



Update on Status of Fault Creep Monitoring using the Alignment Array Network in Northern California

Stephen DeLong, USGS

What other methods have been used to measure fault creep?

Geodolite – long range (wide aperture) survey instrument – measured deformation over kilometers, required careful atmospheric correction from an aircraft. 1 mm resolution, 4-7 mm standard error.



USGS survey team using a laser beam geodolite to monitor motion between fixed points on either side of the San Andreas fault. Aircraft gathers information on atmospheric conditions between geodolite and target several kilometers away.

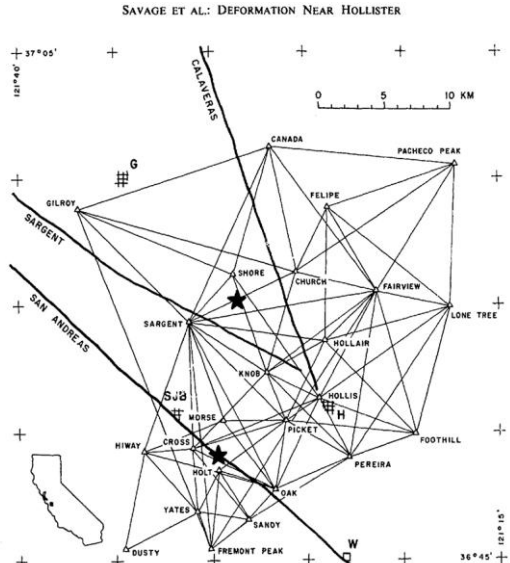


Fig. 1. Hollister trilateration network. Inset map of California in the lower left corner shows the location of the network. The major faults are shown by heavy lines trending from upper left to lower right. The lower star indicates the epicenter of the October 3, 1972 ($M_L = 4.9$), earthquake and the upper star the epicenter of November 28, 1974 ($M_L = 5.1$), earthquake. Also shown are the locations of the towns of Gilroy (G), San Juan Bautista (SJB), and Hollister (H) as well as the location of the Cienega Winery (W).

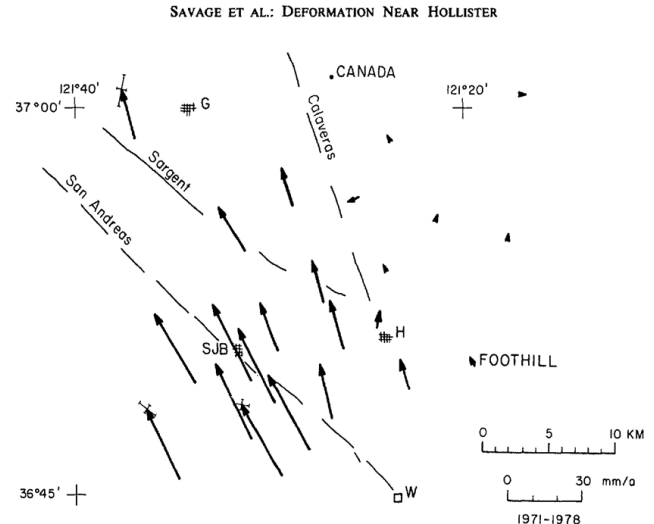


Fig. 5. The 1971–1978 average velocity for geodetic stations in the Hollister network. The velocities, shown by arrows, are measured relative to the motion of station Canada and subject to the assumption that the azimuth from Canada to Foothill remains invariant. Stations may be identified by referring to Figure 1. The principal axes of the 95% confidence ellipse are shown at the head of the arrow for stations Fremont, Dusty, and Gilroy. The confidence ellipses are substantially smaller at the other stations. The faults are shown by dashed lines trending downward to the right. The locations of the Cienega Winery (W) and the towns of Gilroy (G), San Juan Bautista (SJB), and Hollister (H) are also shown.

Savage and Lisowski, 1979; Savage, et al. 1998

What other methods have been used to measure fault creep?

