USE OF INCLINOMETERS FOR ROCK MASS MONITORING

1. Scope

1.1 This method describes the use of inclinometers for rock mass monitoring, lists some available instruments, outlines operating techniques and maintenance requirements, and presents data reduction methods.

2. Apparatus

2.1 An inclinometer is a device for measuring the deviation from the vertical of a flexible casing installed in a borehole. Deviations can be converted to displacements by trigonometric functions. Successive measurements enable the determination of the depth, magnitude, and rate of lateral movement. Fig. 1 shows a typical inclinometer installation.[6.1]

2.2 Many types of inclinometers are commercially available (Tables 1 and 2); however, the most commonly used is the probe type. This type consists of a control box and a probe which is lowered into the casing on a cable. In some probes a cantilevered pendulum with resistance strain gages, vibrating wire, or inductive transducers is used to measure cantilever deflection.[6.2] Other probes use the Wheatstone bridge principle (Slope Inclinometer Model 200 B), the servo accelerometer principle (Slope Indicator Digitilt), or a differential transformer (Dames and Moore, EDR). The probe generally requires a special flexible casing as indicated in Table 2. The electrical output from the probe is measured at the control box and converted to visual display, punched tape, or graphic form.

3. Procedure

3.1 Installation - Inclinometer casing should be installed in a near-vertical hole that intersects the zone of suspected movement.* The hole should extend beyond the zone of expected movement and at least

---

* Measurements in nonvertical holes can be made with some inclinometers; however, before planning such holes manufacturers' specifications should be checked to determine the limitations of the particular instrument being used.

