Inclinometers for Measuring Lateral Displacements

by

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Introduction

Inclinometers are useful in the measurement of horizontal displacement below the ground. The displacement may pertain to movement of earth dams, retaining walls, bending of sheet piles, bulk heads etc. These can also find immense application in monitoring the movement of hill slopes involving landslides, slips and other failures. Quite often, lateral movement starts in a trivial fashion and aggravates into a large movement, causing a lot of damage to both life and property. Such mishaps can be averted if the movements in the incipient stage are detected and appropriate protective measures are adopted. Thus there exists a need for a device which can measure the lateral movement precisely both in direction and magnitude.

There exists a conventional method of triangulation surveying but this technique lacks accuracy and is quite time consuming. A qualitative idea about the lateral movement of the hill slopes can be had by monitoring the deflection of a flexible pvc tube embedded in the ground. The deflection of the pvc tube occurring as a result of lateral movement of the hill slope, can be known by suspending pointers in the pvc tube. Any obstruction to the free movement of the pointer in the pvc tube is indicative of the lateral displacement of the hill slope. The depth of the plane along which the failure has taken place can be known by measuring the position of the pointer in the pvc tube where observation is experienced. This is not a conclusive method and gives only a qualitative estimation about the lateral shift of the hill slope (*Hanna, 1973 and Shannon et. al., 1962*).

The different types of inclinometers developed and in use are (*i*) contact pendulum type, (*ii*) pointer actuated wheatstone bridge type (after Wilson) (*iii*) strain gauge type, and (*iv*) accelerometer type. The contact pendulum type is a mechanical device wherein a pendulum is hinged on ball bearings and assumes a vertical position (Kallstenius and Bargau, *1961* ; Shannon *et. al.* 1962). A micrometer is provided and can be manipulated from the *top with the help of a shaft.* When the micrometer is moved and it makes a contact, a signal is obtained. By counting the necessary number of rotations of the dial to get a contact and comparing with the number of turns required when the instrument is held in the vertical position, the lateral shift can be estimated (Shannon *et. al.*, 1962).

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In the strain gauge type, a strain gauge is fixed on the leaf spring and is stressed by a weight. This is encased in a cylindrical probe which is inserted in a flexible tube. Any change in the inclination of the tube will be accompanied by a change in the length or resistance of the strain gauge (Kallstenius and Bargau, 1961 ; Murray and Irwin, 1970) but this type of inclinometer is affected by temperature changes and dampness in the borehole. Accelerometer type inclinometer is very precise and reliable but its cost of fabrication is enormous. As a consequence, the development and fabrication of pointer type of inclinometer was taken up by Wilson and others (Bjerrum, Kenny and Kjaerusli, 1965 ; Shannon, Wilson, and Mees, 1962, Wilson 1962, 1967; Wilson and Hencock, 1965).

Pointer Type Inclinometer

Principle

The device works on the Wheatstone bridge principle. A freely suspended pointer divides the linear wound resistance into two arms R_1 and R_2 and other two arms R_3 and R_4 are provided by the potentiometer. When R_1/R_2 and R_3/R_4 balance each other, a null point in the galvonometer is obtained. The reading in the potentiometer depends on the position of the pointer on the wire wound resistance. The position of the pointer in turn depends on the inclination of the inclinometer.

Construction

The inclinometer consists of a cyclindrical probe made of aluminium and measures about 40 cm in length, 6.25 cm in diameter and is joined to a control box with the help of a connecting cable with markings. Inside the probe, there is a freely suspended pointer. The pointer with its top end attached to a drum, moves freely on a linearly wound electrical resistance. The linearly wound wire resistance is in the shape of an arc such that the pointer moves through equal distance on the electrical resistance for equal angular displacements on either side of its normal position. This arrangement has been contrived to ensure accuracy of results over the whole range of displacements.

