

P067

## Steep Dip Imaging Using an Orthogonal One-way Wave Equation Migration

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### SUMMARY

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An orthogonal one-way wave equation migration method is implemented to overcome the dip limitation of a one-way wave equation. Besides the conventional downward propagation of the source and receiver wave fields, an extra propagation along horizontal direction is introduced to eliminate the dip limitation. It is very efficient. The cost is about two times of the conventional one way wave equation migration. It doesn't require additional storage for the temporary files, and doesn't include any other overhead.

The results show an impressive improvement of the steep dip image.

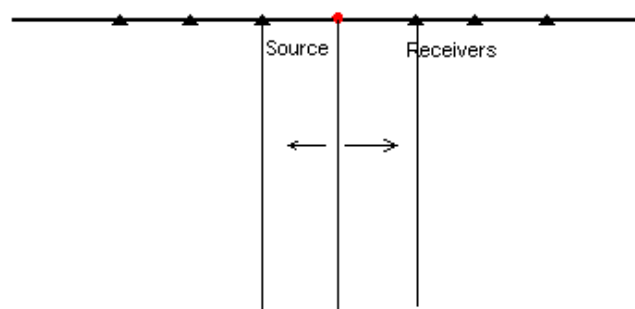
## Introduction

One-way shot gather wave equation migration has become a conventional tool to image complex structures. It is a very efficient method and can produce higher quality images compared to the conventional Kirchhoff pre-stack depth migration. The major issue with it is the dip limitation that it is hard for a one-way wave equation method to image dip angle beyond 65 degree without sacrifice the efficiency. To solve the problem, two-way method is introduced and recently has been a hot spot in development. The two-way method is the best way to image the complex structures, but it costs much more. The computational cost is at least four times higher than the one-way method, not including the huge storage requirement with heavy input/output. A recent trend to reduce the cost is to do a hybrid implementation to combine the one-way and two-way wave equation method into one (Luo etc. 2008, Yoon etc. 2008). An alternative method is to do a two-pass one-way wave equation (Zhang etc. 2006). The wave fields will need to be saved during downward propagation. After propagating to the end, the wave fields will be propagated upward to pick up the turning waves. The cost is about two times of one-way wave equation with the extra cost of saving all the wave fields during downward propagation.

To solve the problem of dip limitation associated with the one-way wave equation, changing the wave field propagation direction is a cheaper way to achieve the same result. Based on the one-way wave equation algorithm, there is no fixed direction to propagate into. The reason to pick the vertical direction to propagate is that it is a nature direction to choose. Theoretically we may choose any direction to propagate the wave fields. In this paper, we propose to propagate in horizontal direction to image the steep dip. Combining the conventional vertical propagation with the newly added horizontal propagation, the dip limitation can be removed.

## Method

The Fourier Finite Difference (FFD) method is used in our implementation. It is a two pass approach. The first pass is the conventional wave equation migration that propagates the wave fields downward. The second pass is to propagate wave fields in the horizontal direction. In a 2D example, the starting source wave field is initialized from the source location. The source wave field propagates horizontally outward from the source in both positive and negative directions simultaneously. When source wave field meets the receiver wave field, it starts to form the image. Figure 1 shows how the process works.



