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Measurement of Soil Creep by Inclinometer

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MEASUREMENT OF SOIL CREEP BY INCLINOMETER

KEY WORDS: Soil mechanics; soil creep; mass soil movement; instrumentation; measurement; inclinometer.

ABSTRACT: Continued inclinometer measurements at borehole sites installed in 1964 in northern California suggest that previously reported rates of soil creep are excessively high. Upon analysis of 35 access casings located in forested and grassland sites, no consistent direction of soil movement could be detected. In addition, no significant rate of soil creep could be found for the 8 years in which boreholes were measured. The study emphasizes the importance of obtaining intimate contact between the sides of the boreholes and the access casing, if soil creep measurements are to provide useful data.

Table 1.--Inclinometer surveys of boreholes in seven sites in northern California[1]

Plot	Azimuth (°)	Slope (pct)	1966 Time (days)	1966 Deviation[2] (°)	1966 Movement[3] (mm/yr)	1967 Time (days)	1967 Deviation[2] (°)	1967 Movement[3] (mm/yr)	1968 Time (days)	1968 Deviation[2] (°)	1968 Movement[3] (mm/yr)	1970 Time (days)	1970 Deviation[2] (°)	1970 Movement[3] (mm/yr)	1972 Time (days)	1972 Deviation[2] (°)	1972 Movement[3] (mm/yr)
2-1	250	42	—	—	—	779	+82	29.33	—	—	—	—	—	—	1788	+58	1.38
2-2	230	32	430	-165	125.91	—	—	—	691	-34	13.38	—	—	—	1441	+120	5.33
2-3	228	35	431	-65	34.19	—	—	—	669	-3	5.42	—	—	—	1467	+30	2.94
2-5	260	35	—	—	—	—	—	—	1110	-69	31.66	—	—	—	1456	+175	2.15
2-6	226	32	—	—	—	—	—	—	1107	-118	13.83	—	—	—	1460	+93	3.75
2-7	230	40	—	—	—	—	—	—	1108	-5	22.41	—	—	—	1461	-167	.16
2-8	252	40	—	—	—	—	—	—	1106	+53	16.60	—	—	—	1461	-20	2.02
4-1	185	35	—	—	—	759	-41	67.17	403	+163	[illegible]	—	—	—	—	—	—
4-2	123	19	—	—	—	751	+86	29.29	402	+12	10.13	—	—	—	—	—	—
4-102	123	19	—	—	—	—	—	—	401	+95	29.86	—	—	—	1418	-75	10.70
4-3	212	25	449	+45	71.89	—	—	—	667	-155	[illegible]	—	—	—	1455	+17	5.62
6-1	189	25	378	+63	101.35	374	-152	24.04	403	[illegible]	8.73	—	—	—	—	—	—
6-2	200	26		(missing)			(missing)		401	[illegible]	11.88	—	—	—	—	—	—
6-102	200	26	—	—	—	354	+119	27.77	403	[illegible]	25.47	—	—	—	1415	+40	3.88
6-3	182	18		(missing)			(missing)		394	+90	6.81	—	—	—	—	—	—
6-103	182	18	—	—	—	368	-28	40.17	399	+169	29.64	—	—	—	1417	-63	6.03
10-1	13	35	230	+136	118.70	—	—	—	338	-89	5.60	617	+47	8.52	718	-26	5.95
10-101	13	35	—	—	—	—		—	502	+134	7.21	616	-56	5.07	686	+113	2.46
10-102	260	45	—	—	—	—		—	—	—	—	1120	-23	5.27	686	-9	2.23
10-3	42	35	230	-169	148.36	299	[illegible]	19.80	—	—	—	1059	+162	3.95	683	+71	2.04
10-103	42	35	—	—	—	—	—	—	—	—	—	1131	-84	49.43	683	+92	80.05
10-4	340	30	231	-42	147.17	428	+98	7.04	—	—	—	1131	+111	11.03	687	-53	17.54
10-104	340	30	—	—	—	—	—	—	—	—	—	1130	-105	2.90	687	+62	11.50
11-1	199	32	232	-172	96.00	—	—	—	913	+17	1.22	—	—	—	1341	[illegible]	4.24
11-101	199	32	—	—	—	—	—	—	—	—	—	702	+79	30.88	762	-112	16.48
11-2	225	32	261	-95	135.93	—	—	—	915	+20	12.57	—	—	—	1343	+172	3.91
11-102	225	32	—	—	—	—	—	—	—	—	—	702	-83	33.31	762	-65	15.59
11-3	174	35	230	-94	67.49	437	+59	15.78	—	—	—	—	—	—	1815	-53	1.49
11-103	174	35	—	—	—	—	—	—	—	—	—	1124	+107	9.49	638	+9	8.36
11-4	165	25	230	+159	169.50	435	-63	9.32	—	—	—	—	—	—	1819	+60	1.25
11-104	165	25	—	—	—	—	—	—	—	—	—	1186	+166	14.54	631	+15	14.45
14-1	355	38	—	—	—	—	—	—	—	—	—	1096	+119	7.12	722	-91	4.21
14-2	350	40	—	—	—	—	—	—	—	—	—	1094	-157	26.09	724	+169	31.80
15-1	260	22	—	—	—	—	—	—	—	—	—	1092	+164	12.63	726	-78	2.03
15-2	265	25	—	—	—	—	—	—	—	—	—	1092	+162	29.02	726	-101	15.59

