APERTURE WIDTH SELECTION CRITERION IN KIRCHHOFF MIGRATION

Richa Rastogi, Sudhakar Yerneni and Suhas Phadke
Center for Development of Advanced Computing, Pune University Campus, Ganesh Khind, Pune 411007, India

ABSTRACT

The Kirchhoff migration provides a representation of seismic data as a summation of diffraction amplitudes along the diffraction hyperbolas govern by the RMS velocity at their apex time sample. Spatial extent of the diffraction hyperbola for an input trace at a particular time sample plays a crucial rule in the practical implementation of Kirchhoff migration. The spatial extent that the actual summation path spans is called as *migration aperture* or *aperture width*. In this paper, we investigate three different selection criterion of aperture width function of time and its affect on 2D post-stack migration. These three methods are *viz.* constant aperture method, maximum horizontal displacement method and diffraction amplitude cutoff method. All the methods have advantages and disadvantage. After investigating and testing all of them, the last method is found to be the best among three as it is efficient.

INTRODUCTION

Seismic migration or "migration" is a special processing of seismic data that maps the dipping events to their true geological locations and collapses the diffractions at the discontinuity points. It is widely used as an indispensable tool for geological interpretation of seismic sections. Kirchhoff migration is one of the popular techniques of migration, which is based on diffraction summation approach.

In Kirchhoff migration, the diffraction hyperbola is collapsed by summing the amplitudes along the hyperbola, then placing it at its apex. The aperture width used for the amplitude summation is an important parameter that affects the performance of the Kirchhoff migration. Given the RMS velocity, v_{rms} at a particular time sample t(0) of a particular output trace, a diffraction hyperbolic path is overlaid on the input section with its apex at corresponding time sample. Equation of hyperbola is

$$t^2(x) = t^2(0) + \frac{4x^2}{v_{rms}^2}$$

where, x is the distance from the output trace location to that of the input trace location and t(x) is the input time computed.

In theory, diffraction hyperbolas extend to infinite time and distance. In practice, we have to deal with truncated hyperbolic summation paths. The spatial extent of the actual summation path span or aperture width is measured in terms of the number of traces the hyperbolic path spans (Yilmaz, 1987).

The curvature of the diffraction hyperbola is governed by the velocity and time. A low velocity hyperbola has narrower aperture when compared to the high velocity hyperbolas (see figure 1a and 1b). Diffraction hyperbolas have different curvatures at different times (see figure 1a and 1b).

This discussion leads us to a conclusion that we require an aperture as a function of velocity and time (see figure 1c). In due course of this paper, we will see the effects of a constant aperture with time on the 2D post-stack results of a synthetic data set. Then we will discuss two other methods of calculating aperture function and their results. Second method is based on horizontal displacement of the events that takes place in migration, depending upon the maximum dip in the section and its medium velocity. Third approach is based on the diffraction amplitude of the source, placed at the reflecting interface that dies down as we move away from the source.

It is recommended to use same aperture width function over the entire data set from one area so that an overall uniformity in amplitude characteristics on migrated section can be maintained (Yilmez, 1987).

CONSTANT APERTURE WIDTH WITH TIME

From the above discussion, we know that the aperture width is measured in terms of number of traces, the hyperbolic path spans (Yilmez, 1987). In a constant aperture-width, the hyperbolic path span for summation remains same for all time levels.

There is no fixed rule for deciding a constant aperture width. Any number of traces can be taken as aperture width or we can take the traces according to the maximum horizontal displacement that takes place in migration.

Constant aperture width method is applied on a 2D post-stack line of SEG/EAGE Overthrust Model (1997). The small aperture width migration (half-aperture 5 traces) has caused smearing in the deeper portion of the section (see figure 2a). This smearing effect has destroyed the dipping events and produced spurious horizontally dominant events. Smearing gradually disappears as we increase the aperture width (half-aperture 20 traces). On the other hand, we can see that large aperture has caused the degradation of migration quality in shallower region and added noise to good shallow data (see figure 2b).

In conclusion, the following assessments can be made regarding the choice of aperture width.

1. A small aperture width causes suppression of steeply dipping events and rapidly varying amplitude changes. It gives rise to random noise, especially in the deeper part of the section; they are horizontally dominant spurious events.