Trilateration arrays

Measured by Electronic Distance Meters (EDMs) (~total stations) over distances of 0 - ~5 km (e.g. HP 3800 EDM with 3 km range)

Irregular arrays of survey monuments, sometimes using other agency monuments

Errors in the range of 4 mm

Complex geometry – complex math

- Savage and Buford, 1973
- Lisowski and Prescott, 1981
- Prescott et al. 1981

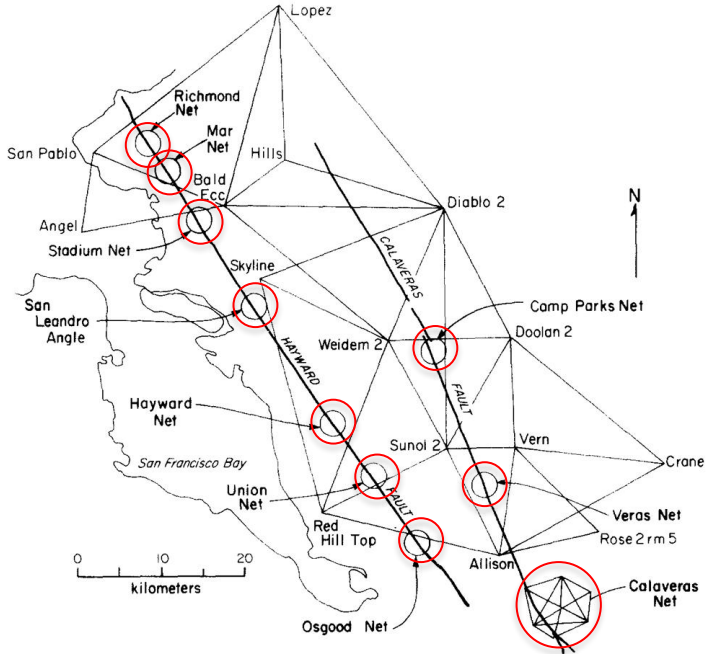


Fig. 1. Sketch of the area east of San Francisco Bay. Straight lines indicate observed distances. Circles indicate networks of several short lines or, in one case, an angle.

What other methods have been used to measure fault creep?

Alignment Arrays

These take many forms. Many of the early arrays consist of > 10 survey monuments in a line across a fault with another monument or two along the fault so that angles measurements indicate fault displacement.

These are all over California with varying levels of documentation. Many were installed between the late 1960s and mid 1980s.

