Pre-stack Migration Aperture And Survey Area Extension

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ABSTRACT: With Pre-stack Time and Depth Migration Technology gaining more and more popularity in the industry, it has been widely felt to readjust the allowance given for migration aperture while designing the field survey. Conventionally migration aperture calculations are made to satisfy the needs of post-stack migration algorithms, and also very often no allowance is given for DMO aperture while adjusting the survey area for mapping a target image. Such type of designs measurably fail in faithful imaging through pre stack migration technology, especially in the fringe zones of target image. In the present study a simple analytical analysis has been made to estimate migration aperture satisfying the needs of pre-stack migration technology. Some real data examples have also been shown.

In order to obtain a meaningful subsurface image, it is very important for a survey designer to select the field geometry and parameters carefully. It is also very important to sufficiently extend the survey area for error free imaging in the fringe zones. This extension may be very large and expensive; therefore it has to be optimally calculated to have a balance between economics and technique. Once data has been acquired, a processor has limited options to enhance the imaging in fringe areas if suitable allowance is not given for migration aperture. The migration aperture and survey area extension consideration has become more important after implementation of pre-stack migration algorithms. Fig. 1 shows example of poor imaging due to lack of allowance given for migration aperture. In order to obtain a clearer image survey area needed to be extended properly. To highlight the effect on imaging of dipping events, PSTM on an available 3D volume has been run by restricting the CMP gathers up to 3 Kms and 5 Kms from the target image. Fig. 2 clearly indicates the loss of resolution in case of lower allowance given for aperture. Therefore calculation of extent of seismic surveys becomes very critical.

Migration process is supposed to achieve –
- repositioning of the seismic events at their correct location
- collapsing the diffracted energy for correct edge definitions.

First objective can be achieved by calculating the distance between actual and recorded event and extending the area by equivalent distance, this calculation depends on the geological dip of the reflectors. On the other hand, substantial portion of the two legs of diffraction hyperbola is required to

Figure 1: Deterioration of images in Fringe Zones of 3D volume
be captured for proper focusing of this energy and this definition is independent of geological dip.

First, we shall discuss the repositioning of the reflected event. The best way of selecting the survey zone is to go for modeling, which is not possible in all the cases, therefore, it is advisable to have some numerical method to obtain the optimum value for migration aperture and area extension. The basic concept of migration aperture and extension of survey area has been illustrated in Fig.3. Segment AB is the target image in the subsurface and QW is the corresponding survey line on the surface. AQ and AA" are image ray and normal incidence ray from point A respectively. The targeted reflector has been mapped as segment A'B' in unmigrated section. It appears that CDP traces up to location A" may be sufficient to correctly map the subsurface point A, because corresponding reflection event A' is contained in CDP trace as event at A". Therefore, A"Q is taken as migration distance or aperture, necessitating the extension of survey area up to full fold CDP location A".

The same situation has been analyzed further in Figure 4 with reference to shot and receiver locations. Point A is recorded at point A' with zero offset shot-receiver pair, and it will be recorded with Shot receiver pair S and R separated by a non zero value for a trace corresponding to CMP location C which is further left to the extended survey zone up to A". In such situation, it is certain that we are not recording subsurface point A even in a single trace (no zero offset trace is recorded in practice) by the said extension of survey zone. It appears now very clearly that the conventional concept of aperture is correct only for stack section or zero-offset section in true sense. Therefore, a need arises to evaluate aperture requirements for non-zero offsets in order to get proper image after pre-stack migrations. In following paragraphs a numerical deduction has been presented for pre-stack migration of non-zero offset traces. At this stage, it may be useful to study the available numerical methods to calculate aperture. An elegant and simple formulation has been offered by Chun and Jacewitz (1981) to estimate the migration aperture.

Horizontal Aperture in distance units = \( \frac{(V^2 T \tan \theta \tau)}{4} \)
Vertical Aperture in Two way time units = \( T \{1 - \sqrt{1 - V^2 \tan^2 \theta \tau}/4\} \)

Where T and V are traveltime and medium velocity and \( \tan \theta \tau = \Delta t/\Delta x \), as measured on unmigrated section.

This formulation makes use of zero offset stack section for calculations, but the two way time and dip obtained from a stack section may not be representative value owing to the major difference between stack section and zero offset section in case of complex geological setup. It will be more useful to consider depths and dips from the conceptualized geological models instead of two-way times and \( \Delta t/\Delta x \) from unmigrated stack sections. With these considerations a more popular formula for calculating migration aperture for a target depth of Z and dip \( \theta \) is given by:

\[ \text{Aperture} = Z \times \tan \theta \]

\[ \text{Aperture} = \frac{Z \times \tan \theta}{4} \]

Calculated aperture for depth point A is OA". Thus if survey is designed to record traces up to A", the trace generated by offset SR will be missed as it is recorded at CMP location C. Aperture should be increased beyond A".
Where $Z = AQ$ and $\theta$ is the geological dip as shown in Figure 3. The same methodology has been adopted in deriving aperture for non-zero offset trace in terms of depth, dip and offset only (Fig. 5).

