Enhancement of Seismic Stacked Section Obtained from a Complex Geological Structure by using Partial CRS-Stack Method

Ariesty R. Asikin[1], Andri Hendriyana[1], and Rachmat Sule[1]

[1] Geophysical Engineering Department, Institut Teknologi Bandung, Bandung, Jawa Barat, Indonesia

E-mail: ariestyasikin@gmail.com

Abstract. Partial CRS-Stack method is proved as an alternative method that can produce excellent subsurface image, especially if this method is applied to a seismic data that is acquired from complex subsurface structure areas. The application of this method will give a new hope in determining subsurface structures in a better way, especially if it is implemented to seismic data obtained from Indonesian region, which is dominated by complex geological structures. The Partial CRS-stack method is tested by using a seismic dataset, which is acquired from eastern part of Indonesia. Here, the continuity of reflectors cannot be seen clearly. To prove the ability of Partial CRS-stack method, its result will be compared with the result obtained from the conventional sequences. The stacked section resulted from Partial CRS-stack is much better than the result of conventional one. This could be understood, since the Partial CRS-stack method uses the information of reflectors along fresnel zone, instead conventional method that only uses information in a CDP. During its processing sequence, CRS kinematic wavefield attributes, e.g. emergence angle (α), radius curvature of normal ray (R_N) and radius curvature of normal incident point ray (R_{NIP}) must be determined previously, which indicates the location and behaviour of reflectors. As a conclusion, the Partial CRS-stack method is proved as a good alternative method to give better seismic sections. Because of this, the interpretation of unclear events that are seen in the conventional stack section can be avoided.

1. Introduction

The most common used geophysical method for oil and gas prospecting is reflection seismic method. This method utilizes the principle of seismic wave propagation inside the earth. Since sedimentary basin is composed by sedimentary layers, some of seismic energy will be reflected back to the surface if the waves reach subsurface interfaces that have contrast acoustic impedances. The arrivals of seismic waves will be registered by receivers that are deployed near earth surface. Those registered data will be processed in order to obtain seismic sections, which illustrate subsurface condition. However, if the subsurface structures are really complex, it would be difficult to obtain good seismic sections, although modern acquisition instrumentations and parameters are used. The success of obtaining good results is depend on what kind of processing technique is implemented to that data.

Conventional stacking method, which embraces the concept of common depth point (CDP), will normally not overcome the classical problem, i.e. how reliable seismic sections can be obtained from an area with complex subsurface geological structures. This conventional method assumes that a reflector composed by many reflector points. Each reflector point, which is part of a reflector plain, is then called as CDP. The concept of CDP can still be used as long as the reflectors are flat or have a uniform dip. If the reflectors are undulated, this concept can actually not be used anymore, since several sources-receivers pairs that develop a CDP gather could not represent a desired CDP point. Thus, special seismic processing technique must be found out in order to substitute the concept of conventional stacking method.

One of advanced processing methods that could overcome those above problems is the CRS-Stack method. This method is based on an assumption that a reflector is composed by many reflection surface segments, which is identical to the width Fresnel zone at a depth. All seismic traces that correspond to this Fresnel zone (which are developed by several source-receiver pairs on a surface) involve in the determination of a stacked seismic trace. Thus, CRS-Stack method is implemented by involvement of more seismic data in order to sum up or stack them into a stacked trace. Seismic data processing by using CRS-Stack method is also known as a multi-focusing method.

