at x_0 is the angle parameter α (Daruartati et al., 2015). The CRS stack equation mathematically uses a second-order Taylor expansion written as follows:

$$t^2(x_m, h) = \left[t_0 + \frac{2\sin\alpha}{v_0}(x_m - x_0)\right]^2 + \frac{2t_0\cos^2\alpha}{v_0}\left[\frac{(x_m - x_0)^2}{R_N} + \frac{h^2}{R_{NIP}}\right] \quad (1)$$

Based on Equation (1), the time sample is symbolized (t_0). Meanwhile (x_0) is the coordinate of the appearance of the normal beam at half offset (h) equal to zero, $(x_m - x_0)$ is the midpoint aperture. The constant velocity near the surface is (v_0). The radius of normal wave curvature is symbolized (R_N), while the normal incident point radius of curvature is symbolized (R_{NIP}), and (α) is the angle of incidence of the reflected wave.

The CRS method can get closer to the actual subsurface geological model by accumulating the distances of the CMP and CDP around it without requiring velocity analysis. In Figure 3 the sum along the midpoint half offset surface is carried out at the CRS Stack stage which is indicated by the green line and then the product is accumulated at the Po point.

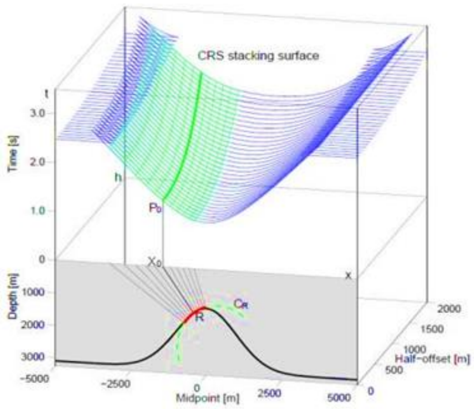

Figure 3. Operator from CRS stack (Jäger, 1999)

3. *Data Enhancement*

The eigenvector filter (Figure 4) is the same as the K-L Kahrunen-Loeve transformation (Hsu, 1990). The NMO-corrected 2D seismic section is treated as a 2D matrix which can be decomposed into its eigenvalues with the appropriate eigenvalues. The existence of a seismic event in the form of a flat reflection pattern is indicated by a high eigenvalue. Conversely, seismic events that are random and less prominent or include noise are shown with small eigenvalues. Thus, improving data quality can take advantage of this filter. If $S(t, x)$ is a data matrix, the corresponding singular-value decomposition (SVD) can be written as $S = U \sum V^T$. Meanwhile, U and V are unitary matrices consisting of left and right eigenvectors of S and $\sum$ a diagonal matrix containing eigenvalues of S (Liu & Liu, 2020).

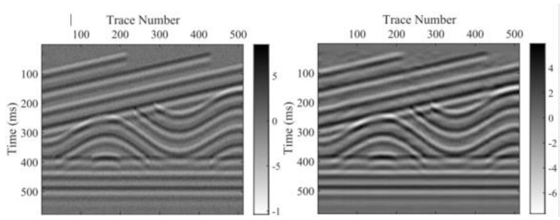

Figure 4. An example of implementing the K-L transformation (Wang et al., 2020).

Results and Discussion

The results of this study are seismic cross-sections with intervals of 0-2200 ms obtained from data processing using the conventional stack method and the CRS stack method both before and after applying data enhancement using the K-L filter.

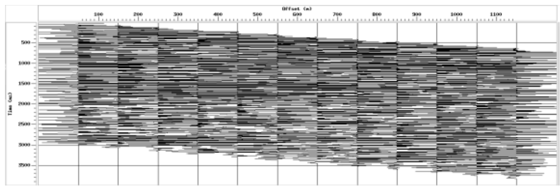

Figure 5. CMP gather.

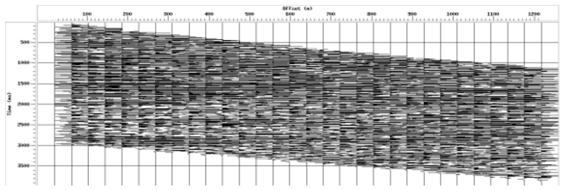

Figure 6. CRS supergather.

