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Duplex Wave Migration and Corner Reflector Approximation

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SUMMARY

Two techniques for imaging of sub-vertical boundaries were studied. The first technique is a simplified approach and based on a corner reflector property which allows to create a zero-offset gather for focused duplex waves. The second technique is a duplex wave migration based on Kirchhoff integral. It was shown that even small deviation from a vertical direction of a corner reflector (by 10 degrees in our case) will result in that the processing with a simplified technique may lead to a wrong interpretation. We also showed that simplified processing of duplex waves generated by corner reflectors may not be applied to a general case of PSS duplex wave.

Introduction

For imaging of vertical boundaries such as salt dome walls, high permeability corridors, low-amplitude faults, etc., duplex waves have been applied recently. (Khromova et al., 2010, Farmer et al., 2006, Malcolm et al., 2011). Duplex wave is a result of two reflections: the first reflection is at sub-horizontal boundary, and the second is at sub-vertical boundary (or vice versa) and recorded at the surface. This allows to obtain information on strike, direction and acoustic properties of sub-vertical boundary from land seismic data. Various Duplex Wave Migration (DWM) algorithms are used for this purpose. One of them is a DWM approach based on Kirchhoff integral (Marmalyevskyy et al., 2006). For calculation of Green's functions, this approach uses both depth-velocity model and sub-horizontal boundary which is a reflector of a duplex wave.

Subject to acquisition geometry, this approach is able to create seismic images of sub-vertical boundaries in a dip range of 70 - 90 degrees. It is important that DWM method does not require a mirror reflection from sub-vertical boundary. This could be a scattering zone like irregular boundary with variable dips and acoustic properties which often occurs in nature.

Another possibility for obtaining information on sub-vertical boundaries is an approximation of duplex wave reflector with corner reflectors (Kozlov et al., 2009). In a simple case, the corner reflector is a couple of orthogonal reflectors. In 2D case, such reflectors bounce wave back to its source. In 3D case, it occurs only when a wavefront plane is perpendicular to a vertical boundary. Data processing to determine information about the sub-vertical boundary is getting much simpler in this case. Particularly, this is due to the fact that it is easy to trace zero-offset rays with duplex wave energy concentrated along travel times of wave diffracted from the point of intersection of vertical and horizontal boundaries of a corner reflector. On the other hand, the properties of diffracted wave created by some diffraction zone will be different from those created by corner reflector, and this helps to discriminate one case from another. This may be extremely important for some practical problems.

However, it is important to understand the limitation of approach based on corner reflectors. In (Kozlov et al., 2009) it is pointed out that lateral velocity variations and non-vertical reflectors affect the main properties of corner reflectors. In this paper we present examples of comparison between corner reflector and based on Kirchhoff integral DWM techniques. In particular, we demonstrate the effect of small deviation of reflector dip from vertical direction on possibility to obtain the sub-vertical boundary parameters, when stronger reflections from horizontal boundaries exist.

Imaging methods

The easiest way to represent the duplex wave is using imaginary source S* of such wave. As it was stated above, there are two types of duplex wave: HV, when wave is reflected at the horizontal boundary first, and then at the vertical boundary, and VH, when ray chart is reversed – first reflection is from vertical boundary, then from horizontal. To create an imaginary source S* for duplex HV-wave, it is necessary to create two imaginary sources consecutively: first for the horizontal boundary S^h, and then a source S^* is created from S^h as a reflection from the vertical boundary. If the boundaries do not deviate from vertical and horizontal, the imaginary sources for HV and VH will be the same.

Fig.1 shows imaginary source S* creation chart. This illustrates that outgoing wave from imaginary source passing through the intersection of vertical and horizontal boundaries O is returning to its true source S, and this is a typical property of a corner reflector. If a pair of orthogonal boundaries is rotated about point O, the property of ray retuning to its true source point will be the same. Thus, it will be easier to create an imaginary source S* by just extending straight line between S and O further to a distance equal to SO.

If the source S is at common midpoint location, than the next source S_1 which creates input to a common midpoint will place the imaginary source at S_1*. It will be shifted to the same distance as the receiver which creates input to this CMP. Thus, the length of S*S will be the length of S_1*S_1. One of the major properties of corner reflectors is a horizontal travel time curve specific for a duplex wave. Moreover, this property is true not only for non-converted waves like PPP, but also for converted PSS waves in case of fully vertical reflecting boundary.