Also: cultural features

Burford and Harsh, 1980
Titus et al 2000s



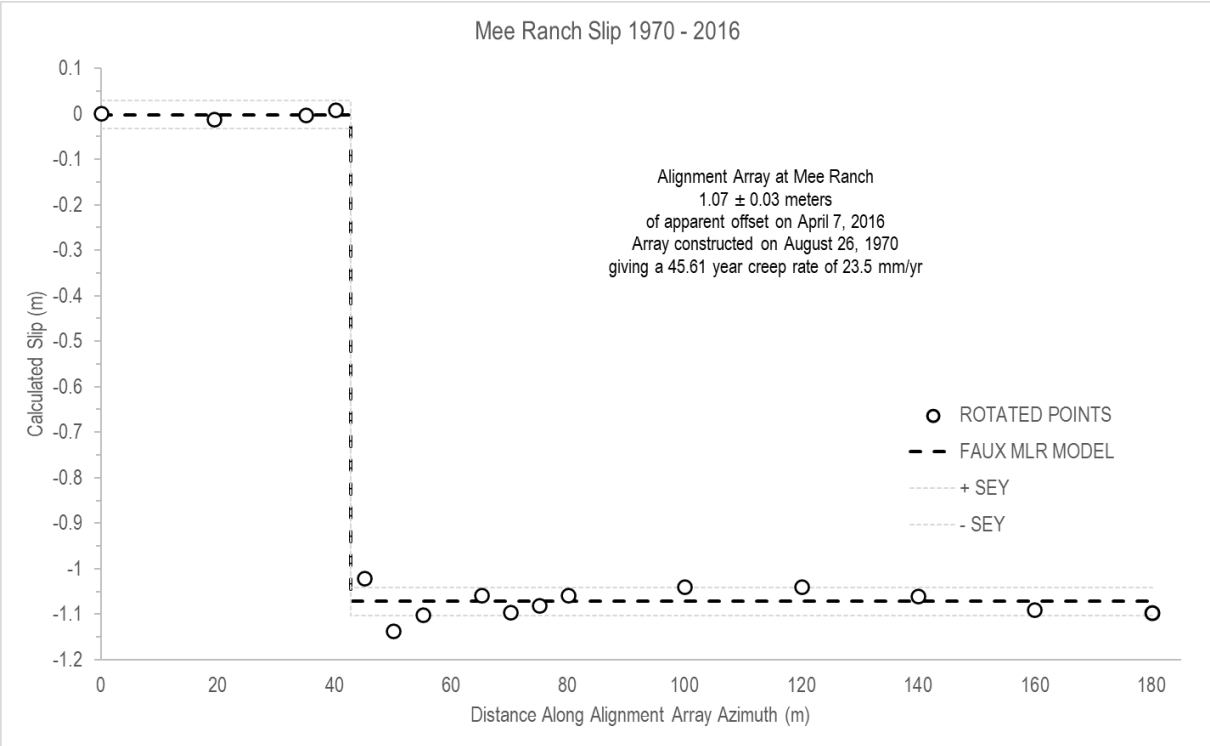
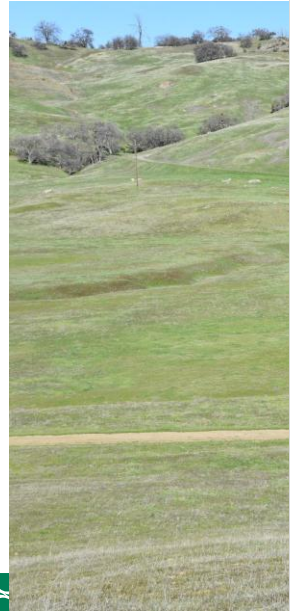
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Creepmeters

You will hear more about these from others.

Started in ~1969 e.g. Schulz et al. (1976), Schulz and Burford (1979), Langbein et al. (2024)

Short aperture (5 – 10 m)



USGS – SFSU Alignment array project

What is this?

Survey monuments placed across fault zones to measure fault creep, coseismic offset, and afterslip.

