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Velocity Calibration for Microseismic Monitoring: Applying Smooth Layered Models With and Without Perforation Timing Measurements

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Abstract

Theorectically, the perforation shot origin time T_0 affects the accuracy of the inverted velocity structure, and therefore the accuracy of subsequent microseismic event locations. The origin time can be obtained from perforation timing measurements or estimated from the picked arrival times. In order to investigate the role of origin time in velocity calibration, we designed two inversion procedures. In procedure A, T_0 is calculated during the Occam's inversion while T_0 is set to its true value in procedure B. A grid search locator is applied on both inverted models to produce two locations. We constructed three synthetic P-wave velocity models and add normally distributed random noise to the synthetic arrival times of all models. The noisy synthetic data are piped through procedure A to obtain location A and through procedure B to produce location B. Graphical analysis show that location A is closer to the true shot location than location B although both are close to each other. If we remove the data noise and repeat the test, location B is closer to the true shot than location A. It was observed that the inverted location A is better in terms of the distance from the true location if using noisy data and location B is better if using noise-free data. This indicates that uncertainties due to data noise cause our inconsistent observation and implies that perforation timing measurements are not necessary and may actually result in a less accurate velocity model.

Introduction

Hydraulic fracture monitoring of induced microseismic activity is the process of monitoring micro-seismicity generated during and related to hydraulic fracture well stimulation. Changes in reservoir stress and pore pressure associated with hydraulic fracturing can create propagation of new fractures and ruptures on existing fractures (shear failure or microseism). The failure emits elastic waves (compressional P and shear S waves) that are recorded by triaxial geophone receivers installed in the nearby monitoring well. The first arrival times of these waves can be picked and locations of the failure can be calculated. This process (known as fracture mapping) allows the direction, length, height, and growth history of the facture to be accurately mapped because the microseismic events should follow the fracture as it propagates (Quirein *et al.* 2006). One of the benefits of the fracture mapping in real time as the stimulation progresses is that the operator can potentially adjust pumping and stimulation parameters, such as pump rate, fluid properties, and volume, to optimize the stimulation within its original design criteria.

The accuracy of the fracture map depends on the accuracy of microseismic locations, which are affected by many limitations such as the accuracy of receiver positioning (locations and orientations), accuracy of first-arrival picks, and particle motion estimates. In particular, a thorough, up-to-date knowledge of the velocity structure between the monitoring and fracturing treatment wells is essential to obtain the most accurate locations (Warpinski *et al.* 2005). Velocity of reservoirs is a function of many parameters, such as rock elastic constants, rock porosity, fluids in pore space, temperatures, and pressures (Telford *et al.* 1991). If the reservoir has been produced for a long time, a depletion-induced pressure drop and pore fluid change may alter reservoir velocities. The existing velocity measurements, for example an open hole logging prior to well completion, may be out-of-date and unsuitable for hydraulic fracture monitoring. Therefore, it is often necessary to re-calibrate the reservoir velocities immediately preceding a monitoring project.

One solution to calibrating velocities is to use arrival time picks of the perforation or string shots performed before the hydraulic fracturing. Receiver locations, perforation or string shot locations, and the picked arrival times are assumed to be known. Various inversion algorithms can be applied to this known information to calibrate a reservoir velocity model.

Several papers have been published to estimate the velocity model by using perforation or string shot data. Using hydraulic fracturing induced micro-earthquake data, Block *et al.* (1994) performed a joint hypocenter-velocity inversion for location, origin time of events, and velocity by the separation of parameters technique and produced a constrained least-squares solution of a 3D S-wave velocity model of the fractured zone. Another joint hypocenter-velocity inversion was