Source and receiver are located at $S$ and $R$ respectively at an offset of $X$. During the process of binning, the trace generated by this $S$-$R$ pair is plotted at CMP location $C$, whereas the image point is vertically below point $Q$. To ensure the capture of image point “$I$” with offset “$X$” CMP trace at location “$C$” is to be recorded during acquisition. Therefore, the migration aperture becomes the distance $CQ$. Owing to the reciprocity of $S$ & $R$ positions, these locations may be interchanged, distance $CQ$ remains unchanged.

In $\rho$ SOR, $SO/PI \& SO=2*SN$ therefore,

\[ PI/ SO = RP/RS \]  

(1)

In $\rho$ SNT, $SN/PI$ therefore,

\[ PI/ SN = (TR+RP) / (TP- RP + RS) \]  

(2)

& also $TP = PI/ \sin \theta$  

(3)

\[ TR+RP = PI / \sin \theta \]  

(4)

From eqn. (1) & (2),

\[ 2*RP/RS = (TR+RP) / (TP- RP + RS) \]

Substituting values from eqn. (4)

\[ 2* \sin \theta * RP/RS = PI / (TP- RP + RS) \]

\[ 2* \sin \theta * RP* (TP- RP + RS) = PI * RS \]  

(5)

Solving for $RP$ from the quadratic eqn.

\[ RP = (PI+RS* \sin \theta) - SQRT \{ (PI^2+RS^2* \sin^2 \theta) \} \]

(6)

For non zero values of $\theta$

\[ RP = RS/2 \] for $\theta = 0$

The other solution is

\[ RP = (PI+RS* \sin \theta) + SQRT \{ (PI^2+RS^2* \sin^2 \theta) \} \]

(6 A)

The second solution pertains to virtual image point shown in Fig. 6, in which we are not interested.

If we take Offset $RS= X$ & depth of image point $I$, i.e. $QI= Z$ (where $PI = Z \sec \theta$) then equation (5) can be re-written as:

\[ RP = (Z \sec \theta+X* \sin \theta) - SQRT \{ (Z^2 \sec^2 \theta+X^2* \sin^2 \theta) \} \]

(7)

Migration Aperture for non zero offset trace $CQ$ can be written as:

\[ CQ = X - (Z \sec \theta+X* \sin \theta) - SQRT \{ (Z^2 \sec^2 \theta+X^2* \sin^2 \theta) \} + Z \tan \theta \]

(8)

Any shot or receiver position located to the right of point $B$ can be ray traced at surface, e.g. $R$ could be ray traced “virtually” only on $S$. The solution obtained by equation (6A) correspond to this situation.
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It can be further simplified as

\[ CQ = \frac{Z \cdot (\sin^2 \theta - \cos^2 \theta)}{\sin^2 \theta} - \sqrt{\frac{Z^2}{\sin^2 \theta} + \frac{X^2}{4}} \]  

(8a)

For a zero offset trace where \( X = 0 \), the migration aperture becomes \( CQ = Z \tan \theta \), which is well known calculation adopted for post stack migration aperture. The eqn. (8) do not take care of refractions at preceding layers as is the case of post stack migration aperture calculation. In the Table 1 aperture calculations are shown. Fig. 7 illustrates migration aperture for 10° & 30° dips. It is interesting to note a low in the curves, i.e., initial decrease in migration distance with increasing depth and then increase of the same with the depth.

Table 1: Aperture Calculation

<table>
<thead>
<tr>
<th>Dip Angle</th>
<th>Depth of Interset: Z</th>
<th>Offset= 0 M</th>
<th>Offset= 2 Km</th>
<th>Offset= 4 Km</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>3 Kms.</td>
<td>1732 m.</td>
<td>1874 m.</td>
<td>2267 m.</td>
</tr>
<tr>
<td>30</td>
<td>4 Kms</td>
<td>2309 m.</td>
<td>2416 m.</td>
<td>2724 m.</td>
</tr>
<tr>
<td>50</td>
<td>3 Kms.</td>
<td>3575 m.</td>
<td>3735 m.</td>
<td>4173 m.</td>
</tr>
<tr>
<td>50</td>
<td>4 Kms</td>
<td>4767 m.</td>
<td>4888 m.</td>
<td>5232 m.</td>
</tr>
</tbody>
</table>

It is obvious to note that apertures are quite large in case of pre-stack migration than those in post stack migration case. The lower most curves in fig 7, representing the zero offset values, give post stack migration apertures. Significant amount of variations in aperture is being observed from post stack to pre-stack migration requirements. In order to correctly image the target maximum possible value of aperture should be considered. With the help of these diagrams, the minimum and maximum aperture may be calculated on the basis of survey offset ranges, depth of target zones and dip ranges. Depending on the maximum value of aperture obtained for the zone of interest, area of survey may be extended as has been shown in Figure 8.

Simple formulations can be made to decide record length in order to correctly capture the target image. For this purpose we can calculate TWT corresponding to event recorded by S-R pair in Figure 5. From the law of cosines, the two way time \( T \) for the ray path shown in figure can be written as-

\[ V^2 T^2 = 4 \cdot (SN)^2 + X^2 - 4 \cdot (SN) \cdot X \cdot \sin \theta \]  

(9)

\( V \) is the average velocity up to image point.