How: change of measured angles, using theodolite

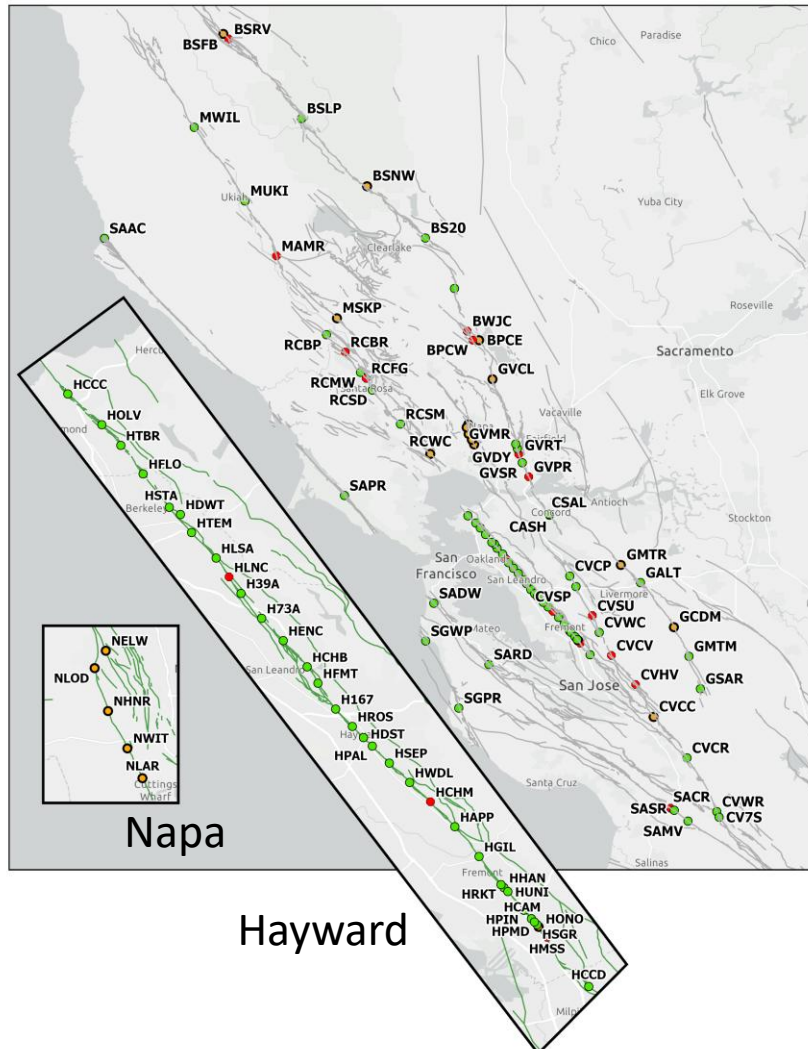
Currently inactive due to retirements at USGS (Lienkaemper) and SFSU (McFarland) and lack of current staffing.

90 arrays in database

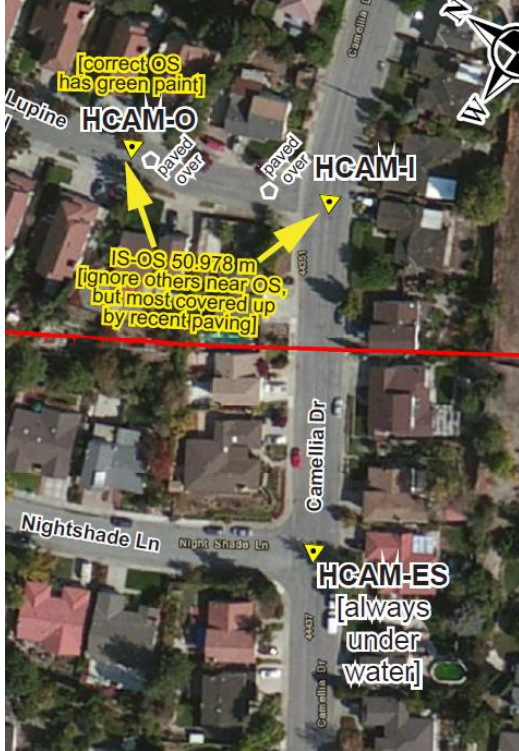
60 “active” arrays

15 inactive/destroyed arrays

15 unknown status



USGS – SFSU Alignment array project



Wild T2000 theodolite:
Angular resolution 0.5" or ~0.24 mm at 100 m.
In practice, most error may arise from setup and human factors

USGS – SFSU Alignment array project

Method – Angle-based measurements of fault creep using three-monument array.

Measurements made with highly accurate but older equipment – Theodolites

Error minimized by experienced operators, consistent measurement practices, statistical error analysis

Issues – monument preservation, Local obstacles to measurement, high labor need, single measurement width can't resolve fault complexity

Strengths – high accuracy, repeatability, consistency of methods over many decades, high standards for methods due to consistency in personnel. Methods also apply to afterslip and a basic array is trivial to install (a durable array is harder to install)