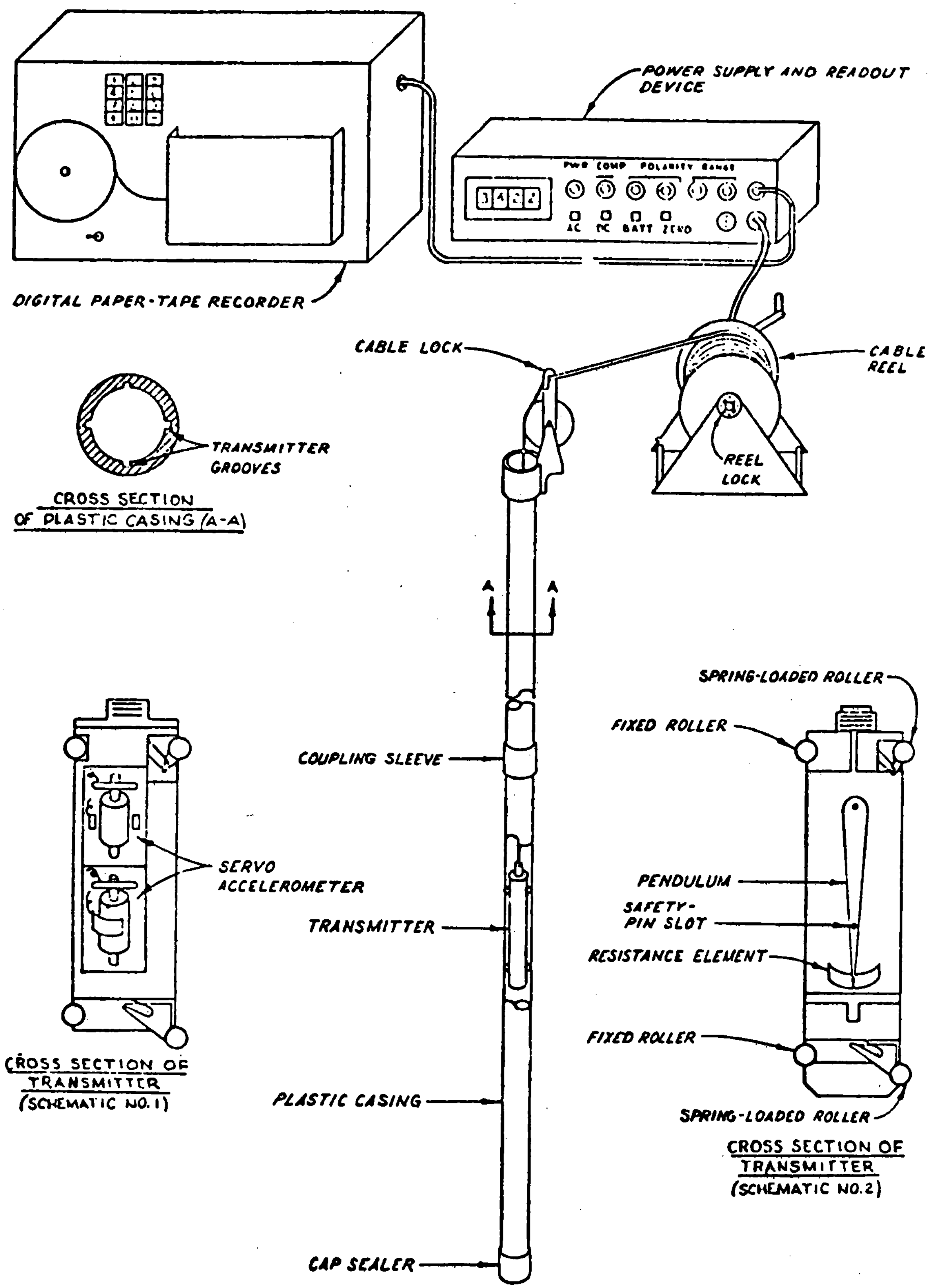


Fig. 1. Typical inclinometer installation (Leach, 1976).

Table 1. Fixed-Position Inclinometers (Franklin and Denton, 1973).

Type	Trade name	Drillhole diameter (mm)	Maximum No. and type of anchors	Range		Sensitivity		Manufacturer
				mm/m	mins	mm/m	secs	
Anchored chain of rods with transducers at pivots	Lateral deformation indicator/chain deflectometer	116–146 (cased)	Not determined	±10	35′	0·1–0·01	20–2	Eastman Interfels
Pivoted rod and proximity transducer	Multiple position deflectometer	75–100	Not determined	±12	40′	0·03	6	Terrametrics
Flexible steel strip with strain gauges in parallel to monitor	Strip gauge	75 or larger as required	Continuous	60 mm radius subject to metal thickness	5400	6·0	1200	Savage (not ye marketed)
Tiltmeter incorporating pendulum and vibrating wire measurement for mounting on retaining walls etc. or rods in drill hole	MDS 81 MDS 81B MDS 82B		As required	±3 ±6 ±12	10′ 20′ 40′	0·01–0·002 0·025–0·004 0·050–0·007	2–0·3 5–0·7 10–1·4	Maihak
Flexible breakable strip with resistors in series to detect depth of movement horizon	Shear strips	76 or larger	60 m strip lengths in series	Shear detection movement only		2–50 mm		Terrametrics

Table 2. Probe Inclinometers (EM 1110-2-1908, 1975, and Franklin and Denton, 1973).

Type	Trade Name	Approximate Casing Size mm	Casing Type	Range mm/m	Range deg	Sensitivity mm/m	Sensitivity sec	Manufacturer
Strain-gaged pendulum	CRL Inclinometer	45 x 45	Square aluminum duct	±88 from vertical	±5	0.075	15	Cementation Research
	Inclinometer	50	Aluminum tubing with keyways	360 from vertical	±20	0.2	36	Soil Instruments
	Borehole clinometer	76 x 76	Square steel tube	±175 from vertical	±10	0.1	20	Structural Behavior Eng. Lab.
	C-350 slope meter	45 x 45	Square steel tube	±577 from vertical	±30	0.075	15	Soiltest
Pendulum with rheostat	Series 200-B slope indicator	81	Aluminum tubing	±467 ±87 from vertical	±25 ±5	1.0	180	Slope Indicator
2 electrolevels at 90 deg, servomotor and compass	Slope reader	51	Plastic	±175 from vertical	±10	0.1	20	Eastman
Servo accelerometers	Digitilt	30/70/81	Aluminum/plastic tube	±577 infinite	±30 ±90	0.1	18	Slope Indicator
Pendulum with vibrating wire, 2 direction, compass or keyway	MDS 83	50 or larger	Aluminum or plastic, keyways optional	±290	±15	0.05	10	Maihak
Pendulum with vibrating wire	68-062 inclinometer	50	Aluminum alloy	±792	±45	0.15	30	ELE/Geonor
Pendulum with differential transformer, automatic recorder	Earth deformation recorder (EDR)	89	Plastic with grooves			0.3% for angles up to 4 deg; 0.15% for angles up to 8 deg		Dames & Moore
Pendulum with vibrating wire	MPF clinometer				15	1		Telemac

