Surface Tilt Fracture Mapping

Pinnacle

GET RESULTS

- Hydraulic fracture azimuth and dip
- Approximate fracture volume and location of fracture center
- Fracture complexity (multi-planar growth, fracture twisting, etc.)

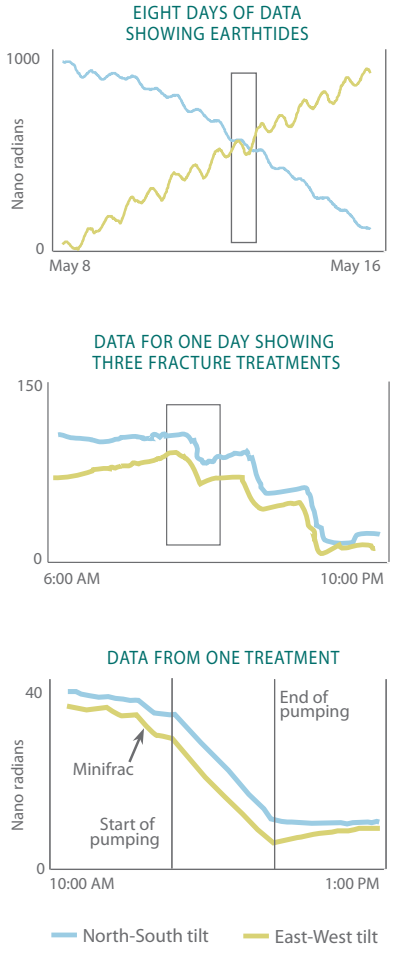
Surface tiltmeter fracture mapping is a unique fracture diagnostic technology in the oil and gas industry that provides a direct measurement of fracture orientation (azimuth and dip), fracture volume, complexity and approximate location. Pinnacle Technologies has performed surface tilt mapping on more than 10,000 fracture treatments.

HOW IT WORKS

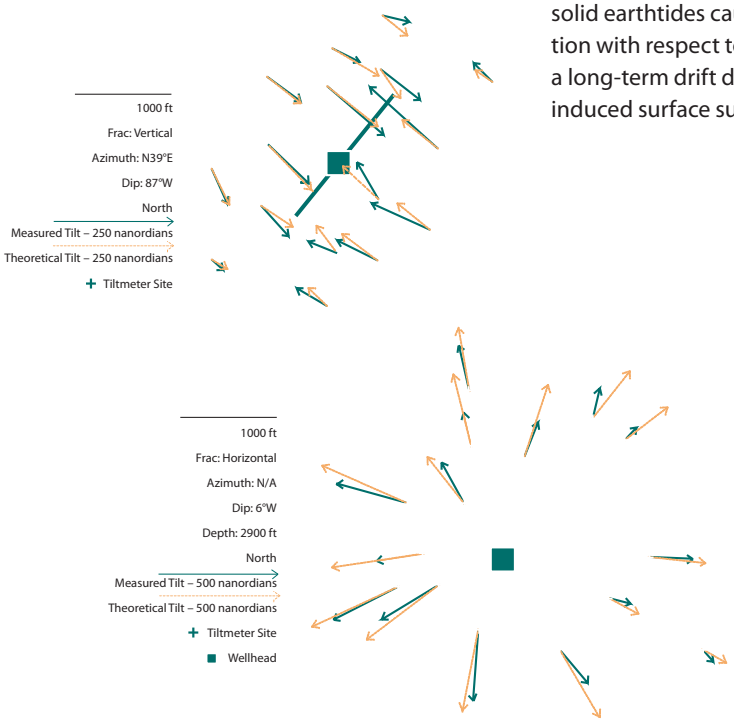
Surface tiltmeter mapping measures the fracture-induced tilt at many points above a hydraulic fracture, and then solves the geophysical inverse problem to determine the fracture parameters that would produce the observed deformation field. While the concept is simple, the magnitudes of the induced surface deformations are quite small and require highly sensitive instruments. A typical hydraulic fracture treatment at 7,000 ft depth results in induced surface tilts of only about 10 nanoradians - (10 parts in a billion). These miniscule tilts are measured with highly sensitive tiltmeters that operate on the same principle as a carpenter's level.

Pinnacle's tiltmeters (sondes are 30 inches long and 2.5 inches in diameter) measure their own tilt on two orthogonal axes. As the instrument tilts, a gas bubble contained within a conductive-liquid-filled glass cavity moves to maintain its alignment with the local gravity vector. Precision electronics detect changes in resistivity between electrodes mounted on the sensor that are caused by repositioning of the gas bubble. Our latest generation of high-resolution tiltmeters can detect tilts of less than one nanoradian and were recognized with a prestigious R & D 100 Award in 1997.