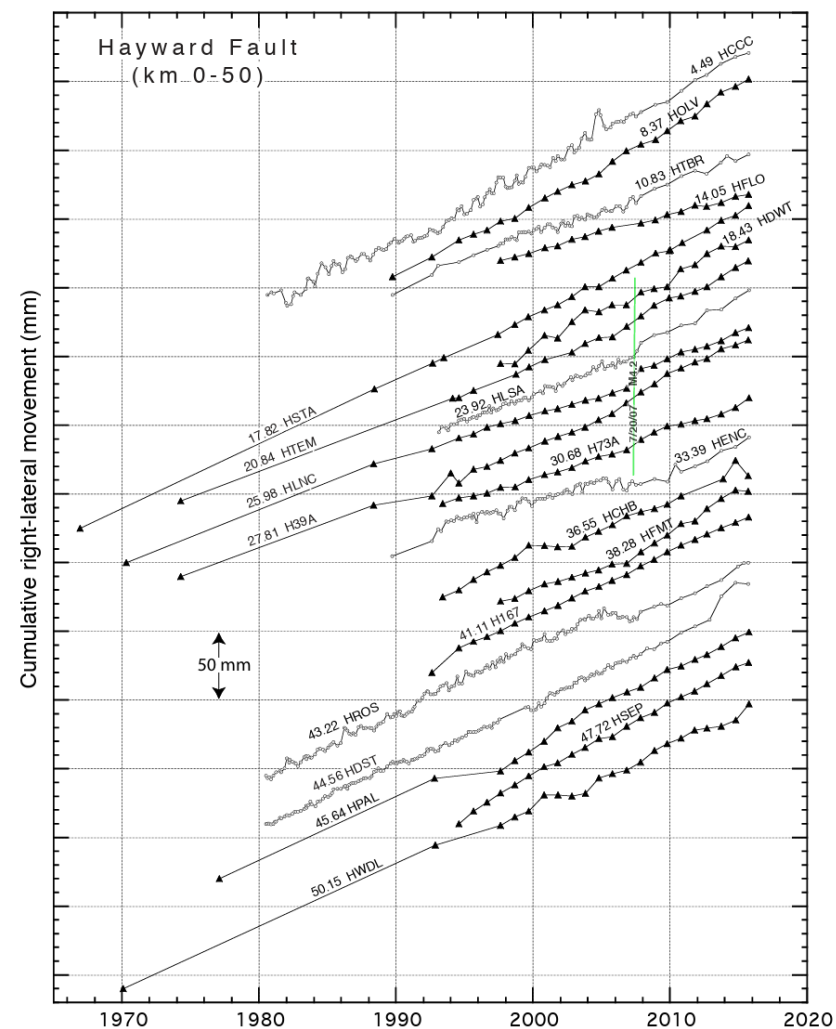
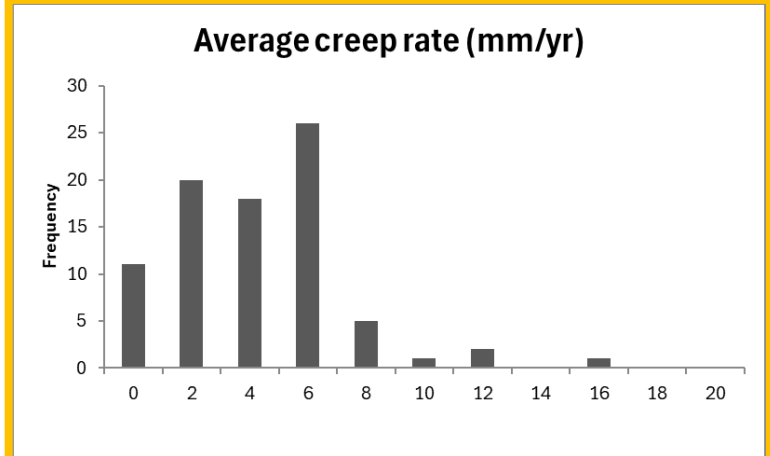
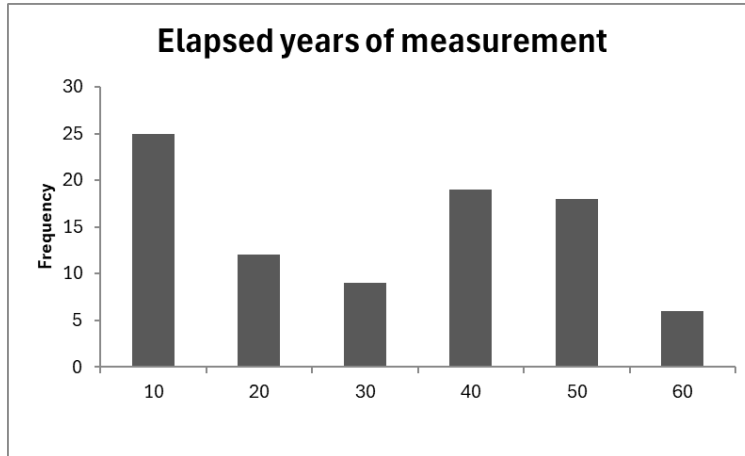
