

Localization of microseismic events and determination of source parameters

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Abstract. We examine the problem of localization determining and a microseismic moment tensor of single microseismic event in the presence of strongly correlated noise. This is a typical problem occurring in monitoring of microseismic events from a daylight surface under conditions of a producing field or surface monitoring of hydraulic fracturing. We offer the solution to this problem based on the method of maximum likelihood. The article presents of decision of this problem and the results of numerical experiments. We discuss some features and problems of the proposed approach and estimate the required computing resources. We develop the problem of determination direction of fracture propagation from microseismic event.

1. Introduction

The hydraulic fracturing (HF) is one of the intensification of oil extraction technologies. HF is mechanical method of influence on the reservoir, based on increasing pressure of fluid in well higher than pore pressure, and lead to creating large fracture. During the process of fracture generation the elastic strain energy emitted, which generated seismic waves. The geophysical control based on this information and used it for monitoring of fracture geometry. This movement can be detected by seismic sensors and used to locate position of seismic sources, which occurred due to hydraulic fracture procedure and allow to evaluate space-time parameters of fracture [1].

The source mechanism of any microseismic event can be characterized by the seismic moment tensor. Aki and Richards [2] introduced the concept of the seismic moment tensor which depends on the source intensity and the medium movement orientation in the source vicinity. The full seismic moment tensor characterizes all possible stresses occurring in the vicinity of the seismic source epicenter. Tensor components M_{ij} are the values of the moments of forces applied along the i -axis when the points of force application are situated along j -axis. Thus, the seismic moment is the most general characteristic of a seismic event.

The condition of observation microseismic from the surface greatly differ than downhole observation. Even the microseismic noise level on the surface significantly higher than noise level in well, when depth of position sensor more than 500 meters. During procedure hydraulic fracturing the set of equipment is working which generate powerful noise, this noise is added to background noise. The level of signal (from source) on surface is much lower than in the case of downhole observations, due to the longer transit time of wave and intense absorption in weathering zone, especially for high



frequency signal. These reasons lead to the fact that the source localization by the beamforming method (that are used in the downhole monitoring) for surface monitoring is not possible, due to too low signal-to-noise ratio and signal is not allocated visually. Thus, the surface microseismic data processing is significantly difficult problem than with a downhole data processing.

The problem of localization of microseismic sources is well-known in the radio engineering [3] as task of detection signals for multi-channel reception and solved by different methods. With regard to the problem of localization microseismic source they have different localization accuracy, robustness to noise, and computational complexity. The most commonly beamforming method and its variants is using for the recovery position of microseismic source. For example, focusing conversion method, which allows dynamically throw out the sensors which not informative. The diffraction stacking method is relatively easily to implement, however, as will be shown below, it is poorly resistant to surface noise.

There is also the method of Time Reverse Modelling [4, 5], which is resistant to surface noise and the accuracy of the localization higher than diffraction stacking method [6].

2. Maximum-likelihood estimation

From the signal theory it is known that the most effective method is a method of detecting signals based on the maximum likelihood principle. With regard to the problem of monitoring hydraulic fracturing the method of maximum likelihood is used as follows. For area of space the discrete grid defined by a increments of 5-10 meters. The nodes of this grid are the points of microseismic intensity recovery.

Then, the most probable amplitude of microseismic event is recovering for each moment of time. Solution is made by comparing the synthetic signals and field data and selecting the amplitude of microseismic events, when the function likelihood is maximized. Synthetic signals calculated in at each node on grid and model is a 3D cube of microseismic events, which include interest area of Earth (also for interval by time). This cube can be subjected to further processing - filtration, separation of individual microseismic events, their rejection by various criteria, etc. The final result of processing is a map of summarized microseismic activity corresponding to different time of phases of hydraulic fracturing.

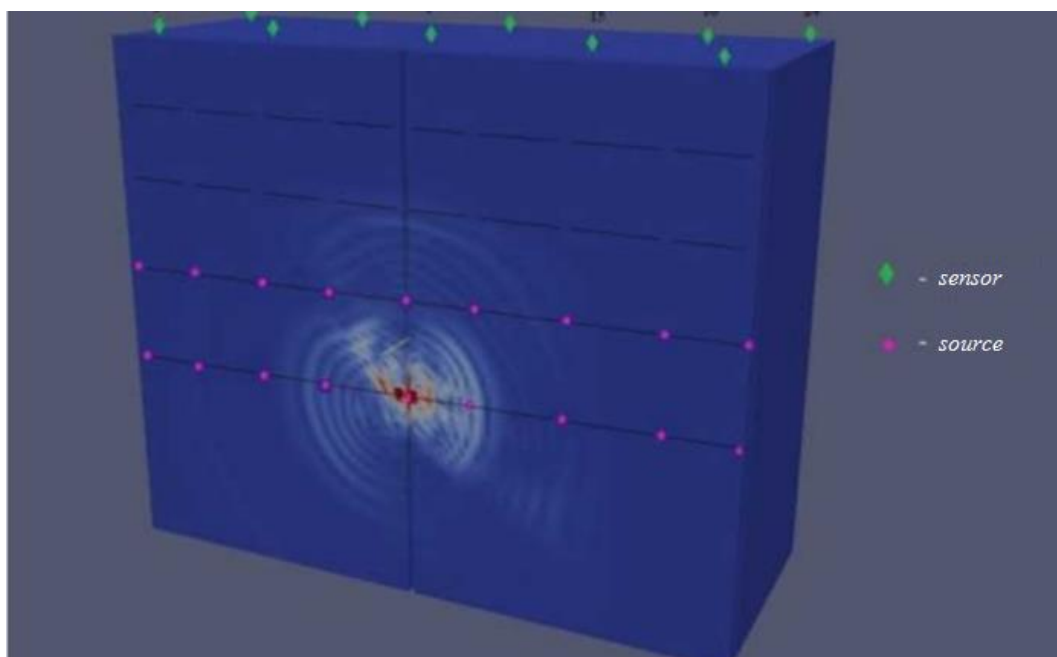


Figure 1. Example of the wave simulation.