The Partial CRS-Stack method is introduced for the first time in 2008 [1]. This method is the generalization of previous existing Zero Offset (ZO) CRS-Stack method, which is introduced in 1998 by the Wave Inversion Technology (WIT) consortium ([4], [3]). Several previous applications of CRS-Stack method are found in published papers, e.g. [6] and [2]. Those previous studies showed that the ZO CRS-Stack is successful in handling seismic data taken from an area with complex subsurface geological structures. Besides better S/N ratio is achieved, the continuity of reflectors is obviously seen on the results of ZO CRS-Stack method. This paper will expose some achievements if Partial CRS-stack method is implemented. In order to fulfill this purpose, a real seismic dataset obtained from complex subsurface conditions is used, and this result is compared to the result obtained from conventional stacking method.
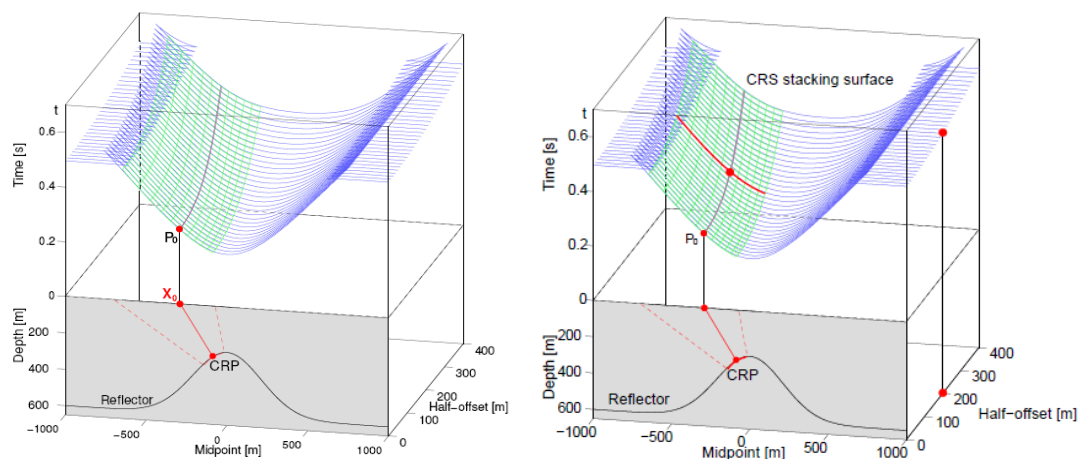

Figure 1. Left: ZO CRS-Stack surface [4] and Right: Partial CRS-Stack surface. The stacking process is conducted only along the red line and stored the result in the red dot [1].

2. Partial CRS-Stack Method

The principle of ZO CRS-Stack and Partial CRS-Stack method is actually quite similar. The significant difference between both methods is seen on the representation of their operators. In the ZO CRS-Stack, traces summation (or stacking process) is carried out along the CRS-Stack surface that is

drawn as green surface in Fig. 1 (left). This summation/stacking is conducted in order to obtain a stacked trace at x_0. This procedure is repeated for other positions. As final output, a stacked section is obtained.

In the Partial CRS-Stack method, the traces summation is carried out in every half-offset. The curvature red line displayed in Fig. 1 (right) illustrates all seismic data that contribute to develop a stacked trace (red point in Fig. 1 right). This procedure is repeated for other half-offset, in order to obtain other stacked traces that are later situated along curvature purple line. This curvature purple line is actually identical to the CMP gather embraced in the conventional stacking method. However, this curvature purple line consists more stacked traces, in which the information related to reflector's dip for each trace is already considered. This curvature purple line is then known as a supergather, which is the final product of Partial CRS-Stack. The supergathers will be more regular than the original CMP gathers.

Before conducting this method, same procedures that are valid in ZO CRS-Stack method must be done previously, i.e. all efforts in order to obtain CRS attributes of emergence angle (α), and the two radii curvature (R_{NIP} and R_N). Those CRS attributes are needed in order to perform stacking process, as it is formulated in Eq. (1). Basically, those CRS attributes can be determined either after performing Automatic CMP-Stack or after CRS-Stack Attributes Optimization [4].