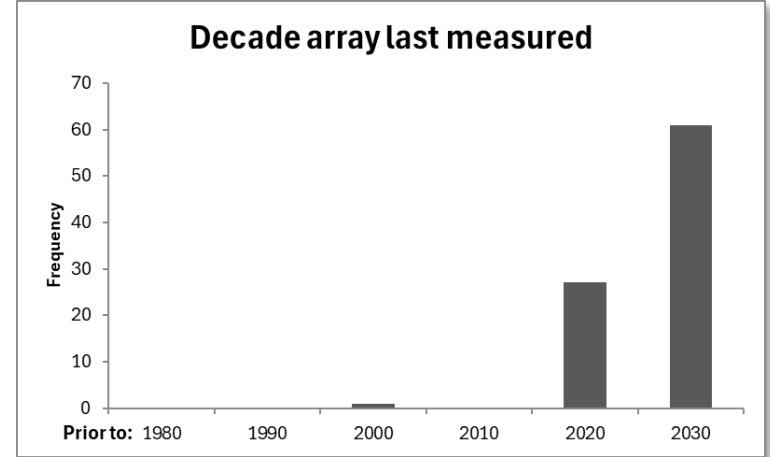
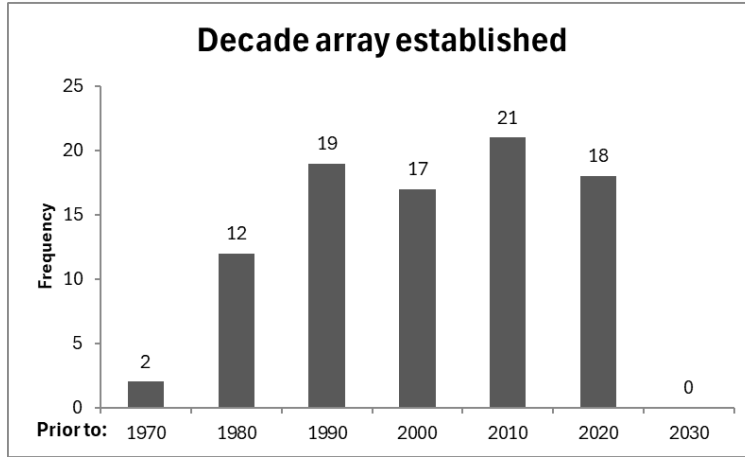