The CRS method has a higher number of traces than conventional methods. The number of traces in the CRS Supergather is controlled by the aperture selection because the aperture in the CRS Stack operator indicates the number of traces from adjacent CMP used in the stacking process.

The CRS method also has a similar amplitude and collects so that it produces a better gather appearance than the conventional method. Gather on the conventional method looks more random and fluctuating. This is shown in Figure 5 and Figure 6.

1. Conventional Stack Method

The stacking process using conventional methods before applying data enhancement on GM3-BIO-NIAS-L10.1 produces a subsurface model as shown in Figure 7. Random noise is still visible in the display which is partially indicated by a yellow box so that it disrupts the main reflector pattern and can complicate later interpretation.

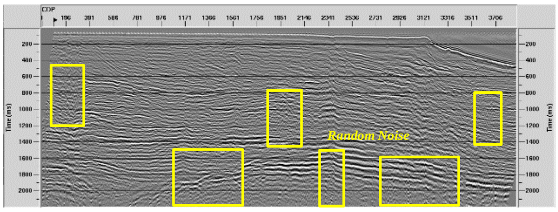

Figure 7. The result of the conventional method stack without the K-L filter.

2. CRS Stack Method

The stacking process using the CRS method on GM3-BIO-NIAS L10.1 before data enhancement is shown in Figure 8. The ZO aperture values on the CRS stack are 0 – 50 ms and 3000 – 150 ms. This value is selected based on trials so that the most optimum cross-sectional quality can be obtained. The appearance of the subsurface model looks cleaner than conventional methods even though data enhancement has not been applied. The main reflector pattern with a large amplitude is visible at certain time intervals indicated by red arrows.

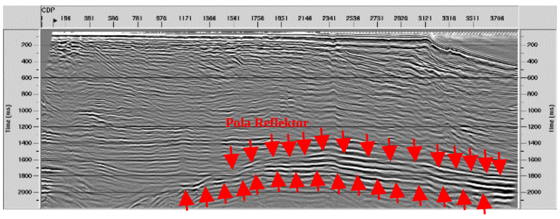

Figure 8. CRS method stack results without K-L filter.

3. Application of K-L Filters

This filter is applied to the conventional method stack results and the CRS method stack results. Generally, the eigenimages in this filter are divided into 3 groups based on their value. Flat components are generally reconstructed using low eigenimages, dipping components using middle eigenimages, and more random components using a higher number of eigenimages. Therefore, to display the noise output from the results of the conventional stack method and the CRS method which will be reduced later by the K-L filter, can use the eigenimage value range of 10% to 100% with a horizontal window width of 120 as shown in Figure 9 and Figure 10.

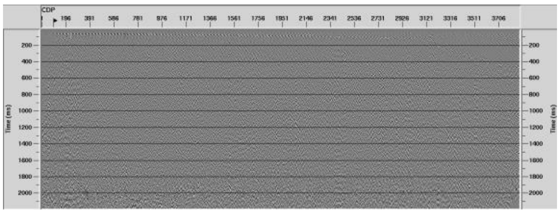

Figure 9. K-L filter noise output from conventional stack results.

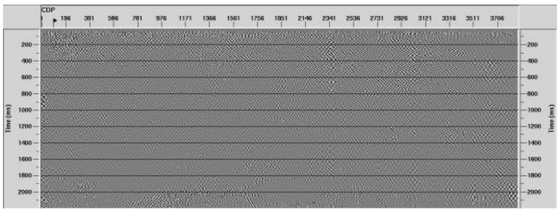

Figure 10. K-L filter noise output from CRS stack results.

The application of the K-L filter to the two results of the stacking method uses an eigenimages value range of 0% to 10% so that the output noise that was previously generated with an eigenimages value range of 10-100% will be reduced. The horizontal window width used is 120, which is obtained from the trial results while still based on existing theory. Thus, the results obtained from the conventional stack method after the application of data enhancement are shown in Figure 11, while Figure 12 is the result of the CRS method stack after the application of data enhancement.

Based on the seismic section, the results of the conventional stack method by applying the K-L filter in Figure 11 shows that the random noise has been reduced, even though the 2D seismic section still looks relatively noisy. Likewise in Figure 12 which is a seismic cross-section of the results of the CRS stack method by applying the K-L filter, the presence of random noise has been maximally eliminated so that the 2D seismic cross-section display is much cleaner than the stack results display using conventional methods with the application of data enhancement. The main reflector pattern is clearer and seen with a larger amplitude in Figure 12. This indicates an increase in seismic resolution and signal-to-noise ratio after using the CRS method and combined with the application of data enhancement using the K-L filter.