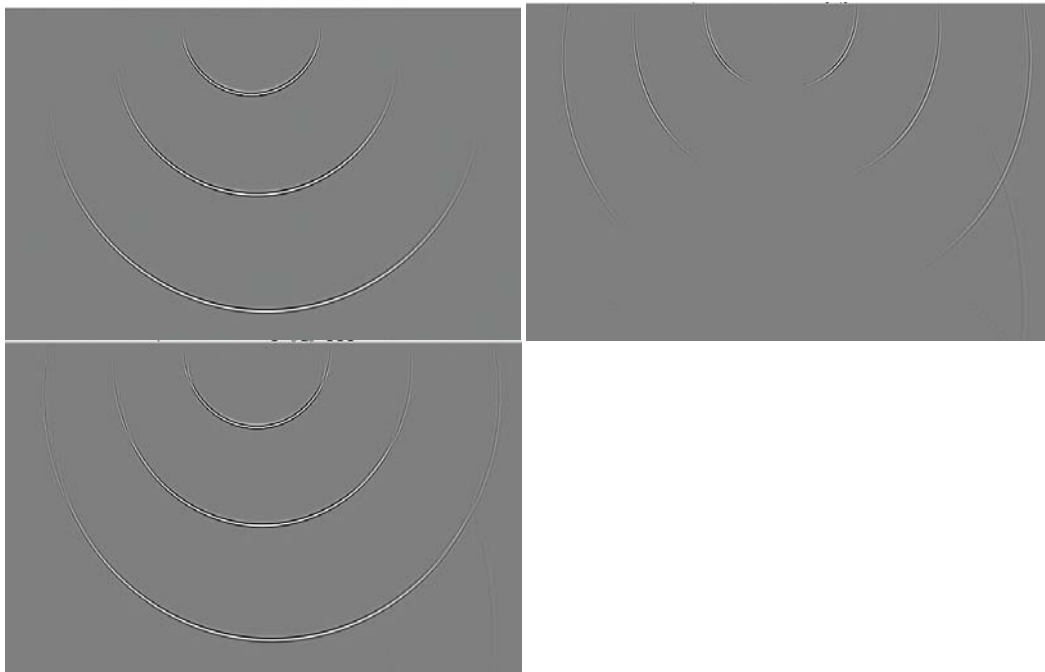
**Figure 1** The source is represented by red dot. The receivers are represented by black triangles. The source wave field is initiated from source plane vertically and propagates to both directions simultaneously. When the source wave field meets with receiver wave field, the image starts to form.

Our implementation of stacking two orthogonal wave fields doesn't require any kernel change. The only change is the propagation direction. It means that this approach is independent to any one-way wave equation migration algorithm.

## Examples

### 2D impulse response

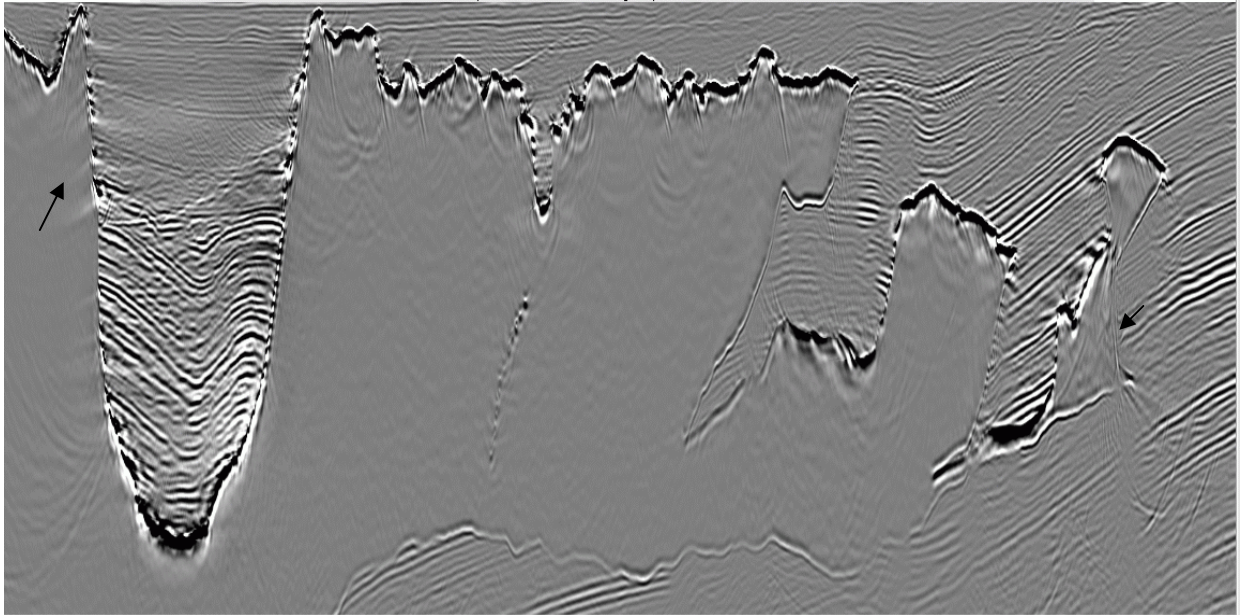
Figure 2 shows a 2D impulse response. It can be seen that the method gives no dip limitation in this approach. The velocity model is  $v(x, z) = 2000.0 + 0.1x + 0.3z$ . The impulses are located in 1 second, 2 second, and 3 second with Ricker wavelets. Figure 2a is the conventional impulse response by one-way FFD algorithm. It shows the dip limitation for higher angle dips. Figure 2b is the horizontal propagation result. It images the steeper dip clearly, but not the near horizontal images. Figure 2c is the stacking of the two images. The combined impulse response shows that the dip limitation is totally eliminated.