Figure 2a shows model consisting of a horizontal boundary and a low-velocity vertical layer. Essentially it is a corner reflector. Figure 2b shows common shot gather generated by full-wave elastic modelling. Red arrow indicates compression PPP wave, and yellow arrow indicates converted PSS wave. Other converted duplex waves are also visible. Figure 2c shows CDP trace gathers where duplex PPP wave (red arrow) and PSS wave (yellow arrow) reflections are horizontal . Small deviations of a duplex wave traveltime curve from a horizontal line are caused by post-critical waves generated on a horizontal boundary.

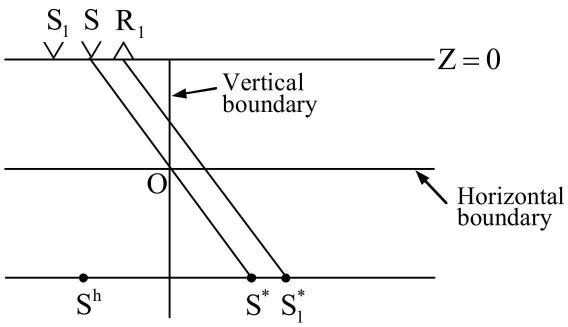
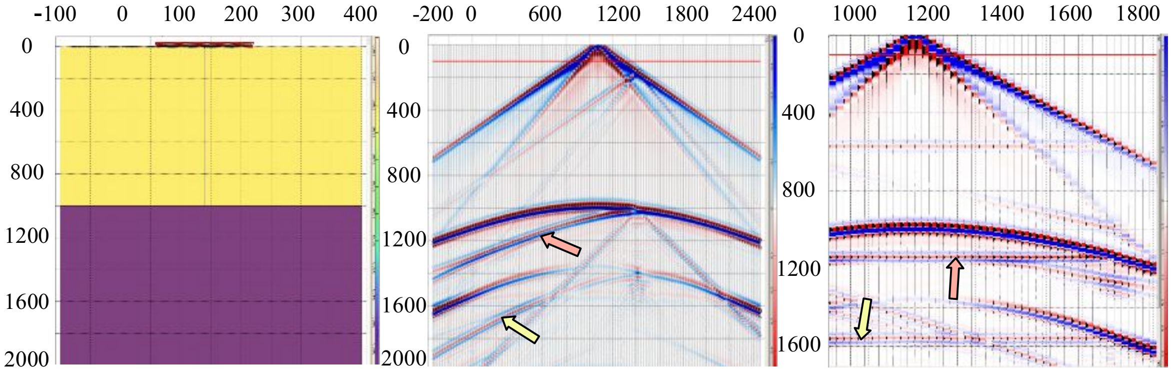


Figure 1. Duplex wave imaginary source creation chart.



a b c

Figure 2. Model-1 (a), common shot gather (b) and CDP gather (c).

The simplest method for focusing duplex waves which uses this property of corner reflector is stacking of seismic traces for one CDP without NMO correction. Such stacking creates a zero-offset gather for duplex waves where reflections from horizontal boundary are attenuated, and duplex waves are amplified by stacking the same phase waves. Kinematically focused duplex compression PPP wave is formally a result of diffraction from the intersection point of vertical and horizontal boundaries. Further focusing of duplex wave as an image of diffraction point is performed by conventional migration (Tverdohlebov, 2011). The difference is that if DWM is applied, it will create an image of sub-vertical boundary.

Synthetic data processing results

Fig. 3a shows zero-offset gather for duplex wave obtained with the above method for a model in Fig. 2. Fig. 3b shows focusing of duplex wave into diffraction point for compressional wave. Fig. 3c shows an image of a diffraction point for converted duplex wave. The image of PPP diffraction point for PPP duplex wave is much better than that for PSS duplex wave. The reason for that is that in case of converted wave, this method is unable to create a zero-offset gather. Each CDP has its own offset which is necessary to take into account for migration. If the corner reflector is rotated about the intersection point of the two boundaries, the property of a horizontal traveltime curve for PSS duplex wave is not valid any more for CDP trace gather. DWM of converted waves does not have such limitations. (Marmalevskyi et al., 2008)

Fig. 4 shows an image of a vertical boundary created with DWM. In this case, unstacked data were used, but zero-offset traces may be also used as an input. DWM method provides signal-to-noise ratio (signal – vertical boundary, noise- horizontal boundary) 2-3 times higher than that when processed with corner reflectors technique.

