

# Appendix A. Instrument capabilities for measuring land-surface displacement

| INSTRUMENT   | AVAILABILITY   | INSTRUMENT CHARACTERISTICS   | DATA COLLECTION CHARACTERISTICS                                 |                       | RANGE  | ACCURACY   | SENSITIVITY TO ENVIRONMENT  | CALIBRATION AND MAINTENANCE                                  | EASE/COST OF INSTALLATION   | EASE/COST OF OPERATION  | POWER REQUIREMENTS  | EASE/COST OF DATA REDUCTION   | COST OF INSTRUMENT   |
|--|--|--|---|-----------------------|--|--|---|--|---|---|---|---|--|
|  |  |  | REMOTE OR DIRECT  | ENTER SUBSIDENCE AREA |  |  |   |  |   |   |   |   |  |
| Steel tape<br>(structure and surface strain, surface and structure crack movement)   | Luffkin; Chesterman; Kueffel & Esser   | Portable, rugged, long life  | Direct  | Yes                   | 100 ft usually; available in 3 to 300 ft lengths   | ±0.01 ft   | Temperature; wind; tension  | Periodically clean, oil, and calibrate against standard tape | Install reference points  | 2 tapemen plus 1 man to set stakes; use with tensioning device, taping pins, plumbob  | None  | Simple  | 100 ft: \$30 to \$300  |
| Invar tape<br>(structure and surface strain, surface and structure crack movement)   | Kueffel & Esser  | Portable, prone to breaking  | Direct  | Yes                   | 50 ft to 100 ft  | ±0.005 ft  | Wind; tension   | Clean periodically   | As above  | 2 tapemen; use with tension frames and weights; for high accuracy repeat readings with 3 tapes                                  | None  | Simple  | 100 ft: \$300<br>150 ft: \$400   |
| Precision level<br>(automatic or tilting with optical micrometer) with invar rod<br>(structure and surface settlement; with tape or tape extensometer for ground tilt) | Jenoptik; Kern; Wild; Leitz; Zeiss   | Portable, rugged, long life  | Direct  | Yes                   | Maximum change in elevation between sights approx. 13 ft; sight length greater than 7 ft and less than 150 ft            | ±0.002 ft to ±0.005 ft over mile circuit   | Wind; bright sunlight   | Check telescope alignment annually                           | Install reference points and bench marks  | 1 instrument man; 1 rod man   | None  | Simple; need 1 engineer; may use computer to reduce large volume of data  | Level: \$850 to \$1500;<br>rod: \$700  |
| Precision theodolite with tape for baseline (triangulation)<br>(surface and structure settlement and strain)   | Kern; Wild; Jenoptik; Leitz  | As above   | Direct  | No                    | 1 sec instrument read to 0.2 sec by angle repetition: 1:20,000 to 1:50,000; best positional accuracy ±0.001 in ±0.005 ft | Temperature; wind; vibration; direct sun; temperature sensitivity minimal with invar tape                    | As above  | Install reference points and 3 instrument stations           | 1 surveyor; and 1 rod man if targets not fixed; 2 men needed for taping of baselines between instrument piers | None  | As above; computer programs readily available                                   | Precision Theodolite: \$3000 to \$9000  |  |
| Optical electronic distance measurement device (EDM)<br>(use with theodolite if not built-in)<br>(structure and surface strain)  | First developed 1948; AGA; Kern  | Portable; retro-reflectors may be portable or fixed to reference point | Direct  | Yes-rod man only      | 20,000 ft  | ±0.02 to 0.2 ft plus 1:25,000 to 1:650,000<br>Mekometer 3000: ±0.0007 ft plus 1:1,000,000 (as good as invar) | Temperature and pressure along line of sight; smog can disrupt readings; may be used day or night | Calibrate against 50 meter invar tape every two years        | Install reference points  | 1 surveyor plus 1 laborer if retro-reflectors portable or adjustable; lower cost per mile of traverse than conventional methods | Rechargeable battery for 1 day's work   | Distance usually automatic; a few provide only phase shift and surveyor must convert to distance  | Typical EDM:<br>Mekometer 3000: \$34,000;<br>reflectors: \$0.50 to \$410                         |
| Infrared EDM<br>(use with theodolite if not built-in)<br>(structure and surface strain and settlement)   | Wild; AGA; Kern; Kueffel & Esser; Zeiss; HP; Precision; Cubic Corp; Tellurometer | As above   | Direct  | Yes-rod man only      | 1000 to 16,000 ft; minimum: 1 ft   | Typically 0.02 ft plus 1:100,000 to 1:300,000; Tellurometer MA 100; 0.002 ft over 300 ft                     | Temperature and pressure; less sensitive than other EDM's; can use day or night and in bright sun | As above   | As above  | As above  | Rechargeable battery for 1 day's work   | Distance usually automatic; most have automatic correction for temperature and pressure   | Reflectors: \$0.50 to \$260 each; EDM: \$3000 to \$7000 without theodolite; Tellurometer MA 100. |