Figure 8. Alinement array measurements, Hayward Fault, sites from km 0 to 50, labeled by km distance (Table 2, Fig. 2).

USGS – SFSU Alignment array project



USGS – SFSU Alignment array project

All data up through last survey in early 2025 are available as a USGS Data Release

This release is v3.0 and is now policy-compliant (machine readable, etc) and simplified from previous versions.

ScienceBase Catalog → USGS Data Release Products → Data from Measurements of ...

Data from Measurements of Creep Rates on northern California Faults, California (ver. 3.0, February 2026) View

Dates

Publication Date : 2017-05-23
 Start Date : 1979
 End Date : 2025-01-11
 Last Revision : 2025-02-10

Citation

McFarland, F.S., Caskey, J.S., and DeLong, S.B., 2017. Data from Measurements of Creep Rates on northern California Faults, California (ver. 3.0, February 2026). U.S. Geological Survey data release. <https://doi.org/10.5066/P17YB0AC>.

Summary

This Data Release summarizes repeat survey measurements made to monitor surface fault creep (tectonic movement along faults that occurs without strong shaking from earthquakes) in northern California, mostly in the greater San Francisco Bay Area. Additional description of these data and the methods used to collect them is provided in the included references. This Data Release provides nearly annual measurements at 90 measurement sites, and includes their approximate locations, calculated creep rates, duration of measurements in years, and notes regarding the status.

Contacts

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 SDC Data Owner : Earthquake Science Center
 USGS Mission Area : Natural Hazards
 Distributor : U.S. Geological Survey - ScienceBase

Attached Files

Click on title to download individual files attached to this item.

summary_metadata.xml	26.69 KB	application/fgdc+xml
Original FGDC Metadata		

Related External Resources

Type: Web Link



Related External Resources

Type: Web Link	
Using Surface Creep Rate to Infer Fraction Locked for Sections of the San Andreas Fault System in Northern California from Alignment Array and GPS Data	https://doi.org/10.1785/0120140117
Data from Theodolite Measurements of Creep Rates on San Francisco Bay Region Faults, California	https://doi.org/10.3133/ofr20091119
Inferences Drawn from Two Decades of Alinement Array Measurements of Creep on Faults in the San Francisco Bay Region	https://doi.org/10.1785/0120020226
Data from Theodolite Measurements of Creep Rates on San Francisco Bay Region Faults, California (version 2.2, July 2023)	https://doi.org/10.5066/F76W9896



USGS – SFSU Alignment array project

Future possibilities for these arrays:

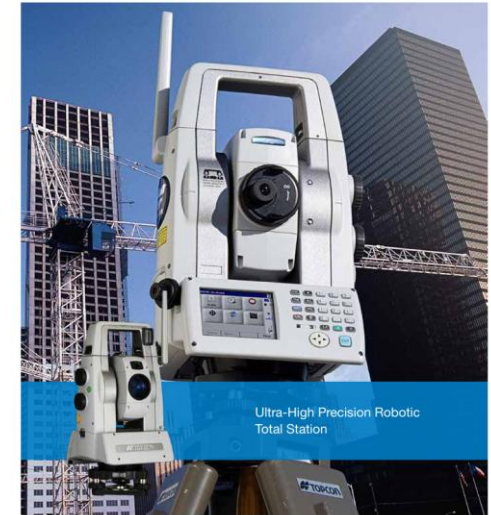
- High accuracy modern measuring station
 - USGS has Topcon MS05 AXII (~\$40k system)
 - 0.5" (0.24 mm @100 mm) angular accuracy or 0.1" (0.48 mm) auto-pointing
- “Standard” Total Station – 3" angular accuracy (1.44 mm @ 100 m) (\$10-15k, less used, can be rented)
- RTK GNSS – 2-3 mm positional accuracy, higher relative accuracy
- Lidar (tripod, mobile, airborne)
- SAR/Imagery
- Creepmeters



TOPCON

High Accuracy Measuring Station

MS AXII Series



Advanced angle calibration

Topcon advanced angle encoder technology with exclusive calibration system provides "best in class" angle accuracy, 0.5" (MS05 AXII) and 1" (MS1 AXII).

Superior auto-pointing accuracy

The auto-pointing accuracy* with the standard prism is 1" (1 mm at 200 m), and 4" (1 mm at 50 m) with a reflective sheet.

*Auto-pointing accuracy is verified using the methods specified by ISO 17123-3.