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

The calculation of partial CRS stacking surface is conducted in a chosen CMP location for every specified sample A(t_A,h_A), as can be seen in Fig. 2. An accurate zero offset time (t_0) and corresponding CRS attributes must be found first. One must search a traveltime hyperbola that is close to the traveltime curve, in which the sample A is situated. The traveltime hyperbola search is conducted within the range [0;t_A] for the corresponding CRS parameters (α, R_N and R_{NIP}). The best fit curve that is chosen is the hyperbola curve that gives minimum deviation between the computed and the observed traveltime for sample A. Thus, the best zero offset traveltimes (t_0') is now obtained, including the corresponding CRS attributes. Since the t_0' time can have only discrete values, the computed t_0 time may deviate slightly from the t_0'.

The t_0 can now be calculated by using α and R_{NIP} attributes that corresponds to t_0', as it is described in Eq. 2.

$$t_0 = -\frac{h_A^2\cos^2\alpha}{V_0 R_{NIP}} + \sqrt{\left(\frac{h_A^2\cos^2\alpha}{V_0 R_{NIP}}\right)^2 + t_A^2} \tag{2}$$

R_{NIP} is assumed to be positive because it is a reflector depth. The negative solution from Eq. 2 is ignored. The obtained t_0 from Eq. 2 is then used in the equation 1 to obtain Partial CRS-stacking surface, as it is written in Eq. 3. This stacking surface is used to sum up the data coherently.

$$t^2[x_m,h] = \left(-\frac{h_A^2\cos^2\alpha}{V_0 R_{NIP}} + \sqrt{\left(\frac{h_A^2\cos^2\alpha}{V_0 R_{NIP}}\right)^2 + t_A^2} + \frac{2\sin\alpha}{V_0}\left(x_m - x_0\right)\right)^2 +$$

$$\frac{2\cos^2\alpha}{V_0}\left(-\frac{h_A^2\cos^2\alpha}{V_0 R_{NIP}} + \sqrt{\left(\frac{h_A^2\cos^2\alpha}{V_0 R_{NIP}}\right)^2 + t_A^2}\left(\frac{\left(x_m - x_0\right)^2}{R_N} + \frac{h_A^2}{R_{NIP}}\right)\right) \tag{3}$$
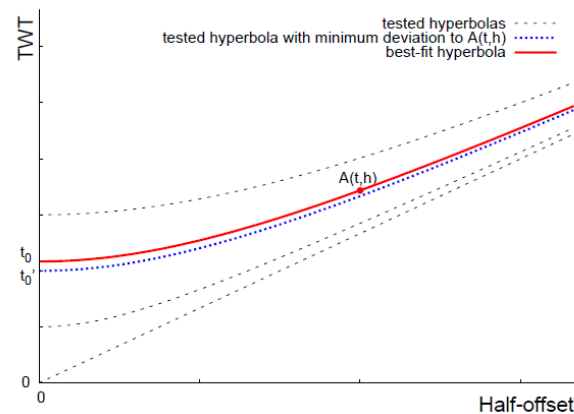
Figure 2: Hyperbola travel time curves that are used to get the most suitable for sample $A(t_A, h_A)$ in the CRS supergather [1].

3. Implemented Case Study

Implementation of Partial CRS-Stack method is conducted by using an onshore seismic dataset. The obtained result will be then compared with the best result, which is obtained from implementing conventional stacking method. The seismic data processing by using conventional stacking method has been done by a third party. The data is acquired from a complex geological structure in eastern part of Indonesia, in which intensive tectonic processes are occurred there. Besides that, the topographic variation is very strong, so that static correction must be applied carefully during pre-processing step. Some acquisition parameters are listed as follow: shot interval = 25 m, receiver interval = 25 m, near offset = 6.25 m, far offset = 4500 m, and maximum fold coverage = 60.

One of the most important parameters in the CRS-Stack processing flows is the aperture size. This value can be determined by estimating the size of Fresnel zone, which can be obtained from the projection surface of the first Fresnel zone. In its calculation, three CRS kinematic wavefield attributes (α, RN and RNIP), which indicate the location and behavior of reflectors, will influence the obtained value of Fresnel zone estimation.