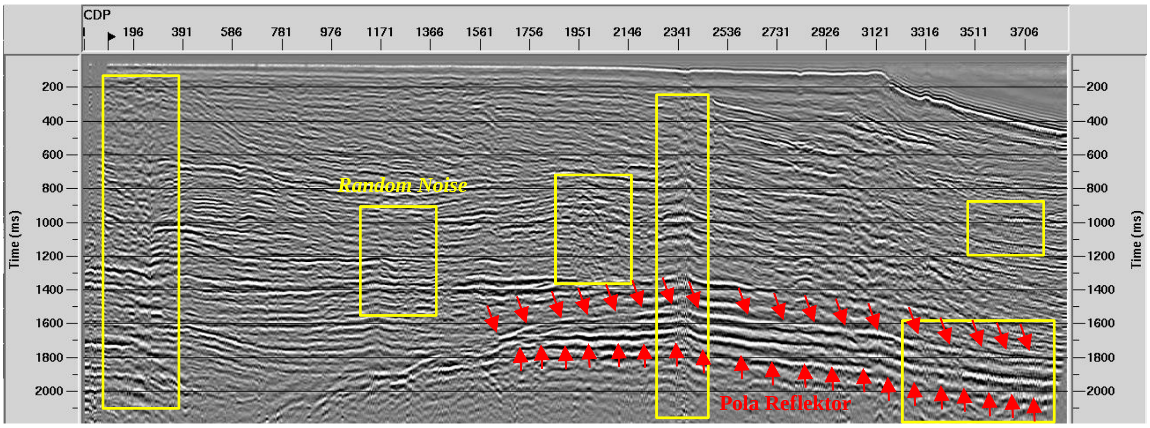

Figure 11. Results of conventional stacking method with K-L filter.

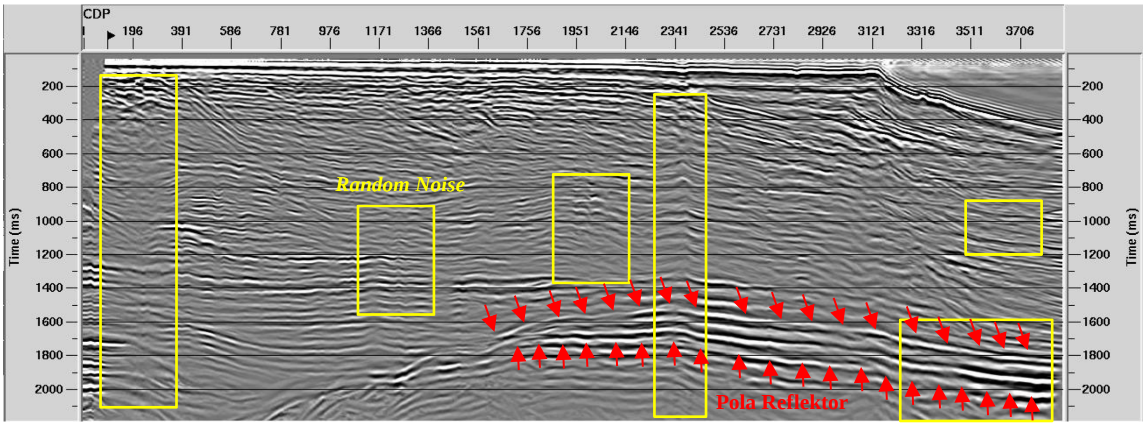

Figure 11. Results of CRS stacking method with K-L filter.

Conclusion

Processing of seismic data using the conventional stack method with the K-L filter combination has not yet produced an optimum 2D seismic cross-section so the use of the Common Reflection Surface (CRS) stack method combined with the K-L filter is required in order to increase the relatively high signal-to-noise ratio.

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Author Contribution

E.D.K.Z. write theory, perform data processing, and perform data analysis. S.R.

and E.W. validate analytical methods and help develop this research. All authors discussed the results and contributed to the final manuscript.

Conflict of Interest

All authors declare that they have no conflicts of interest.

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