In \( \rho \),

\[ SN / TS = \sin \theta \]

\[ SN = (TR + X) \cdot \sin \theta \]

\[ SN = (PI/ \sin \theta - RP + X) \cdot \sin \theta \]

substituting the values from equation 4

\[ SN = PI - RP \cdot \sin \theta + X \cdot \sin \theta \]

In \( \rho \),

\[ QI/PI = \cos \theta \]

the above equation can be re-written as

\[ SN = QI / \cos \theta - RP \cdot \sin \theta + X \cdot \sin \theta \]

\[ SN = Z \sec \theta - RP \cdot \sin \theta + X \cdot \sin \theta \]

Substituting the value of \( RP \) from equation 7 and simplifying, it can be re-written as

Survey area extended by maximum apertures at deeper end and minimum aperture at shallower end both in downdip direction. Thus theoretically CD should be appropriately survey zone with full fold, but due to software constraints traces below present up to B to receive migrated events. To avoid edge effects at B, area should be extended upto D. The survey area with full foldage becomes CD. However foldage may be slightly less between B’ & D’.
SN = (\(Z \sec \theta + X \sin \theta\) + \(\sqrt{Z^2 \sec^2 \theta + X^2 \sin^2 \theta}\))/2

With the help of equations 9 and 10, value of VT for the image point I can be calculated in terms of Z, \(\theta\) and desired far offset X, and with the help of average velocity up to target image the value of two way time can be estimated. Calculated values of TWT for an average velocity of V and a range of offsets and target depths, a nomogram has been prepared in Figure 9.

The value of two way time calculated from such nomograms shall suffice requirements of NMO correction as well as vertical component of pre-stack migration aperture, provided full zone of target image is scanned.

So far in our discussions, we have considered repositioning of reflection points only, now the discussions may be extended to include focusing of energy of diffraction hyperbolas. A zero offset diffraction hyperbola has been shown in Fig.10. For proper collapse of hyperbola a migration aperture equivalent to 30 degree point in the curve is minimum requirement. During processing of any seismic data, aperture must be set to this 30 degree value, even in case of flat reflectors. Normally, this 30 degree point is taken on zero offset diffraction hyperbola, but some consideration for non-zero offset diffraction hyperbola is also required. However, if the geological dips are greater than 30 degrees, aperture must be calculated as per the geological dip values. But for the purpose of survey extension calculations, absence of any diffractor source near boundaries may give advantage of limiting the extensions by actual dips. This may curtail survey expenditures significantly.

Equations (8) and (9) may be used to calculate values of “D” and “T” (Fig.10) on diffraction hyperbola, for all values of shot-receiver offsets and thus final aperture calculations may be made for survey area extensions and record length calculation, if diffractions are present near boundary of the image area. It will be advisable to extend the survey area by a minimum value equivalent to Fresnel Zone for amplitude preservations and spatial resolution. Nomograms given in figures 7 & 9 may also be used for such calculation.

**DISCUSSION**

The discussion may be summarized as follows:

- Note that the Z value taken is at the image location and not at CMP location at that offset.
- Maximum value of shot-receiver offset must be considered for calculation of dislocation of a reflected event and also for the estimation of areal extent of diffracted energy while deciding upon the migration aperture. For this purpose formula and nomograms presented here may be utilized.
- If diffraction sources are not available near the boundaries of image zone, survey area may be extended on the basis of geological dips only.
- If diffraction sources are available near the boundary of image area and geological dip is less than 30 degree, survey area may be extended both updip and downdip on basis of distances involved for 30 degree point on the diffraction legs including nonzero offset’s hyperbolas.
- If diffraction sources are available near the boundary of image area and geological dip is more than 30 degree, survey area may be extended in updip direction on the
basis of distances involved for 30 degree point on the hyperbola; and in downdip direction on the basis of geological dip and maximum value of event dislocation for highest offset.

- In case of flat geology, survey area may be extended by a value equivalent to radius of first Fresnel Zone.
- Recording length may be decided on the basis of 30 degree point on the hyperbola and vertical component of aperture of reflecting point for maximum value of offset.

CONCLUSION

Conventional calculations of post stack migration aperture for extending the survey area, do not suffice the requirements of pre stack migration requirements. Horizontal component of movement of the events from one CDP trace to actual CRP trace is larger than what we anticipate for migration of zero offset section, it varies with offset, depth and dip values. For correct imaging in the complex geological setups, it is to be ensured that image points and diffraction energy from the fringe parts of the target zones are captured with full range of offsets while recording.

ACKNOWLEDGEMENTS

The authors are thankful to Sri D.P. Sinha, DGM (GP), ONGC for his guidance and support. They extend their gratitude to Sri M.B. Singh, GM(GP) for his encouragement and fruitful discussions offered during the course of the work. Authors also state that views expressed here in are theirs and do not necessarily reflect the views of organization, they belong to.

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