15 ft (4.5 m) into soil or rock in which no movement is anticipated. Allowance should be made for loss of the bottom 5 ft (1.5 m) of the hole where sediment accumulation may occur. Casing should be held in place with a sand backfill or a weak cement grout. Casings over 50 ft (15 m) deep should be checked for twist using equipment described in paragraph 4.6 since some of the casings may be received with a built-in twist which would cause considerable errors in observations.[6.3]

3.1.1 Inclinometer casings are commonly installed in either 5- or 10-ft (1.5- or 3.0-m) lengths and are available in either plastic or aluminum. Plastic casing joints are glued. Aluminum casings are coupled with aluminum couplings and riveted, Fig. 2. Care should be taken to ensure that all joints are sealed since leakage can introduce fines into grooves and cause errors in readings. Joints can be sealed with caulking and taped. Greater installation details can be obtained from manufacturers' literature[6.4, 6.5, 6.6, 6.7] or from other sources.[6.3, 6.8]

3.2 Observations - Initial observations should be made after allowing sufficient setting time for the grout around the casing or time for the backfill to settle where sand or gravel is used. Since all displacements are computed based on the position of the casing when installed, the initial position should be verified with at least three separate sets of observations. These observations should be checked closely to see that they agree within the accuracy of the inclinometer being used. Observations should be repeated until satisfactory agreement is obtained. When initial observations are made, the top of the casing should be located with respect to a point outside the zone of expected movement by conventional surveying means and its elevation determined.

3.2.1 The frequency of observations depends upon several factors, the most important of which is the rate of movement. It is necessary to read inclinometers frequently just after installation and, based on