| Infrared EDM (3-D trilateration)<br>(structure and surface settlement and strain)  | As above   | As above   | Direct  | No                    | As above   | As above   | As above  | As above   | Install reference points and instrument stations  | 1 surveyor  | As above  | As above; reduce distances to EDM to coordinates  | As above   |
| Laser EDM<br>(structure and surface strain)  | Developed late 1960's; AGA   | As above   | Direct  | Yes-rod man only      | 5000 to 20,000 ft  | ±0.01 to 0.08 ft and 1:1,000,000; ±0.015 over 19 miles   | Temperature and pressure; smog; dust; fog; air turbulence; sensitive to vibration                 | As above   | As above  | 1 surveyor and 1 rod man  | Lower power consumption than other EDM's; rechargeable battery for 1 day's work | Distance automatic  |  |
| EDM tachymeter<br>(distance, angles, horizontal distance and elevation automatically computed)<br>(structure and surface settlement; and strain)                       | AGA geodimeter models 700 and 710; Wild model DI-35                              | Portable   | Direct with portable reflectors<br>Remote with fixed reflectors | Yes-rod man only      | 1000 to 15,000 ft  | .02 ft plus 1:1,000,000 to .02 ft plus 5:1,000,000   | Temperature; pressure; vibration; dust  | As above   | Install reference points; install instrument stations if used   | 1 surveyor and 1 rod man, if targets not fixed  | Rechargeable battery for 1 day's operation                                      | Automatic data reduction; surveyor may have to enter horizontal or vertical angle to get horizontal distance and elevation (DI-35 only) | \$18,000; \$10,000 (DI-35 without theodolite); reflectors: \$0.50 to \$260 each                  |

| INSTRUMENT   | AVAILABILITY   | INSTRUMENT CHARACTERISTICS   | DATA COLLECTION CHARACTERISTICS |                    | RANGE  | ACCURACY                                  | SENSITIVITY TO ENVIRONMENT   | CALIBRATION AND MAINTENANCE  | EASE / COST OF INSTALLATION  | EASE / COST OF OPERATION   | POWER REQUIREMENTS | EASE / COST OF DATA REDUCTION   | COST OF INSTRUMENT  |
|--|--|--|---------------------------------|--------------------|--|---|--|--|--|--|--------------------|---|---|
|  |  |  | REMOTE OR DIRECT                | ENTER SURFACE AREA |  |   |  |  |  |  |                    |   |   |
| Rod extensometer with dial gauge (ground or structure strain and crack movement)         | Terrametrics; Structural Behavior Engineering Laboratories (see Section 2.2); Fabricated; Mason (1971) | Permanent for monitoring period; recoverable; rugged and dependable                    | Direct                          | Yes                | Displacement ranges to 1.0 in.; resettable gauge; 10 in. to 20 in.; if user fabricated gauge length may be 10 feet | Sensitivity of 0.0001 in.                 | Susceptible to vandalism unless protected; sensitive to temperature  | Calibrate with standard reference bar; easy to replace   | Embed reference points in soil, rock or structure and attach bar; provide protection for instrument  | Simple; one person to read; can use camera recorder and replace film periodically  | Battery for camera | Convert dial readings to displacement; temperature correction                   | \$100 to \$800  |
| Steel tape extensometer (ground or structure strain, convergence)                        | Sinco; Inrad; Terrametrics; Interfels; Soiltest  | Portable; dependable   | Direct                          | Yes                | Displacement ranges of 0.01 in. to 100 ft; gauge length 2 ft to 100 ft   | ±0.01 in.                                 | Reference points susceptible to damage; sensitive to temperature   | Problems with tape breaking; calibrate with standard reference bar; oil periodically and check tensioning device | Embed reference points in soil, rock or structure  | Simple; one person to attach extensometer to reference points, apply tension and read; two people need to take readings for 15' readings | None               | Direct readout of distance makes data reduction simple; temperature corrections | \$500 to \$1500   |