When the circuit is completed by pressing the knob in the control box, the pointer is attracted towards the resistance by a relay and makes contact with it. The linearly wound wire resistance is fixed in a perspex groove. The control box has a coil type potentiometer with counter and a galvanometer. The connecting wire is a three-core wire and is graduated at an interval of every half a meter.

Operation

Before the inclinometer is used in-situ for the measurement of lateral movement, calibration is done in the laboratory between the lateral displacement at a given depth and the reading in the potentiometer, and it is plotted as a curve. A casing pipe with two pairs of grooves at right angle to each other is fixed on a wooden plank and the plank is suspended freely. The probe has two pairs of guide wheels. One pair of fixed wheels is mounted vertically and aligned along the axis of the probe. On the other side, diametrically opposite, is another pair of spring mounted guide wheels. The instrument is so designed that the inclination in the plane defined by these four wheels is directly proportional to the potentiometer reading when the circuit is balanced. The direction of the plane is determined by the fixed wheels. If the fixed wheels traverse the north groove, the instrument is said to be taking North reading. Similarly the instrument is said to be taking South reading when the fixed wheels are tracking the south groove. Observations are taken in a 7.5 cm diameter borehole lined with special casing pipes of aluminium with two sets of longitudinal grooves as described above. These casing pipes, available in 3 m length, are joined together by a coupler. The whole assembly comprising the probe, control box and the casing pipe is shown in Fig. 1. The circuit diagram of the inclinometer is shown in Fig. 2.

The inclinometer measures the inclination of the casing pipe inserted in the borehole at short intervals of depth. One set of readings is taken with fixed wheels tracking the North groove and is designated as DN. The second set of readings is taken with fixed wheels in South groove, called DS. The inclinometer is so adjusted that inclination '*i*' of casing from the vertical is computed from the following relation.

$$\tan i = \frac{DN - DS}{2k}$$

where k is a constant.

Any change in inclination at a given depth produces a change in the difference of dial readings