Unlike the more simple methods such as diffraction stacking, the maximum likelihood estimation method requires knowledge of the waveform expected to sensors from microseismic source, not just the time of the first entry. In the method of diffraction stacking used ray tracing algorithm in this case is not suitable, and the only Full-wave numerical simulation is allows to solve this problem.

Full-wave numerical simulation allows the calculation of the waveform, which came to the sensor. It simulation can work with geology of any complexity, taking into account all possible waves, which generated during the seismic impulse propagating from the source to the receiver and to take into account a geometrical spreading for the actual propagation paths in inhomogeneous space (Fig. 1).

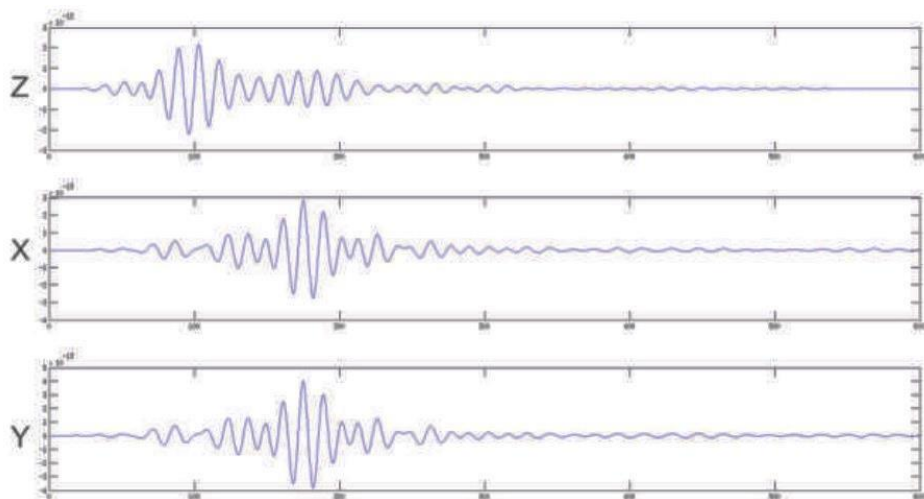


Figure 2. Calculated signals from a receiver for the three components.

Full-wave calculation is exceptionally demanding task, but it lends itself to parallelization, including advanced graphics clusters.

Using specialized software for full-wave modelling and supercomputing complexes [7-16] such a calculation is quite possible for a practical time, that making the maximum likelihood method is effective tool for the localization of weak microseism. And so he can recover the most probable values of the tensor seismic moment by time.

3. Determination of primary direction fracture propagation

Any type of underground events can be expressed in terms of seismic moment tensor. Consider seismic processes that can occur underground, which recorded at the seismic sensors. Fig. 2 shows the types of sources and the corresponding seismic moment tensors.

During hydraulic fracturing procedure occurs breakdown of formation, and fracture is growing, and this is process is source type of tensile crack. Question is of recognition this event among others.

Fig. 2 shows the ideal form of the tensor, in real cases it will also have the off-diagonal elements due to the presence of surface noise. This matrix is real and symmetric, so it can always be reduced to diagonal form by finding the eigenvalues. If we take a certain period of time, we can consider the distribution of the eigenvalues for each of the recovery tensor.

Three submitted by source type (Fig. 2) will produce different distributions of the three eigenvalues. For tensile crack will be two distributions for the first two eigenvalues, which are very close by value and one isolated distribution of the third eigenvalue. The maximum-likelihood estimation method allows to analytically evaluate the distribution and take the threshold for rejection all unlike types of events. Thus restoring only the type of source tensile crack. Monitoring these events makes it possible to identify the primary direction of fracture propagation.

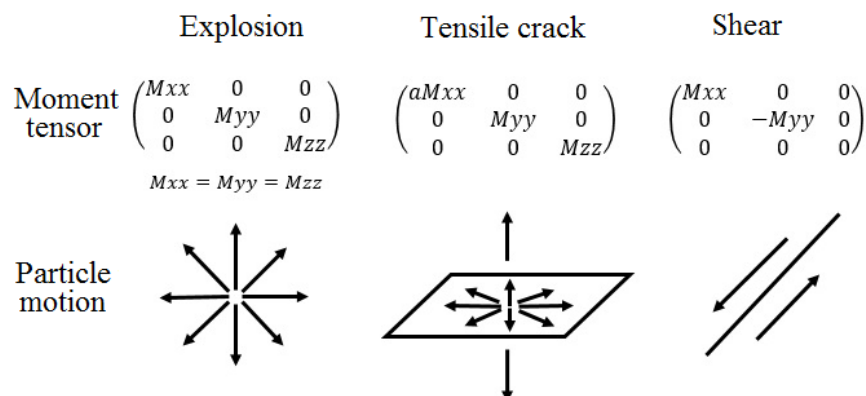


Figure 3. Type of seismic sources.

4. Conclusion

The maximum-likelihood estimation method is the most informative and robust technology of recovery signals. The article presents an approach based on the maximum likelihood method for the recovery of microseismic events, that occurs during hydraulic fracturing. The approach and shows the principle possibility of determining the priority directions of crack propagation using the maximum likelihood method.

Showed the principle possibility of determining the direction of fracture propagation by the maximum-likelihood estimation method.

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