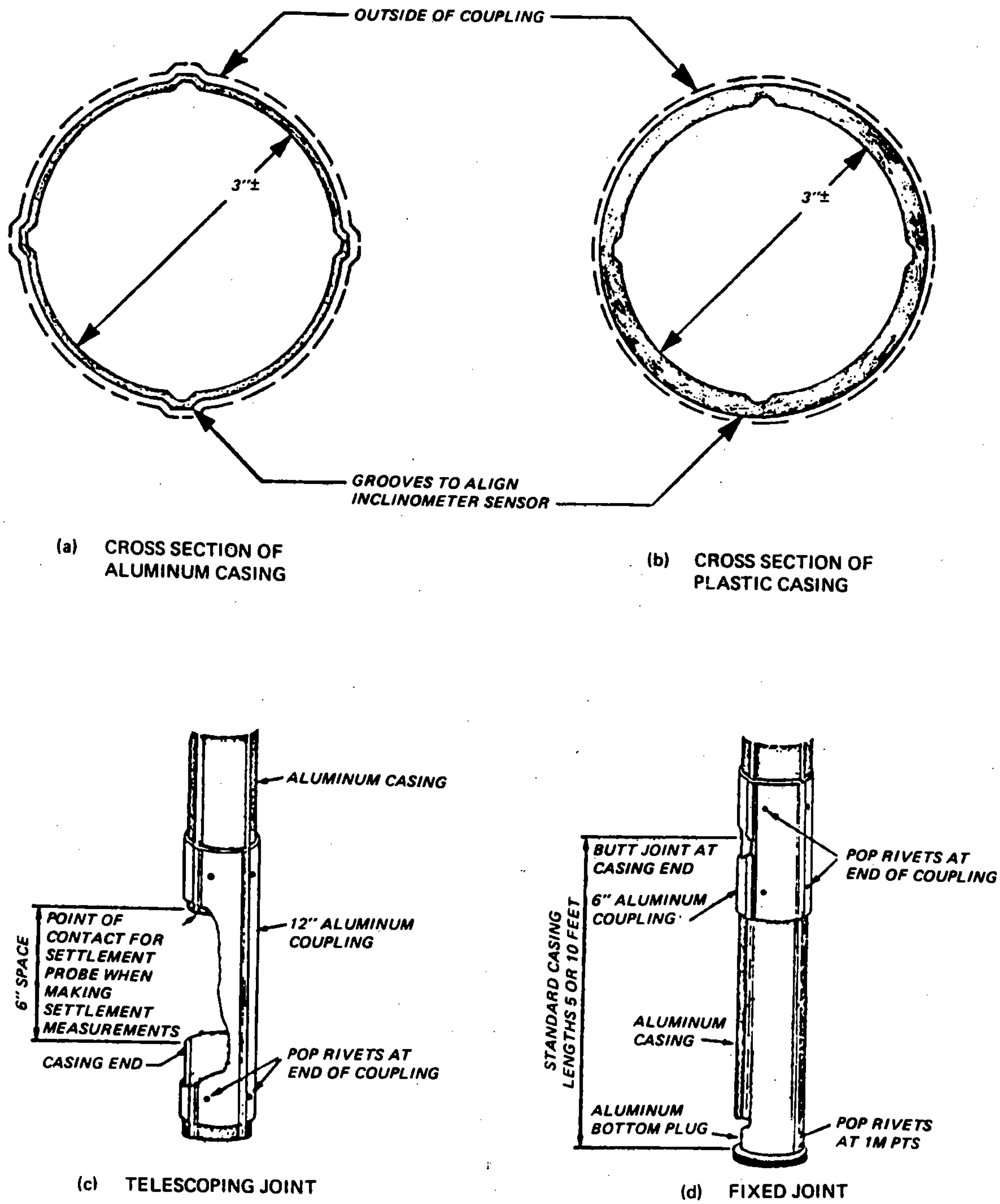


Fig. 2. Inclinometer casing details (Slope Indicator Co.).

these results, to adjust the interval of observations. Observations should coincide with observations of other instrumentation such as extensometers, piezometers, settlement devices, movement surveys, etc.

3.2.2 The procedure for obtaining readings with various inclinometers may vary slightly and manufacturers' literature should be consulted for the current procedure for a particular instrument. However, the general procedure consists of lowering the inclinometer to the bottom of the borehole and beginning the readings. The inclinometer is raised a specified interval,* readings are made, and the procedure repeated until the top of the hole is reached. The inclinometer is removed from the casing, inserted again with the guide wheels in a different groove, lowered to the bottom of the casing, and readings are again made to the top of the hole. This procedure is repeated until a set of readings is obtained for all four grooves. A field check is made by comparing the value of the sum of each set of readings (opposite grooves) and the mean of all sets of readings for the length of the casing. When variations greater than specified by the manufacturer are found, the inclinometer is relocated at that depth and an additional reading is taken. Care should be taken to ensure that readings are obtained at the same depths each time observations are made.

3.3 Maintenance - Maintenance that can be performed in the field on inclinometers is very limited. On probes using 0 ring connections between the probe and the cable, the 0 ring should be checked and replaced as necessary. Electrical connections should be kept clean and dry. On probes using batteries, the battery should be checked and charged when necessary. Manufacturers' literature should be consulted for other maintenance operations and precautions to be exercised in operation of inclinometers.