The output of the CRS Stack method is 'supergathers', which consist more traces than the conventional gathers have. It means that the fold number will increase if Partial CRS-Stack is applied. This is one of the positive implications given by Partial CRS-Stack, because more data involvement occurred here, i.e. throughout the Fresnel zone. Figure 3 shows an example, which shows the difference between a conventional gather (left figure) and its corresponded supergather (right figure). Although 2.4 seconds is set as maximum aperture, the supergather still shows significant improvement. The reflectors are seen more clearly and the content of random noise is minimized.

The velocity spectra of both gathers are seen in Fig. 4. The velocity pattern in the velocity spectra of supergather (right figure) is described in a better way in. The interpreter will be easier to pick the velocity values in that velocity spectra, especially in the area that is restricted by tallow circle. As comparison, the velocity spectra obtained from conventional method is seen in Fig. 4 (left).

The best stack section obtained from conventional stack method is seen in Fig. 5 (top), whereas the stacked section resulted from Partial CRS-Stack method is displayed in Fig. 5 (bottom). If both sections are compared, it can be seen very clearly that the result from Partial CRS-Stack is much better than the result from conventional stack method, in which the reflectors look more continuous than the conventional result. Some deeper reflections, which are not so clear in conventional stacking section, are appeared in the Partial CRS stack results.
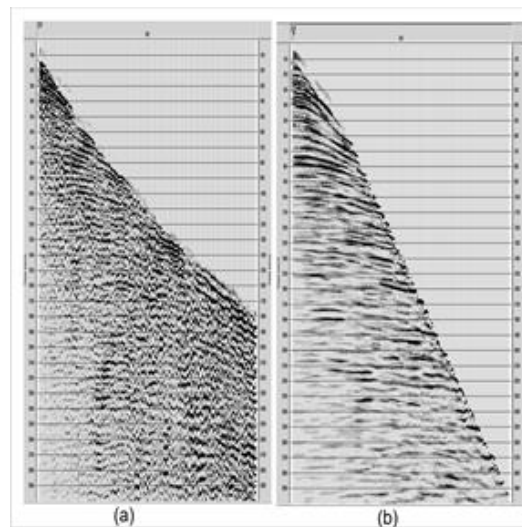
Figure 3. The difference between seismic gather obtained from conventional stacking method (left) and Partial CRS Stack method (right). Maximum aperture of 2.4 s is set for this example, which is not the maximum time.
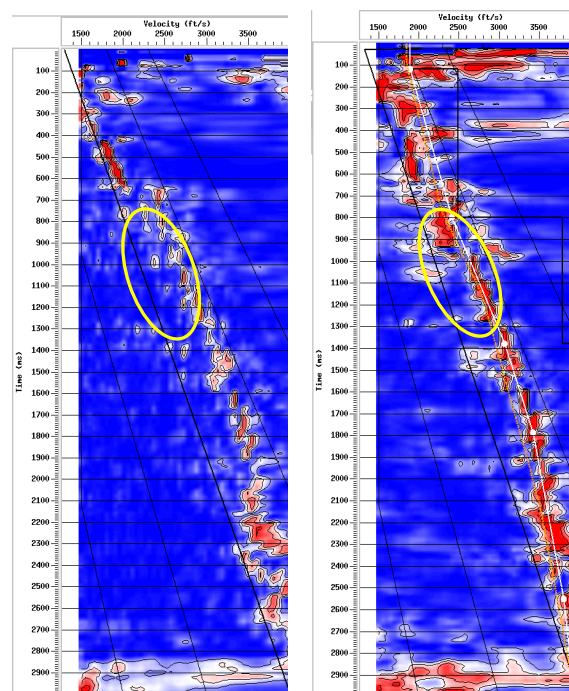

Figure 4. Velocity spectra obtained from conventional stacking method (left) and Partial CRS-Stack method (right).