$$\triangle\ dial = (DN' - DS') - (DN - DS)$$

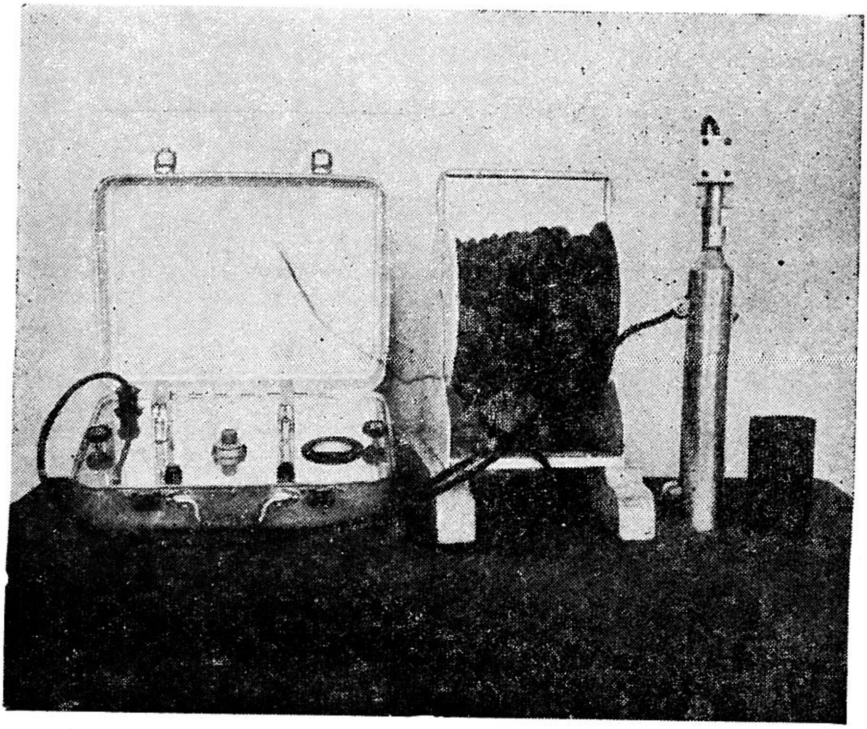

FIGURE 1 Pointer Actuated Inclinometer-Complete Assembly

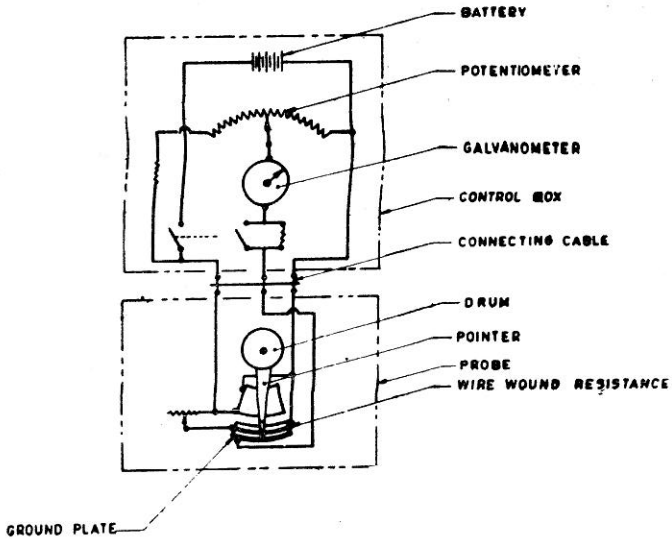

FIGURE 2 Circuit Diagram of Pointer Type Inclinometer

where DN' and DS' are new readings in the North and South grooves respectively.

$$\tan i = \frac{\triangle \, dial}{2k}$$

The lateral movement at each interval depth is given by

$$\triangle M = l \; (\triangle \; \tan i) = \frac{l\,[\,(DN'-DS')-(DN-DS)\,]}{2k}$$

$$= \frac{l}{2k}\,(\triangle \; dial)$$

Calibration

The inclinometer is first calibrated in the laboratory to get the value of the constant k. The special casing pipe was fixed longitudinally on a wooden plank which was suspended freely to have movement in the vertical plane. The casing pipe alongwith the plank was fixed vertically straight and the initial readings at depths of 1, 2 and 3 m were taken. The lower tip of the plank was shifted by 2.5 cm and a new set of readings was taken both in the North and South azimuths. Knowing the lateral displacement of the plank and depth of the probe

$$\tan i = \frac{2.5}{300} = \frac{\triangle \text{ dial}}{2k}$$

Knowing, the dial reading, value of k was computed. Table 1 gives the values of k as obtained for different lateral displacements of the lower tip of the grooved casing pipe. The value of k depends on the magnitude, shape of the wire wound resistance and on the geometrical shape of the pointer.

There is a slight scatter in the value of k as obtained from different observations. On average, k was taken to be equal to 1500.

TABLE 1

Determination of the Constant 'k'

Sr. No.	Displacement at a depth of 3 m (cm)	Value of 'k'
1	2.5	1620
2	5.0	1375
3	7.5	1375
4	10.0	1375
5	15.0	1650

Measurement of Lateral Displacement

Having determined the value of 'k', the inclinometer was used for the measurement of lateral displacement. The inclinometer was displaced through a known distance and the same displacement was computed from the relation

$$m = \frac{l}{2k} (\triangle \text{dial})$$

The value thus obtained was compared with the known one and these two values showed a good degree of agreement as shown in Table 2.

TABLE 2

Comparison of Computed and Actual Displacements at a Depth of 3.0 m

Sr. No.	Actual Displacement (cm)	Computed Displacement (cm)
1	1.37	1.25
2	2.50	2.45
3	5.04	5.00
4	10.00	9.16
5	15.00	14.66

Range of Measurement

The maximum displacement which can be accurately measured by the inclinometer was also determined by displacing the lower tip of the grooved casing pipe to one side and observations were taken for each 2.5 cm displacement. Potentiometer readings were continued to be taken for increasing displacements. Displacements computed from mathematical expression already given in the text, were compared to the actual values and as already shown in Table 2, these values exhibited a good agreement.