[1] Underlined values denote the initial two measurements.

[2] Degrees from downslope azimuth: + = movement to left; - = movement to right

[3] Measured movement at top of casing determined from two successive surveys

MEASUREMENT OF SOIL CREEP BY INCLINOMETER

Robert R. Ziemer[1]

INTRODUCTION

Soil creep often fails to be noticed as a major factor in slope erosion and landscape evolution--mainly because it is less visual than other mass erosion or fluvial processes. Found in varying degrees of association with most other types of soil mass movement, soil creep is the slow, downward movement of entire hillsides. On slopes composed of deep, cohesive soils, soil creep is the major process of mass erosion. This quasi-viscous movement of the soil is the result of shear stresses sufficient to produce permanent deformation, but too small to cause discrete shear failure. Creep often is a critical. factor in the progressive failure of overconsolidated materials that ultimately leads to slumps or earth flows.

Kojan (2) reported representative creep displacements for three forested sites in northern California to be about 2.165 inches (50 mm) per year on the basis of first-year results from 1965 to 1966 (table 1). Observations of the four boreholes used in his study suggest that the reported displacement rates are excessively high, In fact, no consistent direction of soil movement was detected for the duration of the study,and no significant rate of soil creep was found in the 8 years in which the boreholes were observed.

This report presents a new analysis of data already reported by Kojan (2), analysis of new data for the period 1965 to 1972, and offers some conclusions based on this more recent study.

INSTALLING AND MEASURING BOREHOLES

To study the nature of soil creep, Kojan (2) began installing a network of borehole access casings in 1964. By 1966, about 150 had been installed at 17 sites representing a wide range of soil and vegetation types in northwestern California. One site, having 73 access casings, was on, and adjacent to, an active landslide near Moraga, California. Six of the 17 sites, representing 28 access casings, were in forested locations.

[1]*Research Hydrologist, Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Dept. of Agriculture, Berkeley, Calif., stationed at Arcata, Calif.*

The access casings were installed by drilling a borehole with a 3.504-inch (8.9 cm) diameter drill bit. The holes were to be drilled at least 3.28 feet (1 m) into bedrock to obtain a stable foundation. A 2.6-inch (6 cm) OD polyvinylchloride (PVC) tube was pressed into the borehole. Because the soil was rocky, the diameter of the borehole often exceeded 3.504 inches (8.9 cm). The greater the rock content, the more irregular, and in general, the greater the diameter of the borehole.

After the plastic casing was forced into the borehole, the site was allowed to stabilize for one winter before the initial inclinometer survey was made. Kojan (2) assumed that any adjustment of the hole-casing interface would occur within this period: that is, any voids in the borehole would collapse and fill during this time. Subsequent movement in the orientation of the casing thereafter would then be due to deformation of the slope through soil creep.

The access casings were periodically surveyed by means of a *Swedish Geotechnical Institute Strain-Gage Inclinometer* (1). The instrument was modified by installing high resolution strain gages. The inclinometer was calibrated annually in the laboratory by using a high-precision sine plate, gage blocks, and a granite surface plate. Strain measurements were obtained using a *Baldwin-Lima-Hamilton Model* 120 strain indicator.