2. A large aperture degrades the migration quality in the shallower region if the signal to noise ratio is poor. Suppose deeper data in the section is noisy then large aperture will cause noise to creep into the good shallow data. The large aperture also increases the computation time.

So we can say the aperture width is always a compromise with noise. One reason of this type of behaviors of migration with constant aperture with time is that as the time increases the RMS velocity also increases. Therefore, the hyperbolic paths become flattened in time and extended in spatial dimension as seen in the Figure 1c. The summation using smaller aperture includes only the traces near the apex portion of the diffraction hyperbola, where the dip is nearly flat. Hence, the smaller aperture pass only the flat or nearly flat events and we lost the high velocity dipping events at the later times (see figure 2a). Large aperture width at the earlier times causes summation of amplitudes form far of the hyperbolic path spans. It enhances the energy of the reflection of shallow reflectors largely in the form of superposition of a number of semicircles and degrades the quality of the migration near to the surface and below (see figure 2b). To overcome this problem we are required to have an aperture function, which can incorporate the shape of hyperbolic summation paths that changes with the increase in RMS velocity and time.

HORIZONTAL DISPLACEMENT OF EVENTS DURING MIGRATION

With reference to Yilmez, aperture width is closely related to the horizontal displacement that takes place in migration. For any given time the optimal value for the aperture width is defined by twice of the maximum horizontal displacement in migration for the steepest dip of interest in the input section. The formula for calculating horizontal displacement at a particular time t is

$$D_x = \left(\frac{v^2 * t * \tan\theta_t}{4} \right)$$

Dx is the horizontal displacement in the migration of a point in the subsurface in meter, v is the medium velocity in meter/seconds, and $?_t$ is the apparent dip of the reflector as seen on the unmigrated section. Here, $\tan\theta_t$ = ?t/?x, as measured on the unmigrated time section. Where, ?t is measured in seconds and ?x is in meter i.e., number of traces multiplied by trace spacing.

In order to get an aperture-width function varying with time, the above formula can be written as below. For velocity function, we take the average of the interval velocity at each time step of the input section. The horizontal displacement is calculated at each time step t (i) considering the maximum dip of interest in the input section as below.

$$D_x(i) = \left(\frac{v_{ava}^2(i) * t(i) * \Delta t/\Delta x}{4} \right) / \mathrm{delx}$$

Where, i is the time level at which we want the maximum horizontal displacement in terms of number of traces the hyperbolic path spans for summation, delx is the trace spacing. The aperture width at any time level i is given by

A (i)=2*Dx(i) + 1

A test of constant aperture width is applied on 2D post-stack line of SEG/EAGE Overthrust Model (1997) . The calculated horizontal displacement near the surface is very small i.e., less then the trace spacing itself and very large near the basement. In order to make this formula realistic instead of only being theoretical, we defined two parameters lower time cutoff and higher time cutoff. The lower time cutoff is the time near the surface before which, migration required is less. The higher time cutoff is the time level near to the basement after which, not much migration is required. Our aperture width formula is calculated between these two time levels, continued upward and downward as it is for these upper and lower limits. The graph in figure 4 shows the half aperture-width function and other parameters required for its calculation, like lower time cutoff, higher time cutoff and dip parameters.

The result of 2D post-stack migration using above function is given in Figure 3. We can see the difference of the migration results from constant aperture width and a vertically varying aperture width function. The noise at the shallower level is reduced, the deeper events also have become clear then before and diffractions are died down to a certain extent.
There are some practical problems in this type of approach like,

1. If the input section is a noisy data then it is difficult to decide over the maximum dip parameter and every time we have to give this parameter manually to the migration code. We have to choose the steepest dip very carefully as this algorithm gives error onus results over high dips.

2. We have to examine the input section very carefully for lower and upper time cutoff's. It is also a crucial issue to suppress noise in the upper and lower section of sections and for clarity of deeper events. These parameters also have to be supplied to the migration code.

So we can say that this approach is better then the previous one but have its own practical problem. Everything is depending on input data and our judgment.

DIFFRACTION AMPLITUDE CUTOFF

This approach is based on the basic assumption made in Kirchhoff migration i.e., reflecting interfaces in the subsurface are replaced by points (Schneider, 1976). These points act as Huyguns' secondary sources and produce hyperbolic travel time curves. As these sources get closer to each other, superposition of the hyperbolas produces the response of actual reflecting interfaces. These hyperbolas are equivalent to diffractions seen at a fault boundary on stacked section. These diffractions die down as we move away form the source location (Yilmez, 1987).