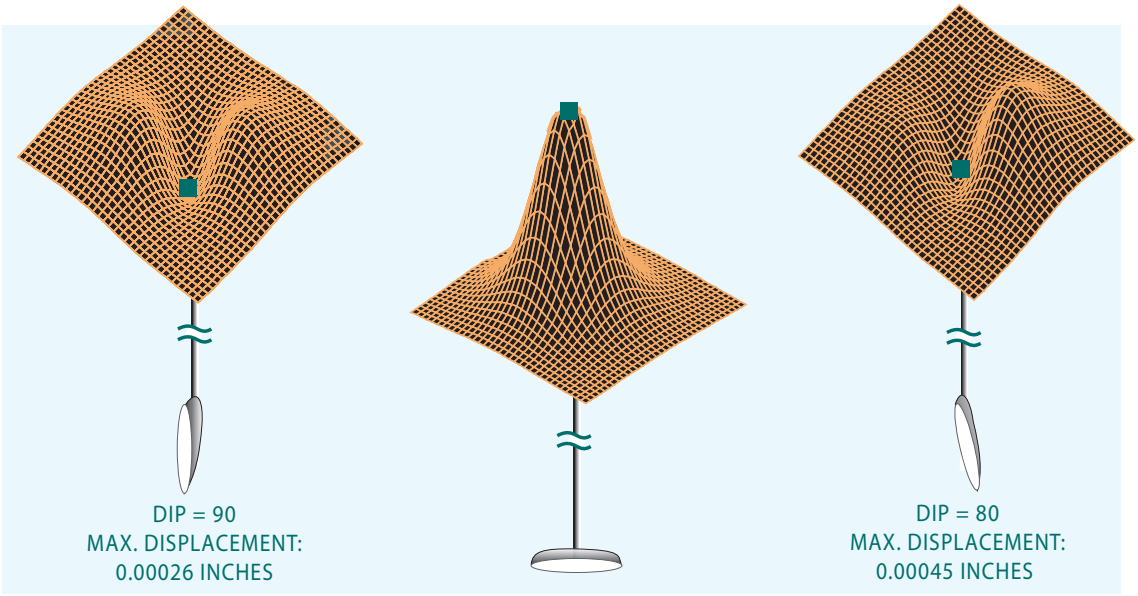
Each tiltmeter site has an instrument surrounded by sand within PVC pipe (3" to 9" diameter) that is cemented in a relatively shallow (10 to 40 ft depth) borehole. The picture at left shows a sample record of tilt data versus time on three different time scales. The first view illustrates the daily swings of the tilt data in response to the solid earthtides caused by the earth's rotation with respect to the sun and moon, and a long-term drift due to minute production-induced surface subsidence.



Three pictures of raw tiltmeter data on different time scales, ranging from one week with clear earthtides to a few hours around a fracture treatment.



Observed and theoretical fracture-induced tilt vectors for vertical (top) and horizontal (bottom) fracture. The vectors point inward to the "trough" following the azimuth of the vertical fracture. The vectors point outward to reflect "bulging" due to horizontal fracture.



Surface deformation for hydraulic fractures of different orientations at 3000 ft depth.

The next zoom-in shows a 16-hour time period when three hydraulic fracture treatment stages (seen clearly in the data) were pumped in the well being monitored. The final close-up is a 3-hour time period that clearly shows fracture-induced tilt from one of the propped fracture treatments. This fracture-induced tilt is recorded at each instrument site to yield an array of observed surface tilt vectors (see picture).

DATA ANALYSIS

The observed tilt data is inverted to find the hydraulic fracture parameters that yield the best fit to the observed data, and a Monte-Carlo technique is employed to estimate parameter uncertainty. The map view at left compares the observed and theoretical fracture-induced tilt vectors from a best-fit fracture solution. Note how a careful visual inspection of the observed tilt vectors alone reveals a trough that runs northeast-southwest (fracture azimuth of N45°E) and that both ridges are of roughly equal magnitude implying a fracture dip that is nearly vertical (87 degrees). In simple single-plane-fracturing cases like this, visual inspection alone reveals the essential results. The bottom shows another overlay of observed and theoretical tilt vectors for the case of a horizontal fracture.

For fracture mapping purposes, an array of 15 to more than 30 tiltmeters are placed around the well to be fractured at radial distances from 15% to 75% of the fracture depth, as this is the region of maximum fracture-induced surface tilt. The exact layout of the monitoring array is not critical. Fracture mapping resolution is primarily dependent on the number of tiltmeter sites employed and the signal-to-noise ratio of the measurements. Resolution of fracture orientation is typically better than 1 degree per 1,000 feet of depth.

Since fracture-induced tilt is measured continuously, fracture mapping can be performed throughout the course of the treatment (and if desired, in real-time). In some cases fractures may initiate in one plane and then twist into another orientation, or initiate secondary fracture growth in another plane at some point in time during a treatment. Other parameters like depth-to-fracture-center may also change significantly during a treatment if, for example, the fracture breaks through a barrier and begins rapid upward (or downward) height growth.

Pinnacle's surface tiltmeter mapping is simply the most robust technique available for determining hydraulic fracture orientation. Pinnacle has a proven track record of technically enhancing fracture diagnostics AND reducing the cost of delivery every year. Please contact us to learn how Pinnacle's award-winning diagnostics can help you.

Houston
281–876–2323
Denver
720–344–3464
Calgary
403–516–2260
Bakersfield
661–335–7711
San Francisco
415–861–1097
Dallas
972–401–0090
Delft
31–15–219–0062
Moscow
7–495–781–4820
Beijing
86–13838562150
Oklahoma City
405–604–5634
Midland
432–386–6791
Reynosa
52–892–42191
Cairo
2025283356–8

Pinnacle
www.pinntech.com