Four measurements of the orientation and inclination of the inclinometer in the casing were made at 1.64-foot (0.5 m) depth increments from the soil surface to the bottom of the hole and replicated from the bottom to the surface. Eight pairs of readings per depth increment were averaged to obtain the best estimate of strain and azimuth for that depth. These data were reduced by computer to yield a projection of the casing along the vertical plane of maximum displacement, and also on the horizontal plane by means of a polar projection (fig. 1). Comparison of the casing configuration between successive surveys showed the direction and amount of movement of the casing at different depths in the soil profile.

The first survey of the six forested sites was made in 1965, except for the 100 series holes and plots 14 and 15 in which the boreholes were drilled in 1966 and surveyed in 1967.

REANALYSIS OF DATA

To estimate the rate of natural soil creep under forest conditions, the six forested sites, having a total of 28 access casings, were studied. For ccmparison one grassland site with seven access casings, located near the forest sites, was also studied; thus, the results reported below are based on the analysis of 35 access casings (table 1).

The instrument readings obtained in the field were subsequently correlated to determine the significance of changes in instrument calibration from survey to survey (4). This correlation study revealed that the annual drift in the

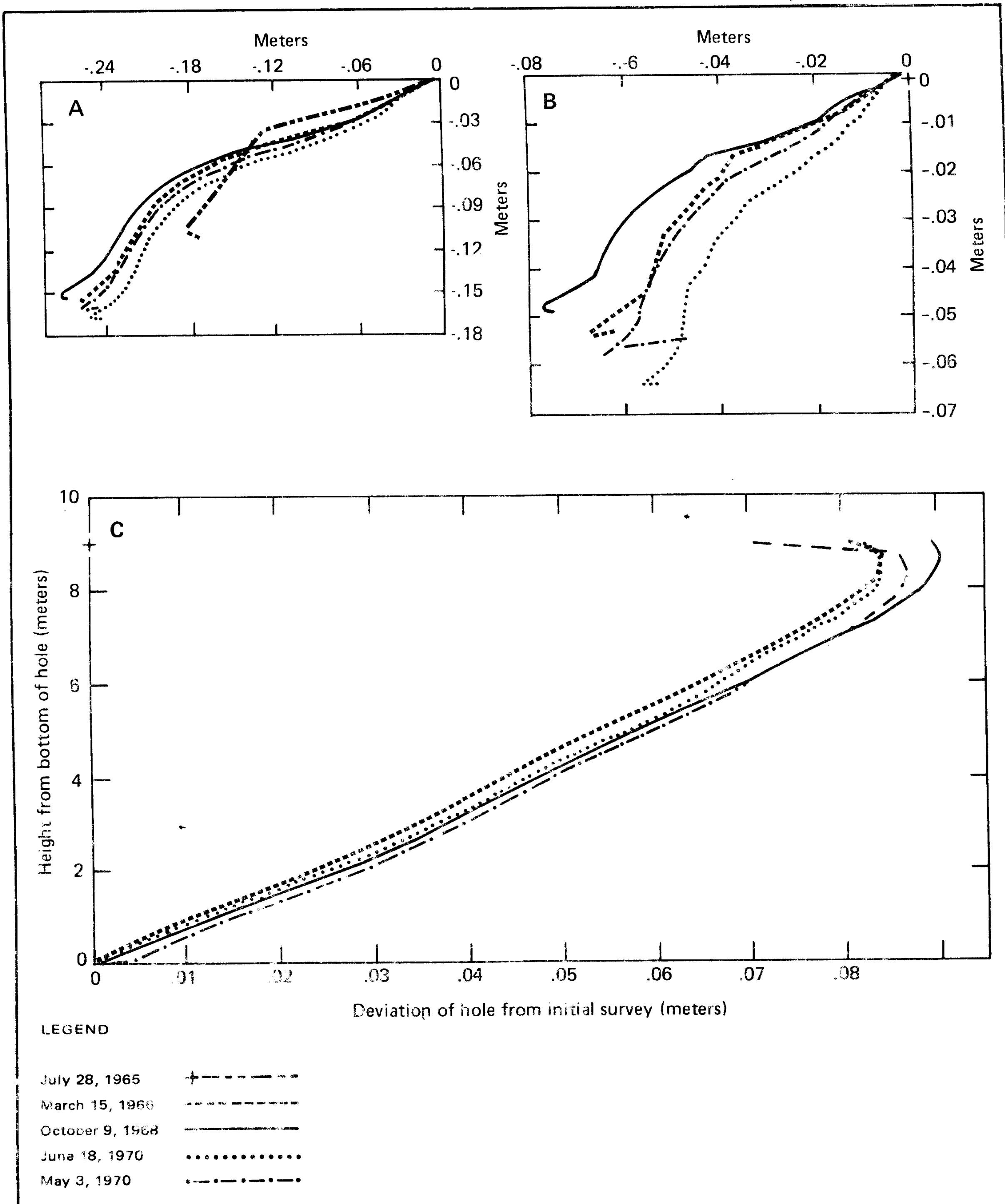

Figure 1.--Polar projections of the casing form, A, and creep deformation, B, at forested plot 10-1. Creep deformation is projected on the plane of maximum displacement, which is 230 degrees, C. Projections A and B are in the southwest quadrant.

instrument calibration was significant, and the separate annual calibration curves were necessary for proper interpretation of the field data.

The next step was to determine the precision of measurement associated with the field measurement. (The measurement error is the combined effect of random instrument "noise" and the operator's ability to null the strain indicator. In practice, these two sources of error are inseparable.) The variance of azimuth and strain reading at each measurement depth was calculated for the boreholes from actual field data, Using these variances, randomly generated azimuth and strain values were obtained. From these generated data, the magnitude of the expected measurement error can be approximated. The average error was equal to a horizontal displacement of the tap of the borehole of about .0787 inches (2 mm) per survey interval in a 26.25-foot (8-m) deep profile, The error is, calculating dispaced area was about 15.5 square inches (0.01 m^2) based on the same profile depth, The measured movement for the 85 intervals reported here exceeded .0787 inches (2 mm) in all but one interval, and exceeded three times the average error in 79 of the 85 intervals. Thus, it became clear that the observed displacement substantially exceeded the instrument error in must cases.

