Modeling of 3D Wave Propagation in Fault Zones − Influence of the Fault's Geometry and its Seismic Properties on the Wave Field

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Summary

An important question in fault zone (FZ) investigations is whether deep FZ structure can be derived from seismograms observed at the surface, especially from trapped waves (FZ waves) which are most sensitive to FZ structures.

Currently, most inversion methods deal with simple FZ models such as 2D fault geometries, a constant FZ width or homogeneous seismic properties.

It is obvious that most FZ can not be described by such models without making significant errors. Thus, knowledge about the influence of 3D fault structure and variations of the seismic properties on the FZ wave field is important to improve current inversion methods.

We perform 3D numerical simulations of wave propagation in seismic fault zones to understand the influence of variable velocity structure and 3D geometry on the recorded seismograms. The algorithm is based on a high−order staggered−grid finite−difference scheme which allows a high flexibility in modifying the model properties.

To understand the influence of parameters such as source location, fault disruption, variation of the FZ shape, inhomogeneities and vertical gradients we modified these properties separately and compared the results to a basic FZ model. Finally, we investigated a more complex model of a continuous FZ that splits up in two segments towards the surface. Such a fault zone is capable of guiding FZ waves in both FZ segments towards the surface. This effect could help to find out whether different fault segments are connected at depth or not.

Strong Influence

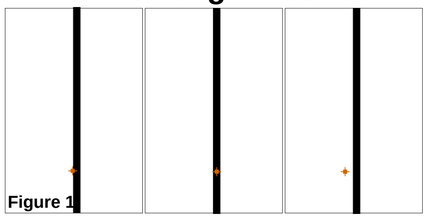


Figure 1

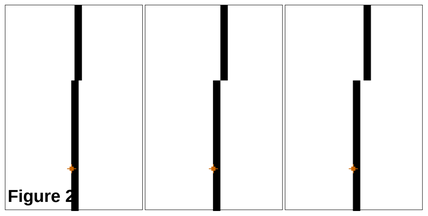


Figure 2

Strong influence on the wave field occurs for variations of the source location (Figure 1) and a disruption of the FZ area (Figure2).
A source located at the FZ boundary (left) generates strong trapped waves, whereas a location within the FZ (center) leads to destructive interference due to the chosen source mechanism. A source located only 1 FZ width outside the FZ (right) leads to weak FZ waves which can not clearly be identified in the seismograms.
A FZ with a lateral disruption of up to one FZ width is capable of guiding FZ waves. For a lateral shift of more than one FZ width only a small portion of trapped energy enters the upper FZ part. Therefore no clear FZ wave arrivals occur in the seismograms.

Moderate Influence

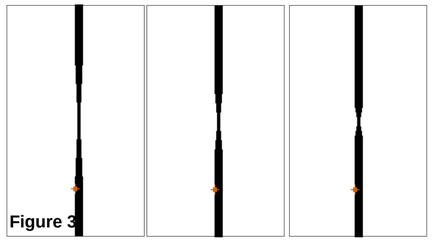


Figure 3

Moderate influence on the wave field is visible for variations of the fault's shape, e.g. a narrowing (bottleneck) of the fault (Figure 3). If the variation of the shape is not too drastic it has minor influence on the FZ wave field. Thus, such structures should be hardly resolvable from seismograms.

Negligible Influence

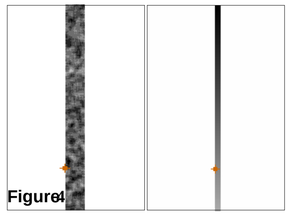


Figure4

An minor influence on the wave field occurs for small scale inhomogeneities and vertical seismic gradients (Figure 4).
Trapped waves in a FZ with small scale variations average out the seismic properties. The seismograms look similar than those of a homogeneous FZ model with average seismic properties. Also seismograms of a FZ model with a vertical gradient can not be discriminated from those generated by a homogeneous FZ model.

Reference Fault

A basic fault (Figure 5) was modeled to be able to separate the effects of the source-receiver positions from the FZ geometry. In all models the source is a double couple with non zero elements $M_{xy}=M_{yx}=M_0$. On the right, velocity seismograms and maximum amplitudes of the y component of FZ waves and direct S waves for three receiver lines orientated perpendicular to the fault are shown. The location of the receiver lines L1-L3 corresponds to Figure 7. The seismograms show that the influence of the receiver position on the FZ wave amplitude is negligible.

Thus, variations of the FZ wave amplitude for different receiver lines in the following models can not be explained by the receiver locations but must originate from the fault structure.

