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AN INSTRUMENT FOR OBSERVATIONS OF SECULAR GROUND TILT

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Abstract

This paper deals with the design and development of a portable water tube tiltmeter. This instrument can be used for measurements of the secular ground tilt in seismic areas. Field procedure for making these measurements have been outlined. Programmes for measuring the ground tilt with this system have already been commenced at the Yammuna Hydel Scheme Project site, Dehradun and in the Pophali Power House area in Maharashtra.

Introduction

It has long been known that in certain regions of the earth, geological processes continue to build up strain. When the strain at any point exceeds the breaking strength of the rocks, rupture starts and propogates for considerable distances. If it were possible to measure ground deformation accompanying the strain build-up in a seismically active region, it might show some correlation between the secular earth's surface tilting and the seismicity. It is felt that if the measurements are made over a long period in seismically active areas, these along with other relevent geophysical data may form a sound basis for predicting earthquakes.

In order to measure the secular ground tilt associated with ground deformations it was decided to develop a portable water tube tilt meter. Instruments for such observations employing same principle are available United states of America and Japan, but are not available commercially. The first set shown in figure 1 was completed in December 1967. The experience gained during the development of this set however led to an improved design. Another set was fabricated in April 1968 incorporating these new features. The paper is intended to report this second instrument in detail.

Description of the Portable Water Tube Tiltmeter System

The system is shown in Figure 2. It consists of two identical cylindrical vessels of 105 mm inner diameter, 120 mm outer diameter and 215 mm height. A built-in partition is provided at the mid height of the vessel. On the lower side of this partition is attached a micrometer spindle whose free end intrudes in the upper half of the vessel through a water leak proof cell, and is capable of being moved up and down by 30 mm. A rack and pinion arrangement is provided to slowly move the micrometer disc whose least count is .0005 mm (1/2 micron). The main scale is in mm and is fixed on the cylindrical vessel itself. A viewing window of 35 mm diameter, is placed above the partition. An adjustable torch bulb is attached to illuminate the free end of the micrometer spindle. The two vessels are connected by a suitable diameter alkathine tubing The water is let in either through the inspection window at the top lid or by removing the top lid. The base plates of these tiltmeters are provided with a seat to ensure their being fixed up in exactly the same position on the tilt base during successive mesurements. A microscope with 30 × magnification fixed to a suitable stand is used for viewing the micrometer spindle's free end when it just touchs the water surface from below. This is done by gradually raising the micrometer splindle to the water surface until the pointer just coincides with its image.

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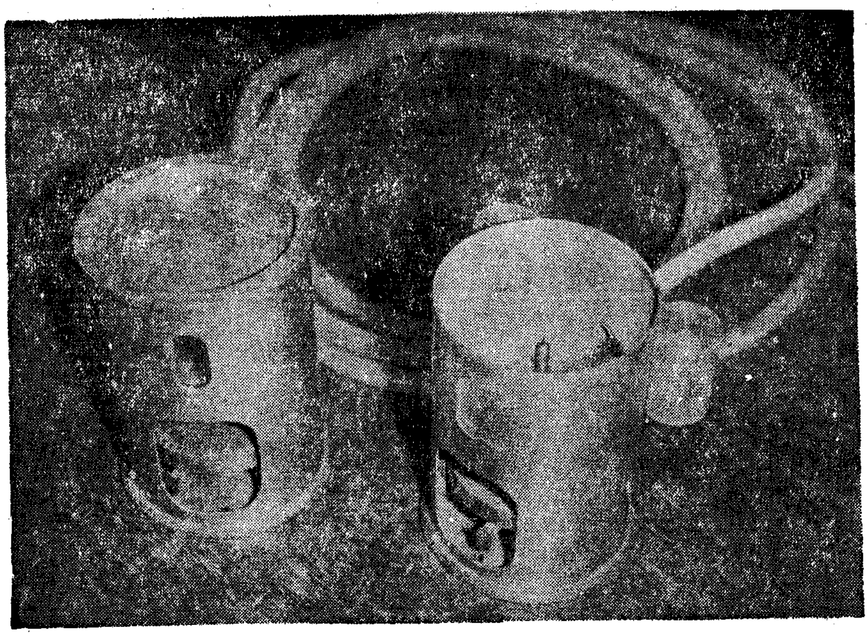

Fig. 1. Portable Water Tube Tiltmeter System in its first stage of development

Fig. 2. Improved design of Portable water Tube Tiltmeter System being used for field measurements

Equation of motion of the water level in the system

For the present purpose, water can be considered as an ideal homogeneous, frictionless, continuous and imcompressible fluid. Let us consider the equation of motion of the water surface (Eaton 59) in the tiltmeter system as shown in Fig. 3.

From Eulers equation we can write –

$$\frac{\partial}{\partial s}\left(\tfrac{1}{2}v^2\right) + \frac{1}{\rho}\frac{\partial p}{\partial s} + g\frac{\partial z}{\partial s} + \frac{\partial v}{\partial t} = 0$$

Where the body force is conservative and other symbols have the following meaning.