The steepness and direction normal to the slope were tabulated for each of the 35 borehole locations (table 1). For example, Plot 2-1 is located on a 42 percent west-southwest slope. The borehole was drilled in 1964. The first survey was made in 1965; the second in 1967; and the third in 1972, The measured movement of the top of the casing was south-southeast (82^o to the left of the slope azimuth) at a rate of 1.15 inches/year (29.33 mm/yr) or a total movement of 2.46 inches (62.60 mm) for the 779-day measurement interval. During the interval from the 1967 survey to the 1972 survey, the casing moved at a rate of .054 inches/year (1.38 mm/yr), or a total of .266 inches (6.77 mm) for the 1,788-day interval, in a south-southwesterly direction (58^0 to the left of the slope azimuth),

RESULTS

In all but three of the 35 casings, the movement during the first: survey interval was substantially larger than that determined by the second and subsequent measurement intervals, The movement during the first interval averaged nearly 14 times greater than that measured by the second interval. In the third survey, 11 of the 14 casings showed greater movement in the second interval than during the third interval. The rate of movement for the second interval averaged four times that measured in the third interval. Only three casings were measured to produce a fourth interval. Two of the three showed greater movement in the third interval than in the fourth interval, but the magnitude of the difference was insignificant.

The direction of measured movement of the borehole casing was an even more disturbing observation, As an initial hypothesis, it might be presumed that soil creep would generally proceed in the downslope direction. However, the measured direction of movement averaged 96^o from the downslope direction for the first survey interval, 76° for the second interval, and 80° for the third interval. In addition, for the first survey interval only one of the casings was moving predominantly downhill, within +30° of the slope azimuth. But eight of the casings were moving predominantly uphill, within ±150° of the slope azimuth. For the second survey interval, seven of the casings were moving downhill and seven were moving uphill. In addition, most casings nearly reversed their direction of movement between surveys. The change in direction of movement between the first and second survey intervals averaged about 130°, with about half of the tubes having a direction change exceeding 150°, Between the second and third survey intervals, the change in direction of the indicated casing movement averaged about 120°.

In addition, 1.0 locations had second casings installed in 1966. The second casing were designated with a 100 series number. Each was located within 3.28 feet (1 m) of the adjacent casing that was installed in 1964. If the measured movement of the casings was in response to soil creep, the tubes would be expected to be moving in about the same direction and at nearly the same rate; however, this was not the pattern observed. Nine measurement intervals span a time period in which direct camparison can be made (table 2). On the average, the adjacent tubes were observed to be moving 107° from one another. The range was from 75° to 163°. The rates of observed movement between the pairs were quite different. Greater movement in the more recently installed casings {the 100 series) was observed in four of the six pairs of casings for the same time interval.