Using this fact, we can decide aperture width in Kirchhoff migration at a particular time level and location in the subsurface. The spatial extent for hyperbolas for summation can be till the point where amplitude drops down to a certain percentage to that of its initial value at its apex.

Berryhill(1997) and Trorey (1977) discussed the diffraction response for a non-zero source and receiver spacing for a vertical fault in a constant velocity medium and gave a formula (Phadke 1989; Berryhill 1977; Trorey 1977).

We make use of the same formula for aperture-width calculation in 2D post-stack Kirchhoff migration. The fault edge is replaced by a point source placed on the reflector interface and its diffraction response is calculated in the profile direction. For a coinciding source-receiver type set up, the source and receiver separation is made nearly zero. The distance this setup moves each time is equal to the trace spacing. The diffraction amplitude is calculated for each move at different time steps. In order to get an aperture width function of time we use vertical velocity function v(t). We take the average of the interval velocities at each time level. We stop calculation of the amplitudes, as it becomes 50 to 10 percent (as desired) to that of the initial amplitude at migration location. This distance is the spatial extent to truncate the hyperbolic path span.

The graph of percentage ratio of diffraction amplitudes of the point diffractor at a distance from the output location to that at output location itself versus the distance from the output location is shown in Figure 7 for various depths of the point diffractor. The amplitude drop for shallow diffractor is more rapid as compared to that for deep diffractors.

The hyperbolic path's lateral extent can be decided on the bases of amplitude percentage at a certain distance from the output location. This distance is divided by the trace spacing to get the half aperture width at a particular time level. The full aperture width at a particular time level is twice of the half aperture width plus one. The number of traces in the aperture width increases as the time increases. In this way, we are preserving the trend of hyperbola's shape, which changes with the increase in the velocity and time. We have a narrow aperture near the surface and wider aperture near basement.

The 2D post-stack migration results using this aperture-width function are shown in Figure 6. The aperture function may vary with the choice of amplitude percentage cutoff. The graph showing different half aperture-width function is shown in Figure 5 for different diffraction amplitude percentage cutoff. The computation time increases as the amplitude cutoff decreases. We can also decide over the distance that we want to look for a certain amplitude percentage cutoff. It is found that for 2D post-stack migration, it is good to use 30 to 10 % diffraction amplitude cutoffs (see figure 6). The deeper events are mapped very sharply in section using 10 percent of amplitude cutoff.

However, in the shallower level we see some noise. On the other hand, the migration using 50 % amplitude cutoff shows less noise in the shallower levels but the deeper event are merging with each other and event boundaries are not clearly mapped. In the section , using 30 % diffraction amplitude cutoff the noise in the shallower region is reduced as well as the deeper events have been mapped clearly.

CONCLUSIONS

In this paper, we have investigated three different criterion of aperture width selection for Kirchhoff migration. The constant aperture width is not appropriate to use for migration, as it doesn't account the effect of time and velocity on the hyperbola. The aperture width function based on horizontal displacement in migration, is a good approach but has its own practical problems as discussed earlier. It needs more inputs, which require careful judgments of input section. The last approach of aperture width calculation is more practical and gives good results. It is based on the diffraction amplitude cutoff percentage at a distance from the migration location. It is found that the diffraction amplitude cutoff percentage affects the performance of the Kirchhoff migration. The less diffraction amplitude cutoff percentage (30 to 10 %) gives good results. Keeping in view the noise in the shallower section and clarity of the events in deeper section, we recommend 30 % diffraction amplitude cutoff (see figure 6b). As this percentage decreases the computation time increases. This work can be extended for 2D prestack, 3D prestack and poststack Kirchhoff migration.

ACKNOLEDGEMENT

Authors wish to thank C-DAC, Pune, for providing computational facility and permission to publish this work.

REFERENCE

1.Berryhill, J. R., 1997, Diffraction response for nonzero separation of source and receiver, Geophysics, 42, 1158-1176.

2.Phadke, S., 1988, Imaging crustal diffraction zones and seismic tomography, Ph.D Thesis, Department of physics, University of Alberta, Edmonton, 65-71.

3.Schneider, W., 1976, Integral formulation for migration in two and three dimension, Geophysics, 43, 49-76.