| Invar wire extensometer (ground or structure strain, convergence)                        | Telemac; Kern  | Portable   | Remote                          | Yes                | Displacement ranges of 2.5 in. to 4.0 in.; gauge length of 3 ft to 150 ft  | ±0.0008 in. to 0.002 in.                  | Reference points susceptible to damage; insignificant temperature effects  | Calibrate with standard reference bar; clean periodically and tensioning device as well as zero drift of readout | As above   | As above   | 12 VDC             | Digital readout of distance makes data reduction simple                         | \$4800  |
| Rod extensometer with LVDT (ground and structure strain and crack movement)              | User fabricated; Kennedy (1971)  | Permanent for monitoring period; may be recoverable; suitable for long-term monitoring | Remote                          | No                 | Displacement ranges of 0.10 in. to 6 in.; gauge length 5 ft to 10 ft   | ±0.001 in.; positive; infinite resolution | Electronics not very sensitive to vibration or temperature, but changes in line resistance, cable length, or input voltage variance; may be subject to corrosion, vandalism and sensitive to temperature | Check for zero drift; easy to replace; calibrate with standard reference bar                                     | Embed reference points in soil, rock or structure; provide protection for instrument; establish zero reading; enclose in telescoping casing for monitoring convergence | Simple; one person to take reading   | None               | Direct reading of distance makes data reduction simple; temperature correction  | LVDT \$200; transducer amplifier and recorder \$800; cable \$14/20 ft |
| Rod extensometer with machinist's scale (ground and structure strain and crack movement) | User fabricated; Utter and Tesco (1965)  | May be permanent for monitoring period or may be portable                              | Direct                          | Yes                | Displacement ranges of 0.1 in. to 10 ft; typical gauge length 3 ft to 10 ft  | Sensitivity of 0.01 in.                   | Susceptible to corrosion, vandalism and sensitive to temperature   | Clean periodically; calibrate with standard reference bar; easy to repair  | Embed reference points in soil, rock or structure; provide protection for instrument   | Simple; one person to take reading   | None               | As above  | Materials and labor \$500   |
| Rod extensometer with micrometer (surface or structure strain and crack movement)        | Micro-precision Engineering Livermore, CA; Blund and Moore, 1973                                       | Portable   | Direct                          | Yes                | Displacement ranges to 3.0 in.; typical gauge length 10 ft   | ±0.005 in.; sensitivity of 0.0004 in.     | Reference points susceptible to damage; sensitive to temperature unless invar  | Clean periodically; calibrate with standard reference bar; easy to repair  | Embed reference points in soil, rock, or structure   | One or two people to move bar, adjust micrometer and take reading  | Penlight battery   | Direct readout of distance makes data reduction simple; temperature correction  | Materials and labor \$600   |

| INSTRUMENT   | AVAILABILITY  | INSTRUMENT CHARACTERISTICS                   | DATA COLLECTION CHARACTERISTICS |                         | RANGE  | ACCURACY  | SENSITIVITY TO ENVIRONMENT   | CALIBRATION AND MAINTENANCE   | EASE/COST OF INSTALLATION  | EASE/COST OF OPERATION   | POWER REQUIREMENTS                  | EASE/COST OF DATA REDUCTION   | COST OF INSTRUMENT  |
|--|---|--|---------------------------------|-------------------------|--|-----------|--|---|--|--|-------------------------------------|---|---|
|  |   |  | REMOTE                          | DIRECT                  |  |           |  |   |  |  |                                     |   |   |
| Single point or differential settlement manometer (structure or settlement)  | Senate; Galileo   | Readout and hoses permanent or portable      | Direct                          | Yes                     | Up to 50 ft of settlement; distances up to 1000 ft; reference points | ±0.25 in. | Susceptible to barometric pressure variations due to sunlight, temperature, and vibration; water cannot be used in freezing conditions | Hoses must be free of air, leaks, little difficulty to repair; hoses; replace hoses; measurement of readout in permanent installation observation | Install reference structure; provide for readout; measurement of readout in permanent installation                                 | Simple; two technicians; system, one for permanent readout; one for portable readout; data entry, and a line sample line; simple timing oscillations | None                                | Convert pressure differences or reading to elevation  | Multiple points and terminal; \$150 to \$500; deairing unit \$300 to \$800  |