4. Data Reduction

4.1 General - The numerical values of the readings (R) obtained from observations with most inclinometers are equal to plus or minus an

---

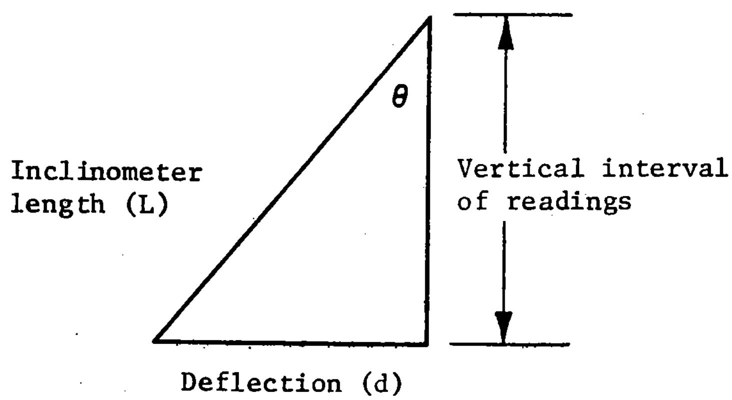
* Greatest accuracy is obtained when the interval of observations equals the wheel spacing of the probe.

instrument constant (K) times the sine of the inclination angle (θ). Expressed mathematically, this is:

$$R = \pm K \sin \theta \tag{1}$$

where the plus or minus sign indicates the direction of movement--plus away from the groove in which the measuring wheel is located and minus toward the groove.

4.1.1 To compute the deflection of the casing from the vertical at any measurement point, the right triangle depicted below is solved:



where L is the distance between measuring wheels. This results in the following expression:

$$d = L \sin \theta \tag{2}$$

The algebraic difference in readings ($R_1 - R_3$) in opposite grooves (180 deg apart) can be used to minimize errors contributed by casing and instrument irregularities.

* The formula is true for the Hall Inclinometer and the Digitilt. For the Model 200-B, the reading is equal to a constant times the tangent of the inclination angle; however, for the range of operation (±12 deg) the tangent is approximately equal to the sine. Manufacturers' literature should be consulted for applicability of this discussion to a particular instrument.

$$\text{Difference} = (R_1 - R_3) = \pm\ 2K \sin \theta \qquad (3)$$

Solving for sin θ

$$\sin \theta = \frac{\text{Difference}}{2K}$$

and substituting into Equation 2 we have

$$d = \frac{L}{2K} \cdot \text{Difference} \qquad (4)$$

4.1.2 Because the prime interest is not the magnitude of the deflection (d) but the change in deflection or magnitude of movement since the initial readings, the initial deflection of the casing must be subtracted from the deflection at some later time.

$$d = d_t - d_i = \frac{L}{2K} (\text{Difference}_t - \text{Difference}_i) \qquad (5)$$

It is also desirable to know the deflected shape of the casing with reference to a fixed point or length. This fixed length is normally considered to be the bottom of the casing so that the formula now becomes:

$$D = \sum_{m=o}^{n} (d_t - d_i) = \frac{1}{2K} \sum_{m=o}^{n} (\text{Difference}_t - \text{Difference}_i)$$

$$D = \frac{1}{2K} \sum_{m=o}^{n} \text{Change} \qquad (6)$$

where m = o is at the bottom of the casing or first measuring point and m = n is at the top of the casing or last measuring point. It is obvious from the above that the initial deflection of the casing need not be computed. Only the Difference is needed.*

---

* As stated previously, several observations should be taken initially. The Difference used above is an average of these observations.

4.2 Hand Calculations - Hand calculations of the deflections in a borehole can be made using the above formula (Equation 6) and the data sheets in Figs. 3 and 4. However, the calculations would require checking of many additions, subtractions, and multiplications for each vertical plane in which deflection measurements were made. Where several boreholes are observed, this would be a long and tedious operation and therefore computer reduction of data is usually performed.

4.3 Computer Data Reduction - Equation 6 is readily adaptable to computer reduction either from data recorded by hand or with automatic data recording devices. Computer programs are available that reduce the data, tabulate, and plot the results. Documentation of two such programs is contained in reference 6.1.