4.SEG/EAGE 3-d modeling series No. 1, 1997, 3-D salt and overthrust models, SEG publications.

5.Torey, A., W., 1977, Diffractions for arbitrary source-receiver locations, Geophysics, 42, 1177-1182.

6.Yilmez, O., 1987, seismic data processing, Society of exploration geophysicits.

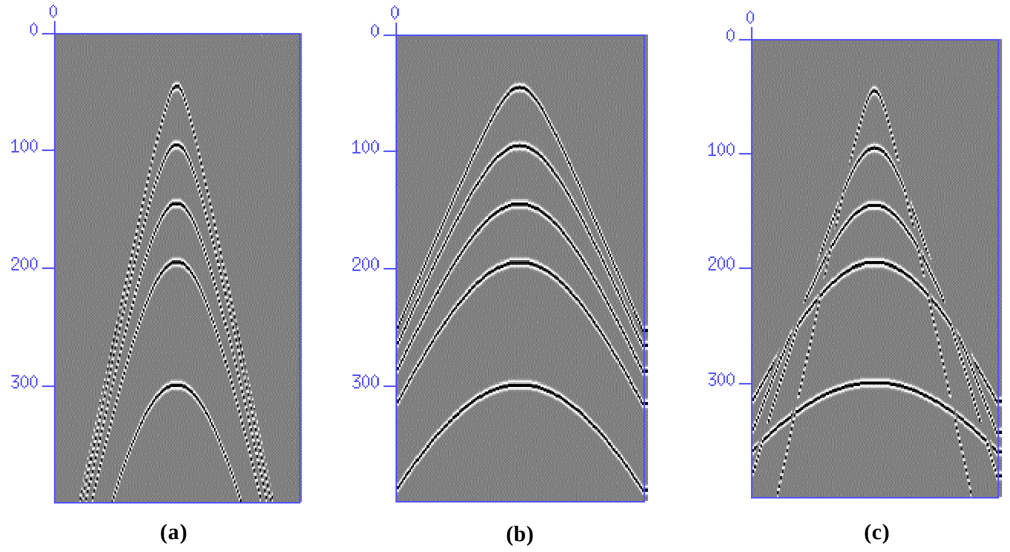
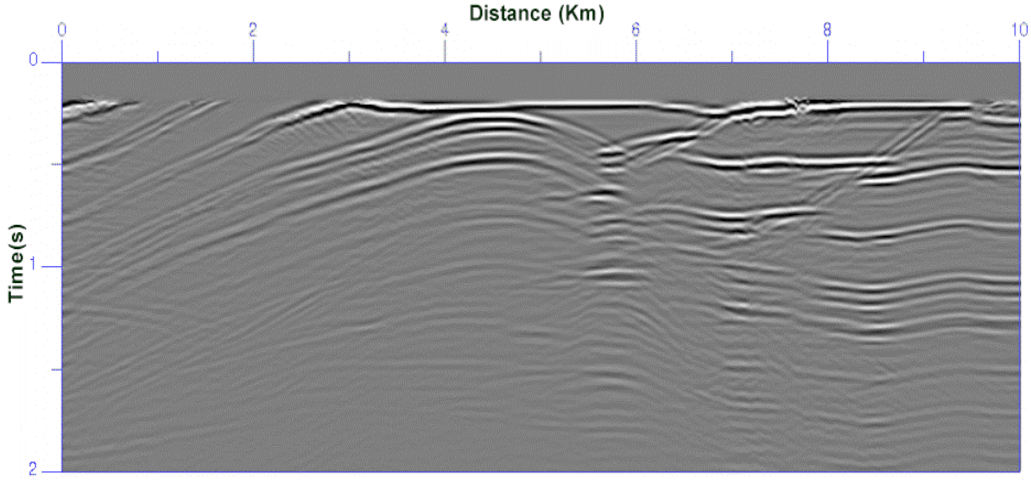
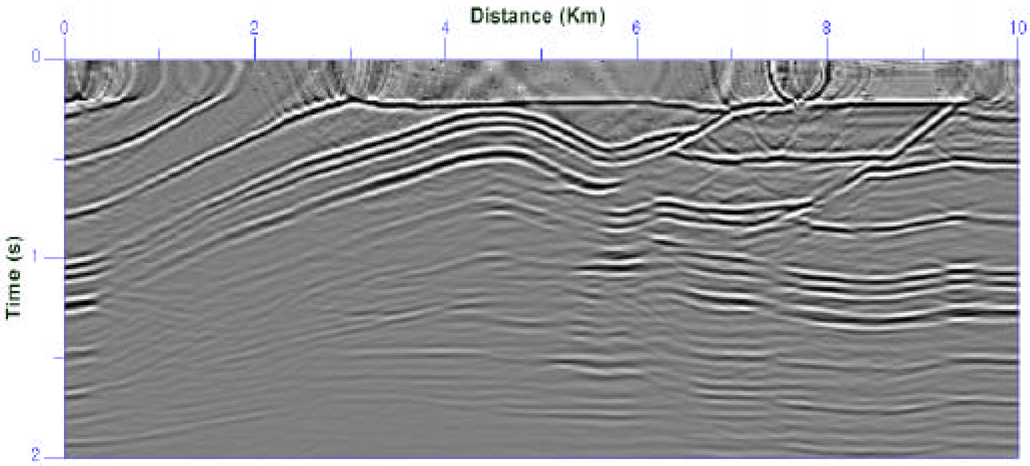