DISCUSSION

The installation of access casings in boreholes without backfilling is not a generally acceptable technique, because the casing must: come in contact with the walls of the borehole. Kojan (2) attempted to solve the interface problem by drilling access holes approximately of the same diameter as the outside diameter of the casing; the casing was then forced into the hole. His idea was to develop, thereby, an almost immediate direct contact of the casing with the soil materials in the borehole wall. At the time, this technique appeared to have a potential for solving a number of difficult problems associated with backfilling boreholes in remote mountainous locations.

The first year of monitoring provided some data that tended to confirm Kojan's concept (2). Continued monitoring of the casings, however, showed an inconsistency in direction and rate of movement in adjacent casings. In addition, a damped oscillation pattern associated with time after installation was observed in the casings. These observations led to the conclusion that there was continuing differential settlement in the boreholes, and that the casings had not reached a stable contact with the borehole walls--even 8 years after installation. It is difficult from these data to determine if the rate of creep in the study sites is significant. Deformation of the casing caused by creep is masked by considerable movement of the casing that

Table 2.--Inclinometer surveys of boreholes at sites with second casings[1]

Plot	Azimuth (°)	Slope (pct)	1968			1970			1972		
			Time (days)	Deviation[2] (°)	Movement[3] (mm/yr)	Time (days)	Deviation[2] (°)	Movement[3] (mm/yr)	Time (days)	Deviation[2] (°)	Movement[3] (mm/yr)
4-2	123	19	402	+12	10.13	--	--	--	--	--	--
4-102	123	19	401	+95	29.86	--	--	--	--	--	--
6-2	200	26	401	+14	11.88	--	--	--	--	--	--
6-102	200	26	403	-61	25.47	--	--	--	--	--	--
6-3	182	18	394	+90	6.81	--	--	--	--	--	--
6-103	182	18	399	+169	29.64	--	--	--	--	--	--
10-I	13	35	--	--	--	617	+47	8.52	718	-26	5.95
10-101	13	35	--	--	--	616	-56	5.07	686	+113	2.46
10-3	42	35	--	--	--	1059	+162	3.95	683	+71	2.04
10-103	42	35	--	--	--	1131	-84	49.43	683	+92	80.05
10-4	340	30	--	--	--	1131	+111	11.03	687	-53	17.54
10-104	340	30	--	--	--	1130	-105	2.90	687	+62	11.50

[1] Underlined values denote the initial two measurements.

[2] Degrees from downslope azimuth: + = movement to left; - = movement to right.

[3] Measured movement at top of casing determined from two successive

appears to be associated with the differential settlement within the hole. The data can only be used to establish an upper limit on the rate of soil creep in the plot.

CONCLUSION

This study reiterates the need to obtain intimate contact between the sides of the borehole and the access casing if soil. creep measurements are to provide useful data, Richardson and Burroughs (3) excavated a number of boreholes for neutron access tubes and found large irregular voids in the borehole surrounding the access tubing. While drilling, the drill tends to vibrate and migrate laterally when the bit encounters a rock or other resistance. Often, the completed borehole is not a uniform cylinder, but has an irregular shape with voids and chambers of various sizes. The spaces must be filled in some manner. Ideally, the fill material should be of the same material that was removed, but this is often impossible to accomplish in practice.

An attractive alternative (which is a common technique) is to grout the borehole, working from the bottom of the borehole toward the top to eliminate air pockets. Often, this practice requires special pumping equipment and a supply of water that is not readily available in remote areas. Another common practice isto backfill the borehole with fine sand, which reaches maximum density when air-dropped. Unfortunately, in wet holes, sand is frequently supported on a slurry surface, and it is very difficult to obtain an adequate backfill below the upper level of the slurry.

D.N. Swanston, research geologist with the Forest Service Pacific Northwest Forest and Range Experiment Station is currently installing borehole inclinometer casings in a 5.12-inch (13 cm) diameter borehole, and is backfilling this rather large hole with pea-sized gravel, which more adequately sinks in the slurry and fills the annular void space around the tube. The first-year results of a study using this procedure appear promising. Thus far, little movement of the new casings has occurred since installation.

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