Common reasons illustrated in Fig. 1 show that this imaging technique with focusing duplex waves to diffraction points will also work for VTI anisotropic medium. Fig. 5a shows duplex wave zero-offset gather in case of VTI anisotropic medium with Thompson's parameters ε= -0.2, δ=0.2. Fig. 5b shows duplex wave focusing in anisotropic case.

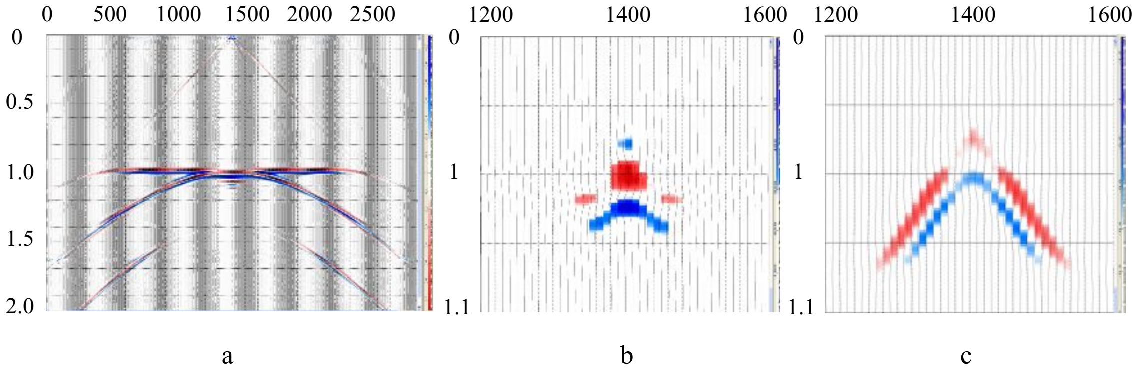


Figure 3. Zero-offset duplex wave gather calculated for model-1 (a), duplex waves focused into image diffraction points for compressional PPP-wave (b), and converted PSS wave (c).

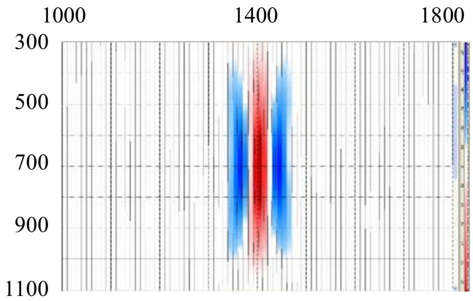


Figure 4. Image of vertical boundary obtained by DWM.

What are the limitations for application of the corner reflector technique? Since it is clear that such limitations exist, each specific case has to be reviewed separately. The most reliable conclusions may be based on modelling. Let us change the model in Fig. 2a by dipping vertical boundary by 10 degrees. Fig. 6a shows this new model. Fig 6b shows modeled CDP gather, and Fig. 6c shows zero-offset duplex wave gather. The last figure shows duplex wave amplitude much smaller than that for reflected wave from horizontal boundary. The shape of computed diffracted wave is also distorted.

Fig. 7a shows migration of zero-offset gather for a dipping boundary case, and Fig. 7b shows DWM results. These figures show that image quality of sub-vertical boundary, obtain by DWM is not getting worse than that for a vertical-boundary case. However, focusing of duplex wave with corner reflector technique appeared to be much worse.

Conclusions

Two techniques for imaging of sub-vertical boundaries were studied. The first technique is a simplified approach and based on a corner reflector property which allows to create a zero-offset gather for focused duplex waves. The second technique is a duplex wave migration based on Kirchhoff integral. It was shown that even small deviation from a vertical direction of a corner reflector (by 10 degrees in our case) will result in that the processing with a simplified technique may lead to a wrong interpretation. We also showed that simplified processing of duplex waves generated by corner reflectors may not be applied to a general case of PSS duplex wave.