Figure 1. Summation paths for Kirchhoff migration in a medium with (a) low velocity (2000 m/s). (b) high velocity (4000 m/s). and (c) vertically varying velocity. Aperture width is small for low velocities and large for high velocities.



(a)



(b)

Figure 2: Test of constant aperture width in Kirchhoff migration (a) 5 traces (b) 20 traces (half aperture-width).

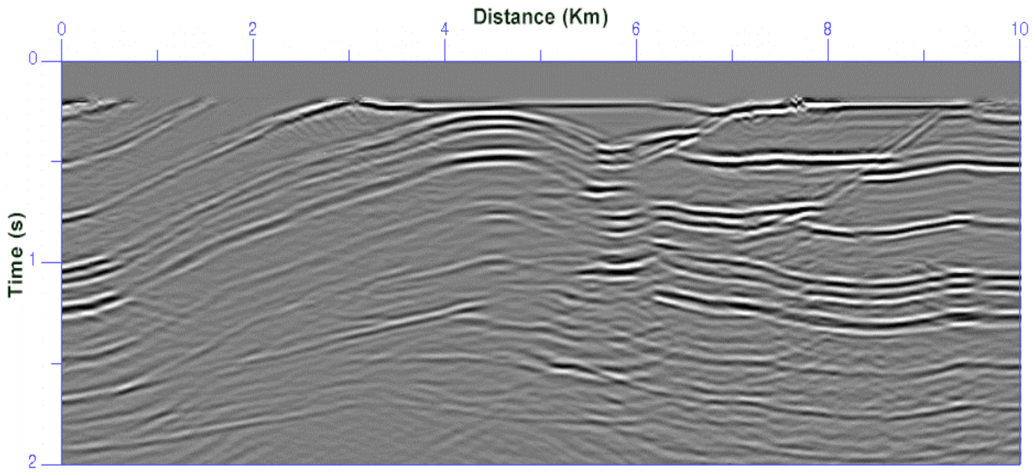


Figure 3. Test of aperture-width function based on horizontal displacement in Kirchhoff migration.

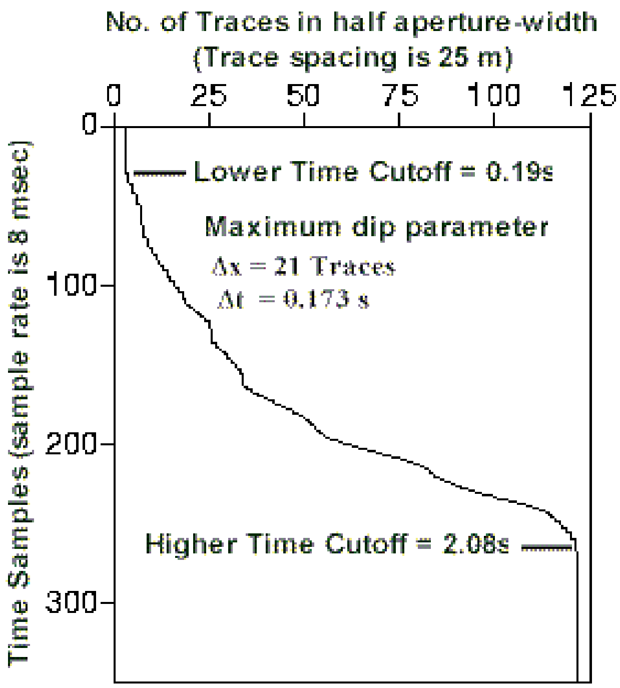


Figure 4: The graph of aperture-width function based horizontal displacement takes place during migration.