| Single point manometer (structure or settlement)                             | Soil and rock instruments; also user fabricated; (1971) | Permanent for monitoring; may be recoverable | Direct                          | No, if hose long enough | Up to 20 ft of settlement  | ±0.50 in. | As above   | Hoses must be free of air, dirt, bubbles, dirt, and repair or replace hoses; elevation of readout device; must be installed before observation    | Hose placed in trench of uniform grade; hose depth provide connection for readout device; hoses must be installed along hose point | Simple; one person to take reading   | None                                | As above  | Readout \$150; tubing \$0.30/ft; deairing unit \$300 to \$800   |
| Single point manometer (structure or settlement)                             | Soil and Rock Instruments                               | As above                                     | Direct                          | As above                | Up to 3 ft of settlement   | ±0.10 in. | As above; problems with electronics; used in freezing temperatures   | As above  | As above; install readout at same elevation; manometer hose  | Simple; one person to establish contact; and take reading  | Battery                             | As above  | 100 ft long manometer with electronics, mercury and alcohol; single point multi-point \$450; multi-point \$300 to \$800 |
| Single point manometer (structure or settlement)                             | Telenac; Galileo  | As above                                     | Direct                          | As above                | Up to 3 ft of settlement   | ±0.20 in. | Susceptible to variations, heating due to sunlight, temperature, and freezing conditions and vandalism                                 | As above  | As above; cell is buried; must be installed below point along hose   | Simple; one person to add water, confirm and get reading   | None                                | Convert graduated reading to elevation  | Flow cell \$35; pressure gage tubing \$15; deairing unit \$300 to \$800   |
| Full profile over-flow type manometer (structure or settlement)              | Telenac   | Permanent for monitoring; recoverable        | Direct                          | As above                | Up to 10 ft of settlement  | ±0.30 in. | As above   | As above  | Casing is placed in trench; readout and pulley installed in pit with manometer provided  | One person to move and add water, confirm and get reading  | None                                | As above  | Readout manual \$200; digital \$400   |
| Full profile air balloon tube settlement device (structure or settlement)    | Soil Instruments  | Probe and readout are portable               | Direct                          | As above                | Up to 10 ft of settlement  | ±0.60 in. | Susceptible to variations in temperature and used in freezing conditions; electric problems with transducer and readout                | Periodic calibration of transducer; steel tape brought to reference point on bar; survey on station each readout observation                      | Tube placed along trench, straight, brought to reference point, and buried   | One person to move probe and reading   | Battery                             | Convert electric readouts to elevation  | Available with electromagnetic monitor horizontal movement \$650; casing \$175  |
| Full profile two liquid pressure balance manometer (structure or settlement) | User fabricated; (1977)                                 | Permanent for monitoring; may be recoverable | Direct or Remote                | As above                | Up to 20 ft of settlement  | ±0.25 in. | As above   | As above; calibration along profile   | Tubing with calibration risers; long trench of uniform grade below and above profile   | One person to move liquid in tube, calibrate and take readings   | None for readout; automatic readout | Convert readings on pressure gage to elevation for automatic readout; gives recording of tubing elevation | Tubing \$0.30/ft; manual readout \$400; automatic readout \$550   |
| Wet with fixed level sensors (surface settlement)                            | User fabricated; Cooke and (1973)                       | Permanent for monitoring; recoverable        | Remote                          | No                      | ±30 minutes; can be mechanically depressed to down 3 degrees up      | 3 min.    | Sensitive to moisture, changes in line length, structure calibration, but zero reading is temperature variation and twist of casing    | Hoses difficult to remove; repair or replacement  | Install flexible sensors in trench and bury  | Simple; one person to adjust and take reading  | Battery or AC main                  | Convert voltage readout to displacement   |   |