It was observed that inclinometer gave consistent readings upto a lateral displacement of 22.5 cm at a depth of 3.0 m and thereafter, the potentiometer gave erratic and inconsistent readings. At that displacement, the contact of the pointer with the resistance became irregular. A displacement of 22.5 cm at a depth of 3.0 m corresponds to angular displacement of about 5.0°. Thus the present inclinometer can measure a displacement of 5° with a fair degree of accuracy. Experience in monitoring lateral movement in the field has shown that lateral movements are quite small in the incipient stage and can well be monitored. This gives the belief that the present device can be gainfully used to monitor the magnitude of displacements actually experienced by hill slopes.

Sensitivity

As inclinometer must have sensitivity of a high order if it is to measure trivial movements of the slopes in the incipient stage. The sensitivity of the foresaid inclinometer was determined by measuring the minimum displacement which would produce a measurable change in the potentiometer reading. The displacement of the lower end of the casing pipe was reduced in stages and the corresponding change in the potentiometer reading was recorded. In the course of taking observations, it was noted that a shift of 0.5 cm at a depth of 300 cm was the minimum displacement which could be measured. This is equivalent to an angular displacement of 6 min. So this inclinometer was found to possess a sensitivity of 6 min which can be deemed to be fairly high in the measurement of lateral movement. For the purpose of examining the accuracy of the results when the displacement is extremely small, the lower tip of the casing pipe was displaced through a distance of 0.5 cm and the corresponding difference in dial readings of the potentiometer were recorded. Displacements as actually imparted in the inclinometer and as computed from the dial reading are given in Table 3.

TABLE 3

Comparison of Small Displacements to Measure Sensitivity

Sr. No.	Actual Displacement (minutes)	Displacement as computed (minutes)
1	6	6
2	7	6
3	7	6
4	14	16

The close agreement between the values supports the fact that the inclinometer possesses adequate degree of sensitivity combined with accuracy. Besides, the inclinometer was found to have same amount of sensitivity at all displacements from its normal position.

Rod Inclinometer

It is a simple mechanical device to measure lateral movement at shallow depths. Essentially, it consists of a central shaft of about 15 mm diameter and is provided with a circular disc at its lower end for proper placement of the inclinometer on the top of the borehole. The circular disc can be moved and tightened to the shaft at a suitable position. In the middle is attached a metallic, longitudinal strip which can be moved around the shaft and tightened in any particular direction. On the outer edge of the strip is hinged a spirit level. With the help of a screw gauge fixed on the bottom of the strip at its inner edge, the spirit level can be tilted upward or downward to bring it finally in the horizontal position. The upward or downward movement of the spirit level can be measured from the position of the screw on the scale of the micrometer. In the upper portion of the shaft, a circular disc is provided with angular divisions from 0 to 360° marked on it. The disc is provided with two slits, which move together. These slits are used to know the direction of the movement.

Functional Principle

A borehole is made at the site where the lateral movement is required to be measured and a pvc tube is inserted in the borehole. The annular space between the pvc tube and the borehole is back-filled with the local soil. The lower end of the shaft of the inclinometer is inserted in the pvc tube and the spirit level is directed along the azimuth in which the lateral movement is expected to take place. The pair of slits are also aligned along the spirit level such that these are in the, same line and the direction is read on the angular scale. By moving the screw gauge/micrometer, the spirit level is brought in the horizontal position and the reading is taken on the micrometer scale. In the subsequent observation to be taken after some period has elapsed, the spirit level is again brought to the horizontal position and the new reading on the scale of the micrometer is noted. The difference of the previous and the new reading on the scale of the micrometer is noted. This difference is interpreted in terms of lateral displacement either in degrees or in centimeters.