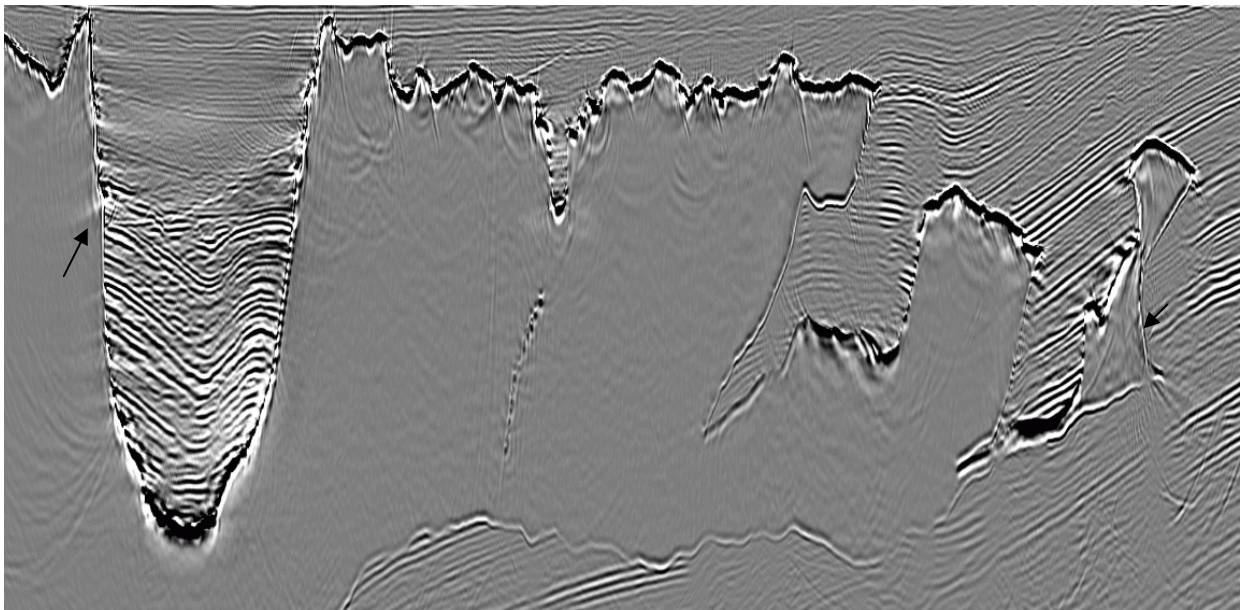
**Figure 2** Impulse response with velocity  $v = 2000 + 0.1x + 0.3z$ . Upper left: Impulse response from conventional FFD one-way wave equation migration. Notice the dip limitation here. Upper right: Impulse response from horizontal propagation FFD one-way wave equation migration. The near vertical image is well imaged. Lower left: Impulse response from orthogonal FFD one-way wave equation migration. It can be seen that the image can go up to any degree of dips.

### 2004 BP 2D Benchmark

The algorithm is applied to the 2004 BP 2D benchmark data (Billette and Brandsberg-Dahl, 2005). The left part of the model represents the rugose salt body with near 90 degree boundaries. Figure 3a is the conventional FFD result, the dip limitation is clearly seen over there. Figure 3b is the migration result using the orthogonal approach we propose in this paper. It can be seen that the better image is shown for the near vertical salt bodies.



*Figure 3a* Migration result from the BP 2004 model using conventional FFD migration. Here only the left part of the result is shown.



*Figure 3b* Migration result from the BP 2004 model using orthogonal one-way FFD migration. The steeper dips are shown clearly.

### Discussions and Conclusions

In this paper, a two-pass orthogonal one-way wave equation migration approach is introduced. The numerical test results are promising. Compared to the more complicated two-pass or two-way approaches, this method is easy to be implemented and more computational efficient. It can be quickly applied to any one-way wave equation method without changing the kernel. It is an easy and efficient alternative. Since the conventional one-way method has been in production for years, this method can be applied in production immediately with confidence.

## **Acknowledgments**

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## **REFERENCES**

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