



Evaluation of MEMS-based In-place Inclinometers in Cold Regions



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<p>Inclinometer probes are used to measure ground movement. While an industry standard, this technology has drawbacks, including costly trips for manual measurements, operator error, and limited measurements due to casing deformation. Relatively new MEMS-based in-place inclinometers (M-IPs) consist of MEMS accelerometer segments separated variously by flexible joints or field-connection systems, and encased in watertight housing. M-IPs provide nearly continuous ground movement measurements, accommodate greater ground movement due to their flexibility, and may contain temperature sensors. Two M-IPs from different manufacturers were evaluated for three different vertical and horizontal applications in Interior Alaska. Each M-IP was evaluated for ease of installation and subsequent retrieval, durability, and functionality in frozen ground. Measurements from both devices compared well to those from the inclinometer probe, indicating that these devices are suitable for use in cold regions. Field experience indicates that the installation procedure for each instrument is better undertaken at above freezing temperatures, due to required manual dexterity and the temperature requirements of casing adhesive. If used to measure both ground movement and temperature in frozen ground, the M-IP temperature sensors should be calibrated. We recommend replacing cold-affected plastic components between installations to avoid unwanted breakage during re-installation.</p>					
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EXECUTIVE SUMMARY

Inclinometer probes are used to measure ground movement. While an industry standard, this technology has drawbacks, including costly trips for manual measurements, operator error, and limited measurements due to casing deformation. Relatively new to the industry, MEMS-based in-place inclinometers (M-IPIs) are composed of a series of MEMS accelerometer segments separated variously by flexible joints or field-connection systems, and encased in a watertight housing. M-IPIs provide nearly continuous ground movement measurements without frequent field trips, accommodate greater ground movement due to their flexibility, and may contain temperature sensors, useful for frozen ground applications. Since M-IPIs have not been evaluated fully for use in cold regions, two M-IPIs from different manufacturers were evaluated for three different applications in Interior Alaska: 1) to monitor creep in frozen ground (vertical installation); 2) to identify and monitor slide shear zones (vertical installation); and 3) to monitor thaw settlement under a newly-constructed embankment (horizontal installation). Each M-IPI was evaluated for ease of installation and subsequent retrieval, durability, and functionality in frozen ground.

Measurements from both devices compared well to those from the inclinometer probe, with small differences in measurements attributed to differences in the devices' geometry and flexibility. Temperature data analysis indicates that the M-IPI devices measured temperatures within $\sim 0.4^{\circ}\text{F}$ of those recorded by a thermistor string. In two separate installations, temperature readings from the M-IPI device served as a check on potentially faulty readings from another sensor, which was an unexpected benefit. In addition to the proposed test sites, one of the M-IPI devices was installed where a large amount of movement was anticipated. The device continued to read during shearing and provided meaningful measurements after shearing. The presence of the M-IPI in the quickly moving landslide provided much more data than we otherwise would have collected due to the remoteness of the installation.

Based on this analysis, these devices are suitable for use in cold regions. Field experience indicates that the installation procedure for each instrument is better undertaken at above freezing temperatures, however, due to required manual dexterity and the temperature requirements of casing adhesive that is typically available. We recommend that, if the needs of the project require the M-IPI device to produce measurements of both ground movement and temperature, the M-IPI temperature sensors are calibrated by the manufacturer before use. Additionally, we recommend replacing any needed cold-affected plastic components between installations to avoid unwanted breakage during re-installation.