Calibration

The calibration between the reading on the micrometer scale and lateral displacement was done by holding the inclinometer straight and the micrometer reading was noted for level position of the spirit level. The whole set-up showing the inclinometer and the calibration arrangement are given in Figs. 3 (a, b). The inclinometer was tilted by displacing the top end of the shaft of inclinometer by 5 mm and the spirit level was brought to level position by moving the micrometer screw and the new reading was noted. For this lateral shift, the angular displacement was also computed. The lateral displacement of the top end of the central shaft was increased to 5 cm in stages of 5 mm and for each new position, the micrometer reading was recorded. Test data depicting the relationship between (*i*) the lateral displacement and micrometer reading and (*ii*) the angular displacement and the micrometer reading, are given in Table 4 and shown in Figs. 4 (*a*, *b*).

Discussion

The pointer actuated type of inclinometer is a sensitive device to monitor the lateral movements both at shallow and large depths. This device can measure lateral movements over a fairly wide range with a reasonable degree of accuracy. As can be discerned from Table 2, displacements computed from the inclinometer observations are quite

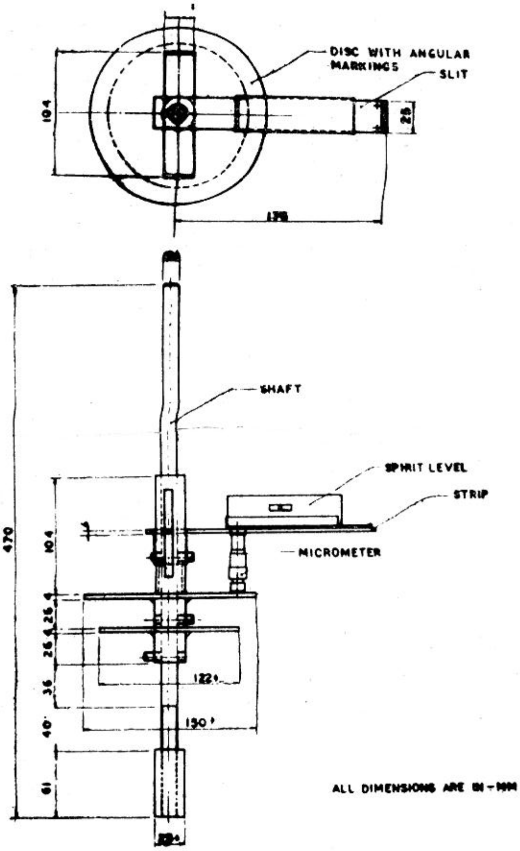

FIGURE 3*a* Rod Inclinometer

TABLE 4

Micrometer Readings with Different Lateral and Angular Displacements

Sr. No.	Reading on the micrometer scale (100 div=1 mm)	Lateral displace-ment (cm)	Angular displace-ment (deg) (computed)	Angular displacement (deg) (measured)
1	95	0.0	0	0
2	205	0.5	33′	1
3	283	1.0	1°—9′	2
4	390	1.5	1°—43′	2.5
5	490	2.0	2°—18′	3.0
6	605	2.5	2°—52′	3.5
7	705	3.0	3°—26′	4.0
8	807	3.5	4°—0′	4.5
9	910	4.0	4°—36′	5.0
10	1000	4.5	5°—9′	5.5