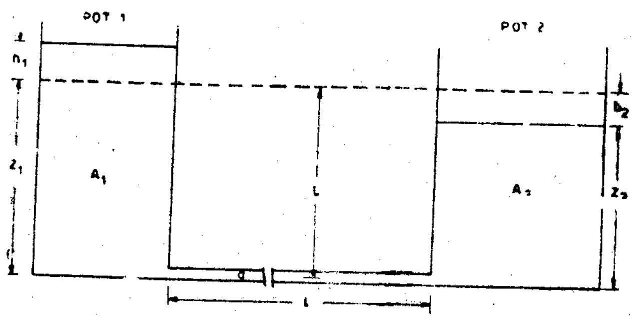

Fig. 3

- v Velocity of the water
- ds element of stream-line
- p external pressure
- z height above arbitrary datum
- g acceleration of gravity
- ρ density of the water

The line integral of Euler's equation along a stream line from Pot 1 to Pot 2 through the water tube can be written.

$$\tfrac{1}{2}\left(v_2^2 - v_1^2\right) + \frac{1}{\rho}\left(P_2 - P_1\right) + g\left(Z_2 - Z_1\right) + \frac{dV_1}{dt}\int_1^2 \frac{A_1}{A(s)}\,ds = 0 \qquad (1)$$

where A_1, A_2 are the cross sectional areas of Pot 1 and Pot 2.

a the cross sectional areas of the Water tube.

l the length of water tube.

L the height of water surfaces in the two pots above the centre of the water tube after equilibrium has been established.

Z, Z_2 the heights above datum of the water surfaces in Pot 1 and Pot 2 and

h_1, h_2 the height of water surfaces in Pot 1 and Pot 2 above its equilibrium position.

equation (1) can than be written in the following form :

$$\rho\left(L + \frac{A_1}{a}l + \frac{A_1}{A_2}L\right) + \frac{\rho}{2}\left(1 - \frac{A_1^2}{A_2^2}\right)\left(\frac{dh}{dt}\right)^2 + \rho g\left(1 + \frac{A_1}{A_2}\right)h = 0 \qquad (2)$$

In the system chosen, the cross-sectional area of either pots is the same, thus

$$\rho\left(2L + \frac{A}{a}l\right)\frac{d^2h}{dt^2} + 2gh = 0 \qquad (3)$$

The first term is the inertia pressure resisting any change in the motion of the water and the second term is the pressure driving the system toward equilibrium. Another term need be included in the equation to account for the pressure required to overcome the internal friction in the water flowing through the tube, since the tube is long and narrow. By Hagen-Poiseuille law this term can be calculated and included in the equation.

$$\frac{d^2h}{dt^2} + \frac{8\,\pi\,\eta\,l\,A}{\rho\,a^2\left(2\,L + \frac{A}{a}\quad\right)}\,\frac{dh}{dt} + \frac{2\,g\,h}{\left(2L + \frac{A}{a}\,l\right)} = 0 \tag{4}$$

where η is the viscosity of water. For the system under discussion $2L << (A/2)\,l$. Equation (4) can therefore be written as follows :

$$\frac{d^2h}{dt^2} + \frac{\pi\,\eta}{a\,\rho}\,\frac{dh}{dt} + \frac{2\,g\,a}{l\,A}\,h = 0 \tag{5}$$

This equation can be solved for 'h' and the critical values of 'a' and 'A' to give critically damped movement of the water surface when connected by a usable tube length. Critical damping is necessary so that the water surface comes to rest in the shortest time after installation of the systems. The first set of tiltmeters was fabricated and tested in April 1968. These tiltmeter pots were initially designed in order to obtain critical damping with a tube length of 55 meters. This length was chosen to enable the system to be placed on tilt bases as far apart as about 50 meters. The resulting values for tube diameter and the pot diameter were respectively 15 mm and 105 mm. These are now being used for measurements of tilts at the Yammuna Hydel Scheme project site and also in the Koyna region. In both these cases the two vessels are placed on specially designed tilt base hubs which have been fixed at interval of about 20 and 30 meters depending upon the availability of tunnel space. The shorter distances between the bases however necessitate the tube to be coiled up, thus retaining the original response.

Laboratory Tests for studying the performance of the Portable Water Tube Tiltmeter System

The unaided eye can resolve a separation of upto 0.1 mm. However, in this system a microscope of only 30 × magnification has been used. As the setting is made by viewing the separation between the pointer and its image, the gap between the water surface and the pointer is effectively doubled. With these considerations it should be possible to make a setting with an accnracy of $\frac{0{\cdot}1}{30 \times 2}$ mm i.e. about two microns. The least count of the instrument which is 0.5 micron can therefore permit a convenient reading for this setting in order to tests the setting accuracy and also to study the influence of personal error, the following two kinds of tests were carried out in the laboratory.

(a) *Repeatability test :* The system was placed on two fixed bases and observations taken both with and without changing the common water level during the test. Each reading was found to deviate by not more than ± 3 micron thus giving an observation of of relative elevation correct within ± 6 micron. However, this error could be reduced by proper training of the eye, since the contribution of personal error was found to be considerable.