4.4 Twist Corrections - In casings over 50 ft (15 m) in length, accumulated twist can cause significant errors in the assumed direction of movement. Casing should therefore be checked for twist using commercially available equipment. If the twist is found to be significant, readings can be corrected using computer programs currently available.[6.1]

5. Reporting Results

5.1 Results of inclinometer measurements are usually reported in two ways: in tabulations of deflections with depth (Fig. 4) and in plots (Fig. 5) showing movement versus depth in relation to the structure, tunnel, or embankment near which movement is being monitored.

6. References

6.1 Leach, Roy E., "Evaluation of Some Inclinometers, Related Instruments, and Data Reduction Techniques," Miscellaneous Paper S-76-12, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi, 1976.

6.2 Franklin, J. A. and Denton, P. E., "The Monitoring of Rock Slopes," The Quarterly Journal of Engineering Geology, Vol 6, No. 3-4, 1973.

FIELD SHEET

INCLINOMETER WELL NO. IN 3

Project X - Mining of Tunnel 2
After Shove 216, Face +3

SHEET 1 OF 1

DATE 9/15/72 0900 0915 INSTR 1Z0021 READ WH/FS CALC WH CHKD HM

DEPTH	DIFF	AZ = SPRING N		DIFF	CHANGE	DIFF	AZ = SPRING S		DIFF	CHANGE
		AN	AS				BN	BS		
74		+137	-126	+263	+11		+121	-141	+262	-20
72		+136	-126	+262	+10		+142	-150	+292	-8
70		+021	-019	+040	+2		+103	-108	+211	-5
68		-045	+058	-103	+13		+132	-145	+277	-13
66		-070	+083	-153	+13		+136	-154	+290	-18
64		+068	-058	+126	+10		+380	-395	+775	-15
62		+104	-090	+194	+14		+405	-423	+828	-18
60		+104	-081	+185	+23		+373	-406	+779	-33
58		+060	-048	+108	+12		+264	-278	+542	-14
56		+053	-039	+092	+14		+245	-265	+510	-20
54		+031	-026	+057	+05		+262	-267	+529	-5
52		+066	-054	+120	+11		+186	-206	+392	-20
50		+004	+011	-007	+15		+191	-211	+402	-20
48		-010	+028	-038	+18		+315	-339	+654	-24
46		+173	-161	+334	+12		+334	-353	+687	-19
44		+145	-134	+279	+11		+376	-370	+746	+6
42		+118	-107	+227	+11		+353	-388	+741	-35
40		+092	-080	+172	+12		+326	-339	+665	-13
38		+080	-073	+153	+7		+321	-364	+685	-43
36		+038	-027	+065	+11		+293	-307	+600	-14
34		-078	+092	-170	+14		+371	-384	+755	-13
32		+083	-062	+145	+21		+318	-325	+643	-7
30		+179	-165	+344	+14		+191	-212	+403	-21
28		+192	-178	+370	+14		+154	-173	+327	-19
26		+245	-231	+476	+14		+000	-022	+022	-22
24		+256	-242	+498	+14		-079	+068	-147	-11
22		+185	-172	+357	+13		-132	+101	-233	-31
20		+114	-107	+221	+7		-044	+037	-081	-7
18		+043	-031	+074	+12		-032	+015	-047	-17
16		+009	-000	+009	+9		-014	-003	-011	-17
14		+141	-128	+269	+13		-001	-021	+020	-22
12		+124	-110	+234	+14		+009	-028	+037	-19
10		+009	+013	-004	+22		-026	+001	-027	-25
8		-076	+087	-163	+11		+021	-039	+060	-18
6		-046	+060	-106	+14		+025	-044	+069	-19
4		+038	-030	+068	+8		+040	-047	+087	-7
2		+057	-044	+101	+13		+011	-028	+039	-17
					∠180°					∠180°

Fig. 3. Field data sheet for borehole inclinometer measurements (Cording, 1975).