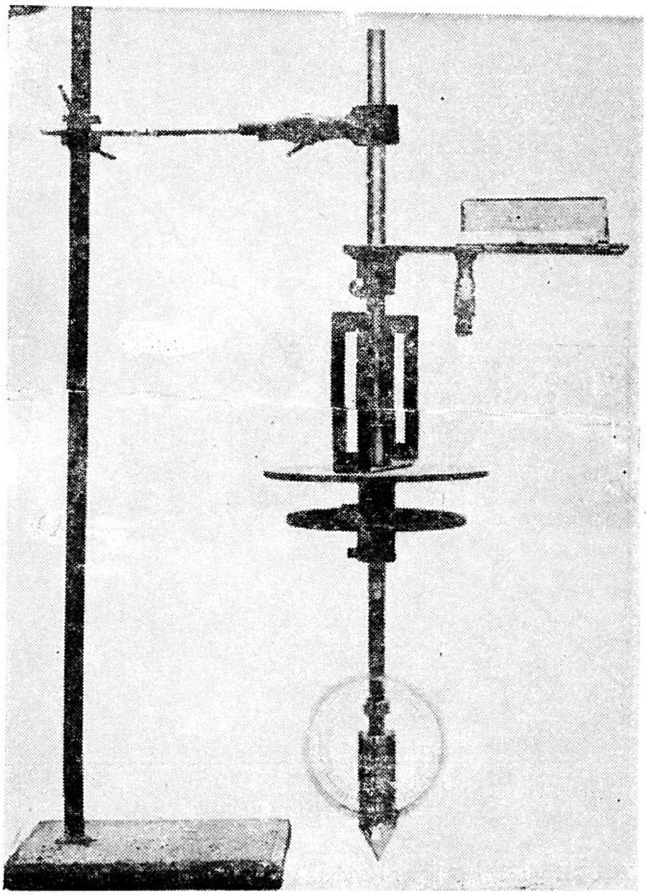

FIGURE 3*b* Calibration Arrangement for Rod Inclinometer

in concurrence with the actual displacements in a large measure. The scatter between the two values is about five percent which is not of much consequence. In fact, the values computed from inclinometer observations are consistently slightly higher than the actual ones. This one side consistent difference can be attributed to the fact that value of '*k*' has been taken as an approximate average and possibly, this may be on the excessive side. Laboratory measurements have shown that the inclinometer can measure movement equivalent to an angular displacement of five degrees. However at large displacements, it was observed that the pointer sometimes fails to make a contact with the wire resistance. Besides, at large displacements, the consistency of results diminishes slightly. An improvement in the shape of the pointer and having more uniformity in number of turns of the resistance wire per unit length are contemplated to achieve better results.

The rod inclinometer can serve as a convenient tool to measure displacement in the lateral direction at shallow depths. Its range of measurement also extends to about 5 degrees. As can be seen from Table 4, the angular displacements calculated from physical measurements