If both sections in Fig. 5 are compared, it can be seen several differences, some of them are marked with black circles. The reflections that are unclear in the conventional stack section are now become more clearly in the stack section produced by Partial CRS-Stack. The shape of synclinal structure in the bottom figure can be better recognized, especially the base of that synclinal structure. The random noises that usually appeared between reflectors in the conventional stack section are now seen very clearly in the stack section produced by Partial CRS-Stack method. It makes some internal characters between reflectors can be better interpreted for seismic stratigraphy analysis purpose.
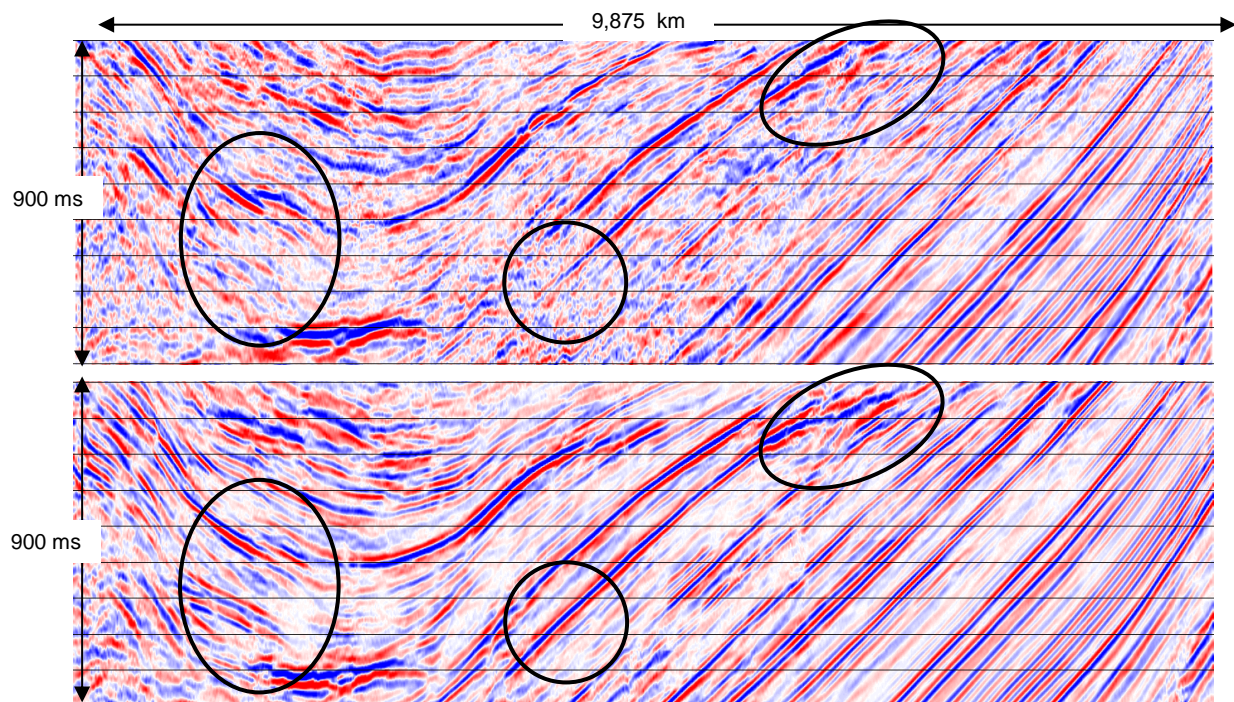
Figure 5. The difference between stack section obtained from conventional stacking method (top) and from Partial CRS-Stack method (bottom). The reflection continuities and S/N ratio are enhanced in the result of Partial CRS-Stack method.

4. Conclusion

The example showed in this paper proved the significant ability of Partial CRS-Stack method in enhancing the quality of seismic data. The significant improvement could be seen, if this method is implemented to the data that is acquired from an area with complex subsurface geological structures. If one faces irregular seismic data, this method can provide supergathers as output data, which contain denser traces. The fold number can be increased by implementing Partial CRS-Stack. Finally, this method could be suitable to be implemented for exploration purposes in Indonesian region, since most of Indonesia's geological conditions are very complex due to active tectonic processes.

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