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A mercury column vertical movement measurement device for geotechnical engineering

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Synopsis

Methods of measuring the vertical movement of points below ground are briefly reviewed, whereafter the application of one particular method is closely examined. The use of a mercury manometer, where only one leg of the mercury column is visible, is shown to be viable in South African temperature conditions and an improved method of determining the level of a buried settlement measuring cell, using a mercury column as a switch, is described.

Introduction

Probably the simplest method of measuring settlement is by direct survey levelling, using extension rods to reach buried plates when the settlement of points beneath the ground is required (see Fig 1). However, where soil filling and compacting operations must take place above the buried level plates, damage to the vertical tube containing the extension rod above a buried plate can (and often does) occur.

One means of avoiding the need for a vertical tube up to the point of measurement is to use a liquid-filled tube, which may run horizontally. There are two basic methods of utilizing a liquid-filled tube, which are illustrated in Fig 2. In the first, shown in Fig 2(a), deaired water is fed into tube A until an overflow occurs inside the settlement cell. The feed is then stopped and the level at which the water stands in tube A is the same as the overflow level in the buried cell. Clearly the accessible length of tube A needs to be at the same level as the settlement cell.

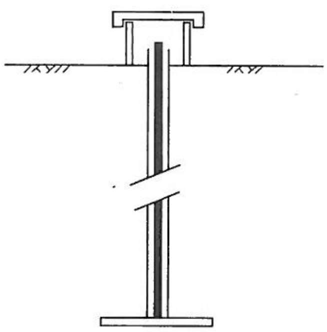

Fig 1: Subsurface vertical movement measurement by means of a rod in a tube

In the second method, the height of a column of fluid is determined by measuring the pressure that it exerts. This priniciple can be used to measure the movement of a cell lying either above or below the level of the monitoring station. Probably the most common situation is where the cell lies below the station, and this is illustrated in Fig 2(b). Techniques are available to enable the pressure transducer to be at the monitoring station end, so that it is recoverable. In all cases, the accuracy of measurement depends on both the accuracy of the pressure transducer and the amount of movement of the cell relative to the height difference between the cell and the monitoring station.

This paper refers to the latter type of settlement measuring device, which was originally described by Irwin[1].

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This paper was submitted to independent referees for scrutiny prior to acceptance for publication.

Movement measurement device utilizing a mercury switch

Fig 3 illustrates the principle and method of operation. The mercury in the tube forms part of an electrical circuit to show when the mercury just touches the stainless steel fitting at the base of the movement cell. The gas pressure in the movement cell, needed to hold up the mercury column, will vary if the cell goes up or down relative to the level *M* at the measuring station.

This gas pressure is measured with a mercury manometer, in which case the head difference in the manometer, H_m, may be assumed to be equal to the difference in elevation H_c between the cell and level *M* of the mercury column. (The accuracy of this assumption is considered in the section below.)

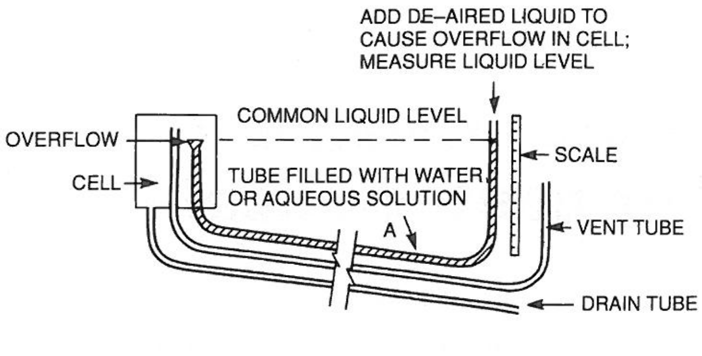
Secondary effects of temperature and tube volume change creep under pressure

The tubes from the movement cell must be flexible and they are therefore subject to significant volume change under pressure, which will affect the level *M* of the mercury. If this volume change were only elastic, it could be ignored, as it would be practically constant each time the mercury column was raised to level *M*. That is to say, the different elastic volume changes caused by the change in pressure as the cell moved vertically could be ignored if a material as stiff as nylon were used for the tube. However, the amount of volume change caused by creep will vary with time and temperature, both of which could vary between different occasions of measurement. To eliminate this problem, Irwin[1] made a flat horizontal coil of the tube at the top, fixed in elevation, so that the top of the mercury column at *M* always lay within the coil, and hence was always at the same elevation.