JOB NO 121 Sht. 5 of 5

INCLINOMETER WELL NO. IN3

SLOT BEARING B Axis: East(-) West(+)

PROJECT X - MINING of TUNNEL 2

DEPTH	INITIAL 3/21/71	DATE 9/15/72 0900 INST 180021, K .0006, C: DIFF	CHANGE	ΣCHANGE	DEFL	DATE 9/15/72 INST 180021, K .0006, C: DIFF	CHANGE	ΣCHANGE	DEFL
2'	+128	+039	-89	-650	-.39"	+050	-78	-711	-.43"
4	+156	+087	-69	-561	-.34	+090	-66	-633	-.38
6	+129	+069	-60	-492	-.30	+070	-59	-567	-.34
8	+117	+060	-57	-432	-.26	+057	-60	-508	-.30
10	+088	-027	-60	-375	-.22	-032	-65	-448	-.27
12	+083	+037	-46	-315	-.19	+033	-50	-383	-.23
14	+066	+020	-46	-269	-.16	+014	-52	-333	-.20
16	+026	-011	-37	-223	-.13	-015	-41	-281	-.17
18	-020	-047	-27	-186	-.11	-049	-29	-240	-.14
20	-068	-081	-13	-159	-.10	-083	-15	-211	-.13
22	-211	-233	-22	-146	-.09	-235	-24	-196	-.12
24	-131	-147	-16	-126	-.08	-149	-18	-172	-.10
26	+035	+022	-13	-110	-.07	+028	-7	-154	-.09
28	+324	+327	+3	-97	-.06	+333	+9	-147	-.09
30	+413	+403	-10	-100	-.06	+405	-8	-156	-.09
32	+682	+643	-39	-90	-.05	+637	-45	-148	-.09
34	+800	+755	-45	-61	-.03	+753	-47	-103	-.06
36	+640	+600	-40	-6	0	+600	-40	-56	-.03
38	+730	+685	-45	+34	+.02	+685	-45	-16	-.01
40	+700	+665	-35	+79	+.05	+661	-39	+29	+.02
42	+770	+741	-29	+114	+.07	+739	-31	+68	+.04
44	+740	+746	+6	+143	+.09	+750	+10	+99	+.06
46	+677	+687	+10	+137	+.08	+685	+8	+89	+.05
48	+641	+654	+13	+127	+.08	+649	+8	+81	+.05
50	+383	+402	+19	+114	+.07	+405	+22	+73	+.04
52	+375	+392	+17	+95	+.06	+395	+20	+51	+.03
54	+515	+529	+14	+78	+.05	+529	+14	+31	+.02
56	+494	+510	+16	+64	+.04	+504	+10	+17	+.01
58	+525	+542	+17	+48	+.03	+538	+13	+7	0
60	+770	+779	+9	+31	+.02	+777	+7	-6	0
62	+824	+828	+4	+22	+.01	+822	-2	-13	-.01
64	+780	+775	-5	+18	+.01	+769	-11	-11	-.01
66	+291	+290	-1	+23	+.01	+284	-7	0	0
68	+275	+277	+2	+24	+.01	+273	-2	+7	0
70	+207	+211	+4	+22	+.01	+205	-2	+9	+.01
72	+282	+292	+10	+18	+.01	+288	+6	+11	+.01
74	+254	+262	+8	+8	0	+259	+5	+5	0
	+8435	+12783		-652		12724		-711	

Fig. 4. Summary sheet for borehole inclinometer calculations (Cording, 1975).