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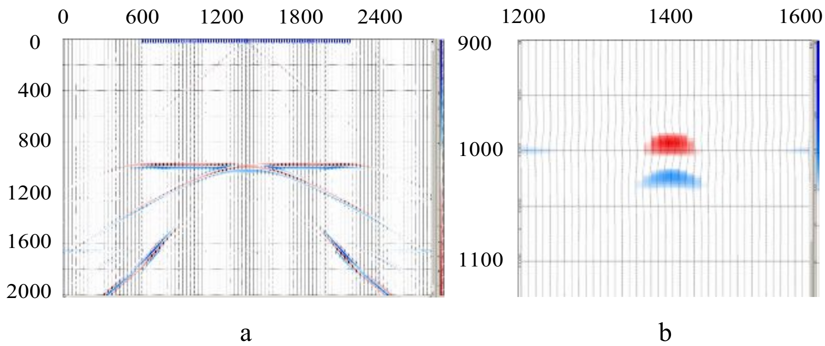

Figure 5. Zero-offset duplex wave gather (a) and duplex wave focused to diffraction points for VTI medium (b).

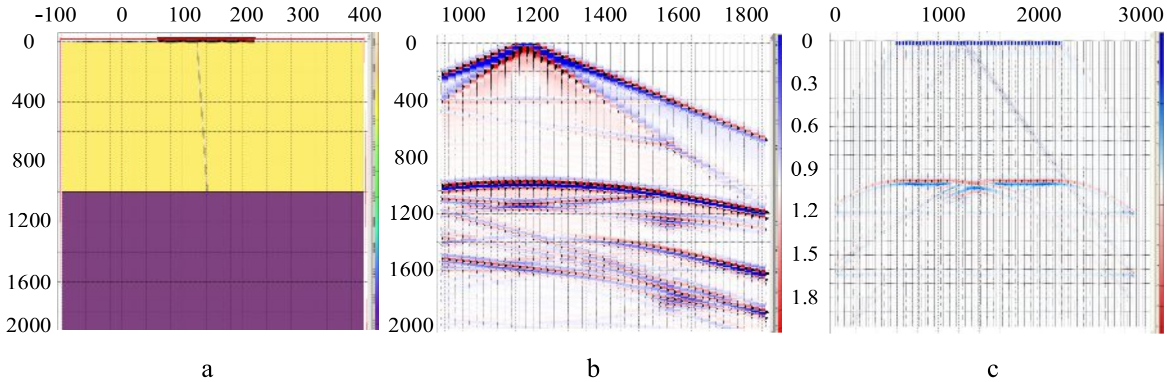

Figure 6. Model-2 with dipping boundary (a), CDP trace gather (b) and zero-offset duplex wave *gather (c).*

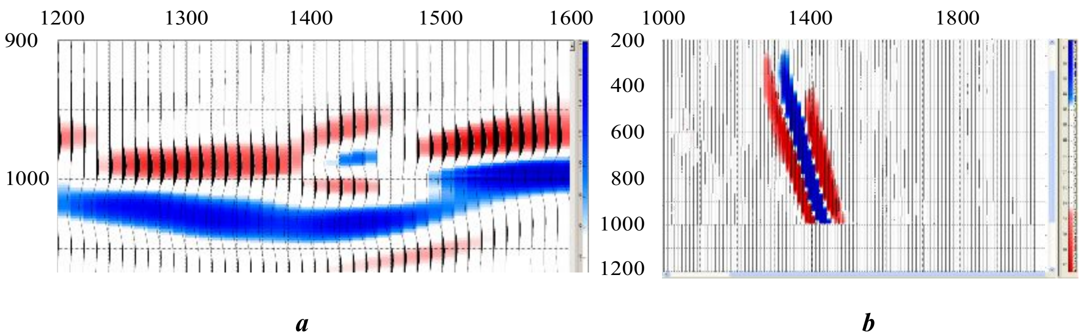

Figure 7. Migration of duplex wave zero-offset traces (a) and migration of duplex waves (b).