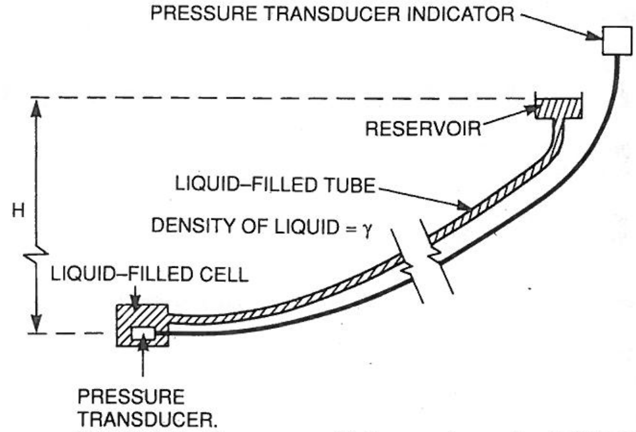
The fact that a difference in temperature (and hence density) between the mercury in the movement cell tube and the mercury in the manometer would mean that the manometer reading H_m was not the same as the height difference for the cell H_c was recognized by Irwin. His recommendation (made under English conditions) was to take measurements when the temperature difference between the mercury above and below ground was small, and so reduce the error to a negligible size.

However, for South African temperature conditions, the effects must be more carefully examined. Consider first the movement cell tube. Temperature-induced strains of the diameter of the tube and the volume of the mercury will cause the length of the mercury column to vary. For full interpretation, the following information is needed:

1. The absolute level of the top of the mercury column, *M*
2. The temperature along the tube
3. The coefficients of thermal expansion of the tube material and the mercury.



(a) Water overflow level principle



(b) Pressure from a head of liquid

Fig 2: Measurement of vertical movement using liquid-filled tubes

By using the same device of coiling the top of the tube that was described for the creep phenomenon, the effect of thermal expansion of the tube material can be eliminated.

Considering now the manometer, if the difference in level between the cell and the monitoring station, H_c, is relatively small, then the whole of the manometer can be kept above ground. In this case, the diameter of the tube has no effect on H_m, and knowledge of the temperature and hence density of the mercury enables an absolute pressure to be obtained from H_m. The height of the mercury column held up by this pressure in the moving cell can then be found.

Where H_c is more than approximately 2 m, however, it becomes difficult to maintain both ends of the mercury column in the manometer above ground, and it becomes more practical to keep just the higher column in view. This is discussed below, together with the problem of different mercury densities.

Use of a manometer for large mercury height differences

Fig 4 shows the arrangement that has been used for large pressure measurement. The mercury level N is established relative to a fixed datum for the initial position of the movement cell. Change in the pressure P caused by cell movement can then be obtained from the change in the mercury level at N, provided that (a) the diameter of the manometer tubing remains constant and (b) the density of the mercury in the manometer is known. However, temperature changes will affect both these parameters.

Let us consider first the effect of temperature change on the tubing. The material most likely to be used is nylon, because it is the cheapest material with suitable mechanical properties. It has a linear coefficient of thermal expansion of $80 \times 10^{-6}/°C$, compared with $60 \times 10^{-6}/°C$ for mercury. Based on the temperature-induced volume change of a mercury-in-nylon manometer, the drop in the level of the mercury observed for the situation shown in Fig 4 is given by:

$$\delta H = 30 \times 10^{-6} \times \ell_o \times \Delta T$$

where ℓ_o = the initial length of the mercury-filled tube and ΔT = change in temperature. (The derivation of this equation is given in the appendix.)

For example, assume ℓ_o = 4 000 mm and ΔT = 10°C, then δH = 1,2 mm.

Greater depths of burial of a movement cell are of course possible, giving greater values of ℓ_o. However, these would be likely to lead to more stable temperatures than ΔT = 10°C over the length of the manometer tube below ground, hence compensating for the greater ℓ_o.

The biggest range of temperature change will be on that part of the manometer's mercury column above ground. Assuming a projection above ground of 1 000 mm and a temperature change in the shade of 20°C, then δH = 0,6 mm.

Hence, for conservatively high estimates of temperature variation between the times of measurement of the movements, an error of the