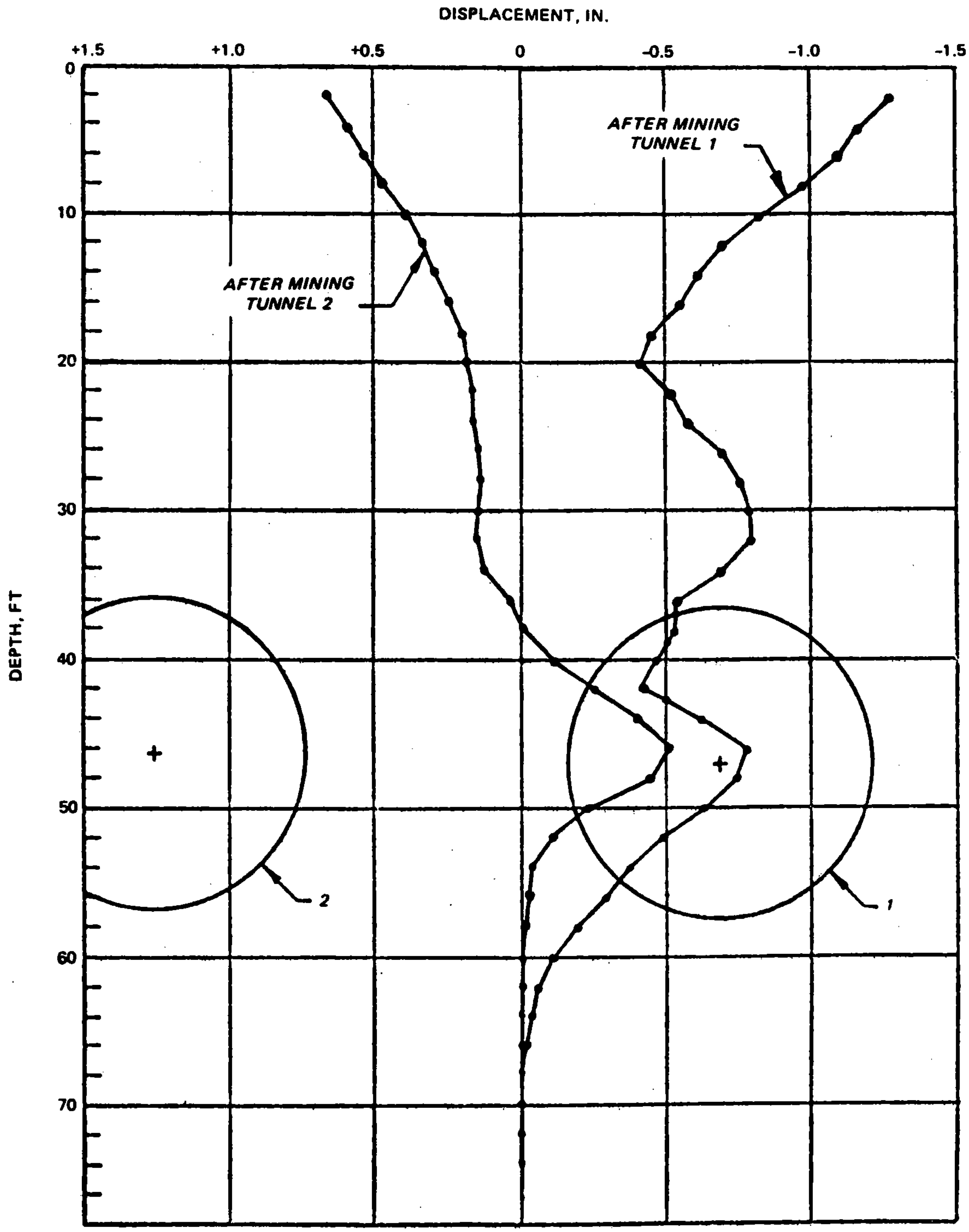


Fig. 5. Typical lateral movement profile from borehole inclinometer (Cording, 1975).

6.3 Department of the Army, Office, Chief of Engineers, "Instrumentation of Earth and Rock-Fill Dams, Part 2, Earth-Movement and Pressure Measuring Devices," Engineering Manual EM 1110-2-1908, Washington, D. C., 1975.

6.4 "Instruction Manual, Series 200-B Instrument," Seattle, Washington.

6.5 ______________________, "Instruction, Digitilt with Tally Tape Perforator Model 50303," Seattle, Washington.

6.6 Geo-Testing, Inc., "Instruction Manual, Hall Inclo-Meter System," San Rafael, California.

6.7 Soiltest, Inc., "Operating Instructions, Model C-350 Slope Meter," Evanston, Illinois.

6.8 Cording, E. J., et al., "Methods for Geotechnical Observations and Instrumentation of Tunneling," Vol I and II, NSF Research Grant GI-33644X, Department of Civil Engineering, University of Illinois, Urbana, Illinois, 1975.