(b) *Testing by measurement of the sag af a beam supported at two ends and loaded at the middle :* A 6″×8″ steel channel of U shaped section and 18 feet in length was supported on two knife edges 16 feet apart. Arrangement was made for loading the channel in the centre at 1 kg. steps One tilt base was fixed a ltttle distance away from the beam and the other was built on the steel channel itself. The sag could be measured with an accuracy comparable with the results abtained theoretically.

Considerations influencing observation procedures

The ground deformation in any region may be considered to consist of two components (i) local deformation and (ii) the regional deformation. Local deformation may vary widely both in space and time and may arise from various causes, the most important of which are enumerated below :

(i) Differential surface heating,
(ii) Local surface loading,
(iii) Under Mining,
(iv) Action of ocean tides on the coast.

The deformation due to differential surface heating will in general show diurnal and seasonal variations. Local surface loading in a region may be due to heavy engineering installations, reservior loading at a dam site or volcanic activity, and may result in observable ground deformations. Similarly undermined areas might undergo a gradual subsidence producing an observable ground deformation. Deformations have also been reported in coastal areas with changes in the sea level. All these local deformations appear to have the same order but may be much larger as compared with the regional deformation associated with the elastic strain buid-up in the crust in seismically activc areas. The tiltmeter would respond to the total deformation suffered by the region but the effects of various local factors can be eliminated by planning the observations suitably.

The component of local deformation outlined above is expected to have different sign at different points. Thus, if the distance between two points selected for observation is large they should be expected to be eliminated from the readings. For the present purpose 20 to 30 M can be consihered large distance (Hagiwara 47). The influence of temperature variations on the tilt observations can also be eliminated by installing the measuring system in underground tunnels. A field procedure accordingly framed to bring out only the effect of the regional tilt is described below :

Field Procedure

The instrument is installed in L shaped underground tunnels. Three tilt bases are located at intervals of 30 M and each of these is allotted a number and its location specified in the records. The portable system with its accessories can be carried to the observatory in three boxes. The two smaller boxes contain one tiltmeter each along with their accessories and the third contains the alkathine tubing and other accessories and tools. Great care is taken to ensure that during successive observations the same pot, which is also numbered, is replaced on a given base. The reading are tabulated as shown in Table 1.

TABLE 1

Format for reporting Tiltmeter Observations

OBS No. First *Date* 22.9.68 *Time* 10.50 A.M.
Location Cable Passage, Power House, Pophali *Temperature* 26.5° C

Tilt Base No	(ONE)			(TWO)			Height of Tilt base in earlier Col. above the Other (mm).
Pot No.	(ONE)			(TWO)			
	mm			mm			
Sl. No.	00.0	.000/2	00.000	00.0	.000/2	00.000	
(1)	10.50	287	10.643	11.00	430	11.215	
(2)	10.50	283	10.542	11.00	435	11.213	11.214
(3)	10.50	280	11.540	11.00	428	11.214	10.642
							—.572

At least three set of readings with or without changing the water level in the system are taken at the time of one observation. If the zero error of the system has to be accounted for, the measurements should be repeated after inter-changing the pots on the two bases. It is felt that routine observations of the secular tilt should be satisfactory if the observations are repeated once every two months. Since such observations would in general be required to be made over several years the records need be maintained very systematically.

The system can also be adopted for studies of engineering problems such as the study of slow foundation settlements, rock srreep in tunnels, ground sinking in undermined areas and precise leveling. In such applications the field procedure in general would be further simplified as the observations would normally extend over a limited period. Such observations could even be made on suitabily constructed tilt bases on the surface. The effect of temperature variations then be accounted for by repeating observations at the same hour of the day during a particular study.

Ground Tilt Observations in the Kala-Amb drift

Three tilt basis have been constructed in the Kala-amb drift at the Yammuna Hydel Scheme project site, Dehradun. The first set of ground tilt observation have been already made with this system. The drift passess through the Krol and Nahan thrusts which are considered to be active. It is expected that measurements of tilt will throw light on the order of movements taking place along these thrusts.

Ground Tilt Observation in Pophali area

The underground construction in Pophali Power House of the Koyna Hydro-electric Project has made it possible to plan observations of secular tilt in this region also. Nine tilt bases have been established in this area at locations which are given below :

Location	No. of Bases
Approach Tunnel	2
Access passage to the value house	2
Cable passage	2
Intermediate Aqueduct	3

The first set of observations have been already taken in view of the frequent local tremors occurring in the area, it has now been planned to make tilt measurements every day for about a month. It is hoped that this will bring out the correspondence, if any between the ground tilt and the occurrence of tremors.

Conclusions

On the basis of trail tests, the portable Water Tube Tiltmeter system reported has been found suitable for measurements of the secular ground tilt. The system is expected to yield useful data in the Kala-amb drift at the Yammuna Hydel Scheme project site in the Himalayas and in the Pophali Power House area in Maharashtra. In the Pophali area these observations may enable establish correspondence between ground tilt and earthquake tremors.

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