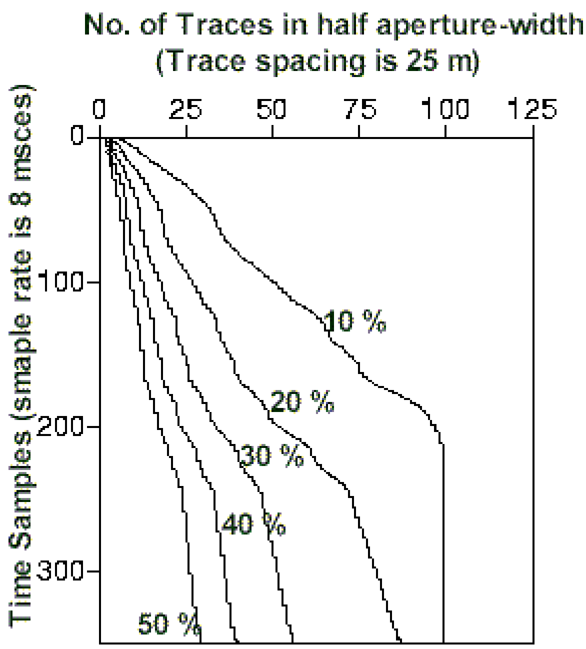
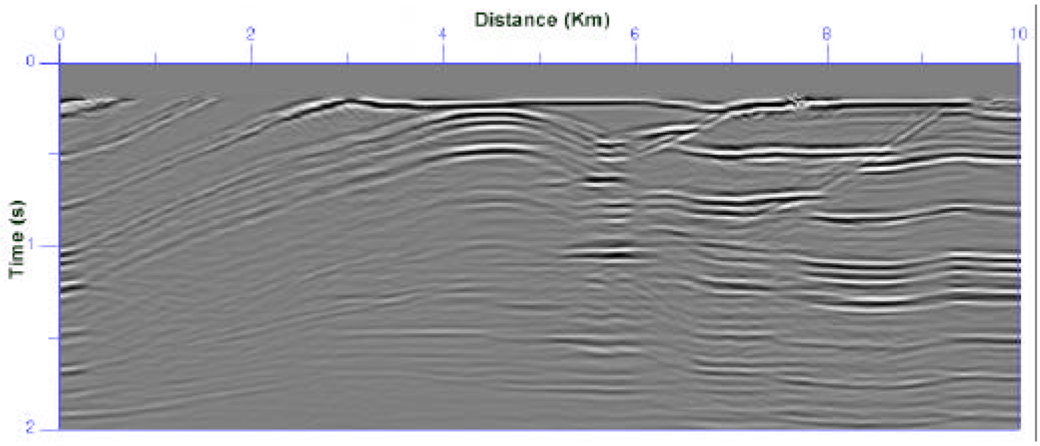
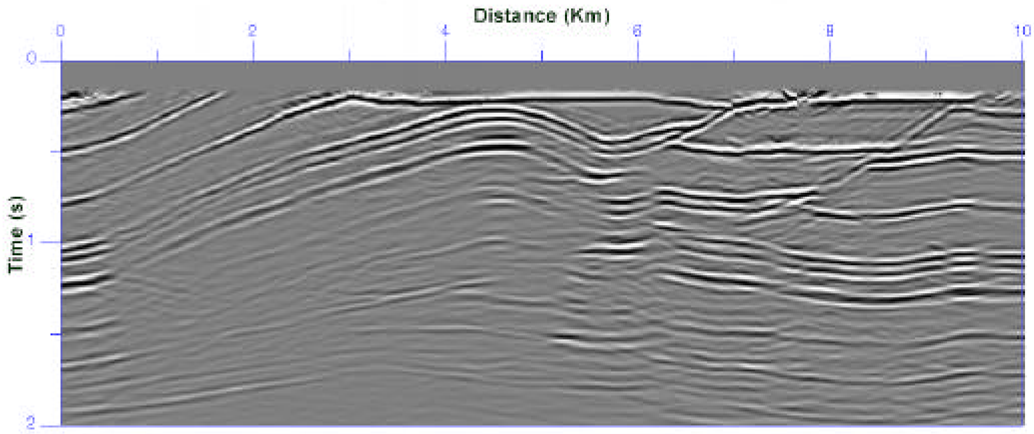