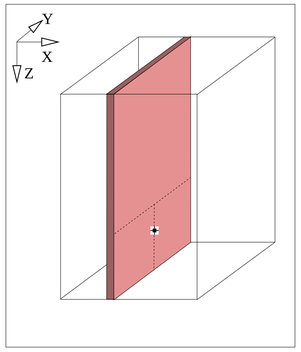
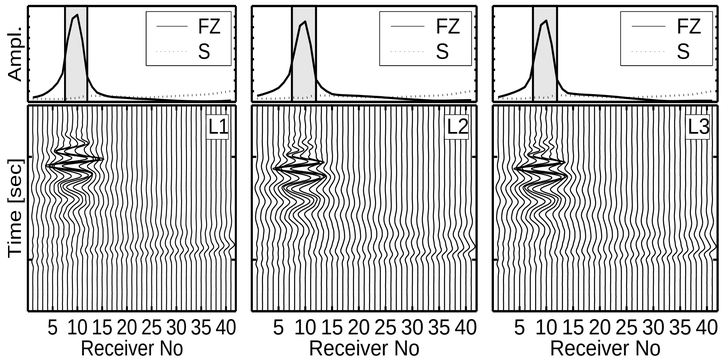


Figure 5



Split Fault − Source Centered

A fault that is continuous at depth and splits up in two segments towards the surface is shown in Figure 6. The source is located in the lower part, where the fault is still continuous. The receiver setup is shown in Figure 7, where the brown rectangles correspond to the intersection of the FZ with the surface.

The maximum FZ wave amplitude is visible at the outermost receiver line L1. With decreasing distance towards the bifurcation point the FZ waves in the seismograms become weaker.

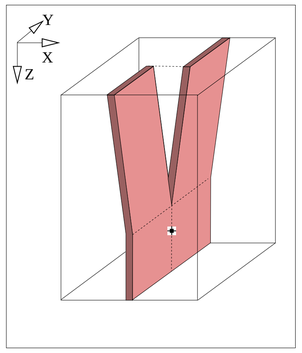
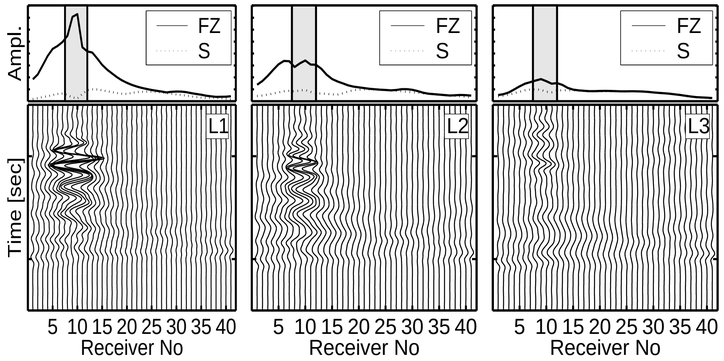
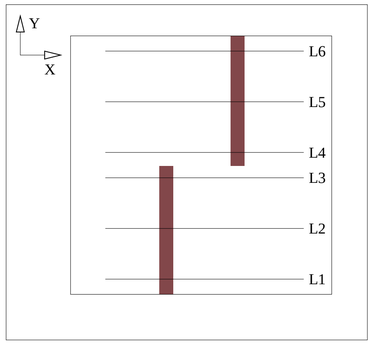


Figure 6



Split Fault − Source Shifted Laterally

Figure 7 shows seismograms for the split fault model described above. In contrast to Figure 6, the source is shifted laterally towards one fault segment. The receiver lines L4-L6 which are located on top of the fault segment containing the source show strong FZ waves. Additionally, the other segment shows weaker but still prominent FZ waves.



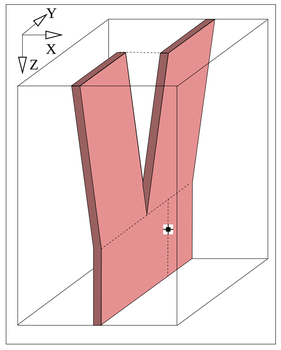
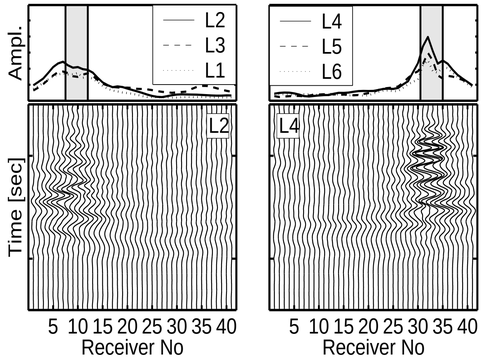


Figure 7



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