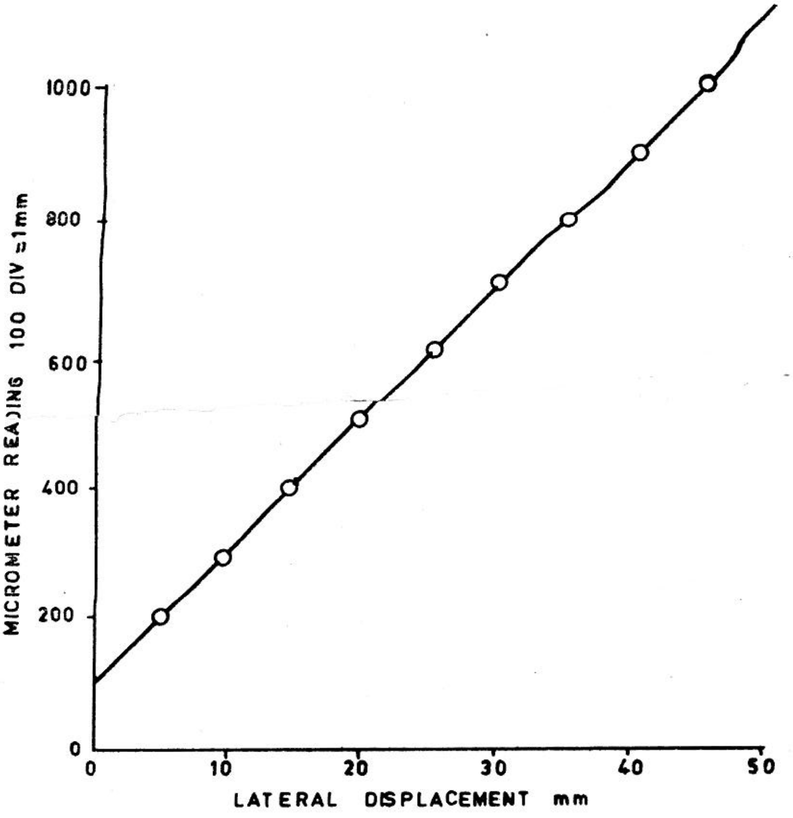

FIGURE 4*a* Micrometer Reading versus Lateral Displacement

and those actually observed, do not differ appreciably. Whatever difference exists between these two sets of values is because of the fact that visual observations cannot measure the fraction of a degree very precisely. In actual practice, measurements of lateral movement are made at each metre of the total depth of the borehole. Sometimes when there is a sharp sliding along a given plane situated at some depth, the precise measurement of depth can be made by taking observations at shorter intervals. It has been seen that pointer type inclinometer gives erratic results sometimes if handled carelessly. This may happen due to dislodging of the fixed wheels of the probe from the groove provided in the casing pipe as this results in change of azimuth.

1. The pointer actuated electrical inclinometer can be used to measure lateral movement with a fair degree of precision. The device has a sensitivity of 6 min. and can measure angular displacements upto 5 deg.

2. For shallow depths, rod inclinometer serves as an acceptable substitute for the measurement of lateral movement.

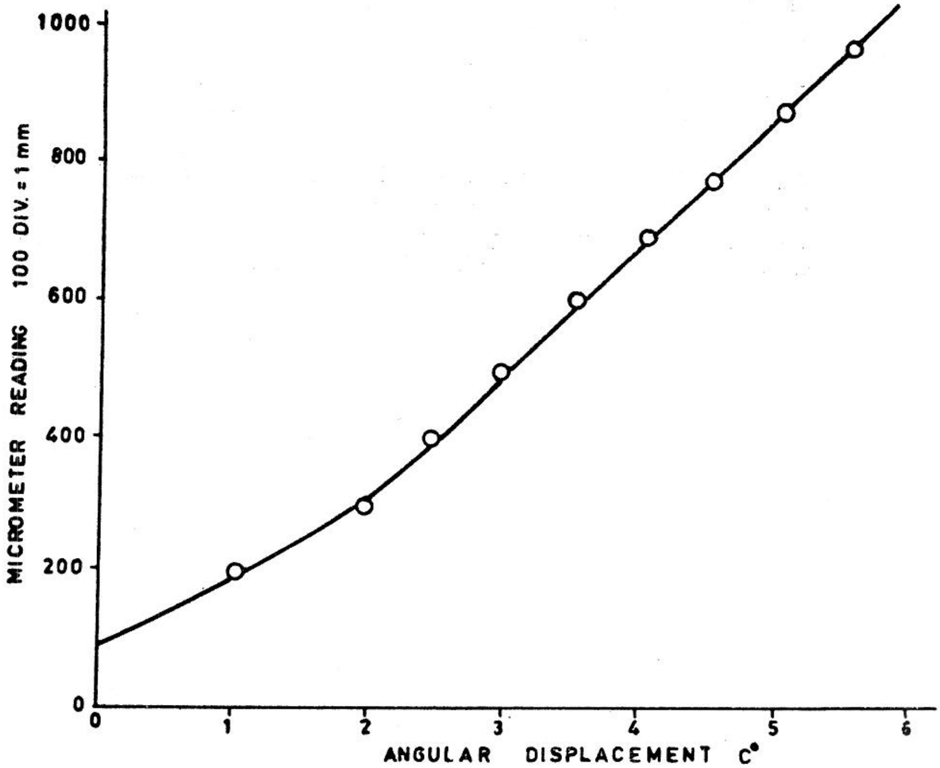

FIGURE 4*b* Micrometer Reading versus Angular Displacement

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