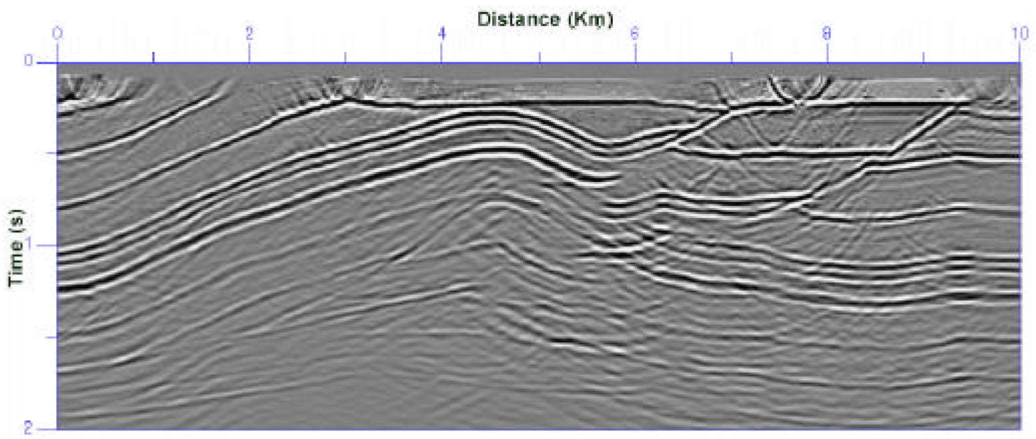
Figure 5: The graph of half aperture-width function of various percentage of diffraction amplitude cutoff ratio.



(a)



(b)



(c)

Figure 6. Test of aperture-width function based on various diffraction amplitude cutoffs in Kirchhoff migration (a) 50 % amplitude cutoff (b) 30 % amplitude cutoff and (c) 10 % amplitude cutoff.

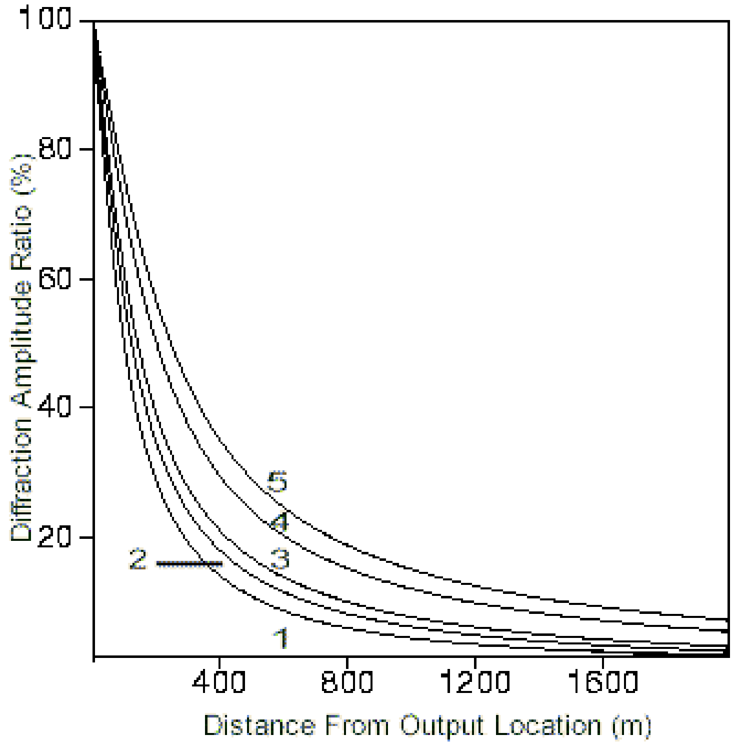


Figure 7: The graph of percentage ratio of diffraction amplitudes of the point diffractor at a distance from the output location to that at output location versus the distance from the output location for various depths. **1**. 500m **2**. 750m **3**. 1000m **4**. 2000m **5**. 3000m.