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|---|---|--|---------------------------------|--------|-------------------|-----------------------------|---|---------------------------------------|--|---|--------------------|---|--|
|   |   |  | REMOTE                          | DIRECT |                   |                             |   |                                       |  |   |                    |   |  |
| Electrolytic type tiltmeter (ground tilt)   | BAC   | Portable; long service records; permanent installation for best accuracy | Yes                             | Remote | 0.5 to 1.0 degree | 1.0 to 2.0 seconds of arc   | Sensitive to temperature; possible electric problems including zero drift due to residual instability of metals and cements; permanent installation may be subject to vandalism | Check for zero drift                  | Install base plates on reference stations                                    | One person with moderate training to take portable reading; device must be mounted on base plate for each reading | Battery            | Convert digital readout to tilt angle   | readout \$1500; stations to \$100 each     |
| Spirit level type tiltmeter (ground tilt)   | Galileo   | Portable; rugged long operating life                                     | Yes                             | Direct | 0.5 to 1.0 degree | 5.0 to 10.0 seconds of arc  | Moderately sensitive to temperature; reference points may be subject to vandalism   | Check zero at 180 degrees             | As above   | Simple; one person to mount level and read  | None               | Simple; direct readout of tilt angle is given                                 | readout \$1200; stations to \$100 each     |
| Vibrating wire type tiltmeter (ground tilt)   | Telemac; Mathak                                       | Portable; rugged long term stability                                     | Yes                             | Remote | 1.5 degree        | 0.3 to 10.0 seconds of arc  | Relatively insensitive to temperature or moisture; reference points may be subject to vandalism   | None                                  | As above   | One person to mount tiltmeter and take reading; time and training required depends on readout device used         | Battery            | Convert vibrating frequency, analog reading, or digital readout to tilt angle | Tiltmeter \$1200; readout \$3000 to \$4500 |
| Force balance servo-accelerometer type tiltmeter (ground tilt)                                  | Sinco; Terra; Technology; Schaevitz; Geotesting       | Portable; moderately delicate  | Yes                             | Remote | ±30 degrees       | 10.0 to 80.0 seconds of arc | As above  | None                                  | As above   | One person with moderate training to mount tiltmeter and take reading   | Battery            | Convert digital readout to tilt angle   | Tiltmeter \$2900; readout \$1100           |
| Rod extensometer, micrometer, and spirit level (ground tilt)                                    | Micro Precision Engineering; Galileo                  | Portable; rugged   | Yes                             | Remote | 0.5 to 1.0 degree | 5.0 to 10.0 seconds of arc  | Moderately sensitive to temperature; reference points may be subject to vandalism   | Check zero by readings at 180 degrees | Reference points embedded in soil, rock or structure                         | One person with moderate training to mount bar, adjust level and read   | None               | Simple; direct readout of tilt angle is given                                 | \$3500                                     |
| Rod extensometer with leveling bubble and leveling screw, and LVDT, or dial gauge (ground tilt) | User fabricated; Hendron, et al, (1975); Nason (1971) | Permanent for monitoring period  | Yes                             | Direct | 5.0 degrees       | 50.0 seconds of arc         | Susceptible to corrosion and vandalism unless protected   | None                                  | Extensometer mounted on reference points embedded in soil, rock or structure | Simple, one person to adjust screw and take reading   | None               | Convert leveling screw reading to tilt angle                                  | \$1500 to \$3500                           |