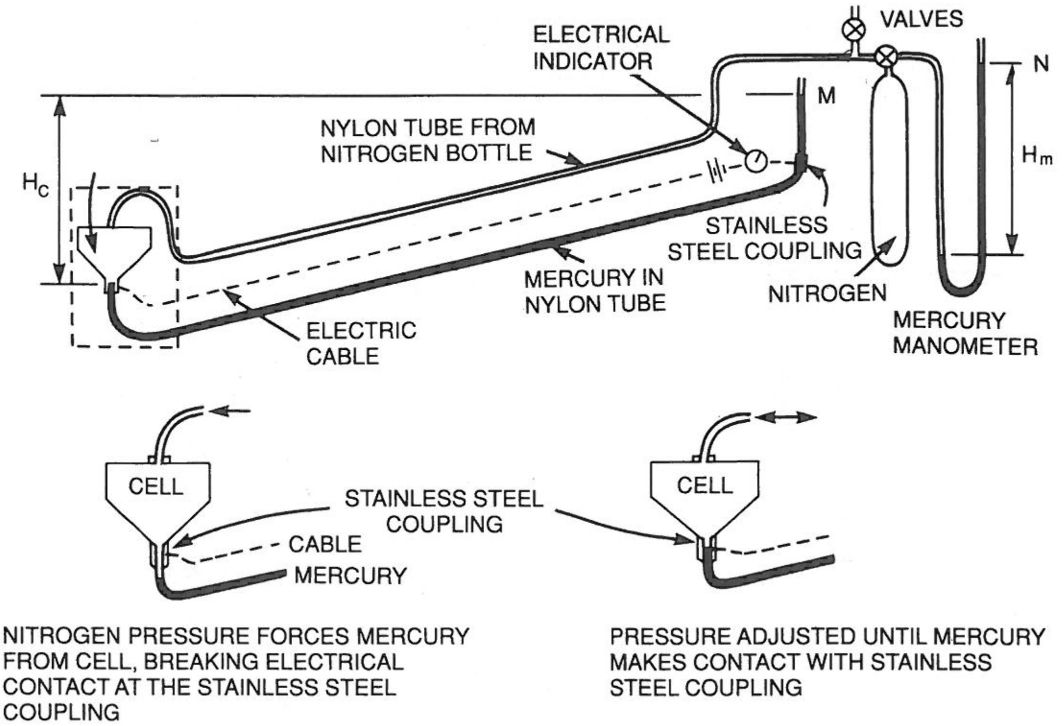


Fig 3: Mercury settlement measuring device according to Irwin[1]

order of 2 x (1,2 + 0,6) ≃ 4 mm can be expected. For the settlement of bulk earthworks, this is probably quite acceptable. If greater accuracy is required, then thermocouples below ground and a thermometer above ground can be used to check the temperature variation, and Eqn 1 enables a correction to be made.

Let us consider now the question of variation of the density of the mercury. If the densities of the mercury in the movement cell's tube and the manometer tube are the same, then the change in pressure *P* caused by a unit movement of the cell will produce the same amount of change in differential head in the manometer. That is, a half-unit change in level *N* on Fig 4 will occur. With the arrangement shown in Fig 4, the densities are likely to be the same because of probable uniformity of below-ground temperatures and the above-ground tubes being in the same location.

If temperatures did differ, then the relative heights of the mercury columns in the two tubes below and above ground would influence the magnitude of error that would be incurred. To assess the error, assume that both tubes have the same height below and above ground, and the temperature difference between the two tubes is 10°C. This would cause a density difference in the mercury of 0,18 per cent. That is, for a one metre change in the level of the movement cell, the movement recorded by the manometer would be in error by 1,8 mm. This magnitude of error is probably acceptable in all circumstances, but if it were not, temperature measurements with thermocouples along the tubes would enable a correction to be made.

Hence it is concluded that for moderate height differences between moving cell and measuring station (up to 4 m), using nylon movement cell tubing, all temperature-induced errors are likely to be negligibly small in the context of bulk earthworks settlements.

Practical problems in the use of the mercury switch type of vertical movement gauge

Although it is not mentioned in the literature, I had great difficulty (in fact I did not succeed) in producing a continuous thread of mercury in the movement cell tube, so that it could form part of the electric circuit. It was anticipated that pouring the mercury into the tube would include air bubbles, and so the following system was devised. After installing the movement cell with its lower tube empty, mercury was poured into the top of that tube (past point *M* on Fig 3). All the mercury was pushed into the movement cell by applying gas pressure at point *M*, and then the pressure was suddenly released so that the mercury ran back from the cell into the tube. By having the diameter of the cell tapering towards the diameter of the tube, it was hoped to produce continuity of mercury in the tube. However, this was not achieved. The reason is not known, but it may be that when the gas pressure is released at the top end of the tube, the drop in pressure at the bottom end is not sudden enough, making the flow out of the cell build up only gradually, which causes air in the tube to be trapped in bubbles.

The problem was solved by using the mercury inside the cell as a bridging connection between platinum contacts, as shown in Fig 5. The method of operation is as follows when making a reading of the current position of the cell. Gas pressure first pushes the mercury out of the cell and then the source of pressure is cut off at valve 1 on Fig 5 and valve 2

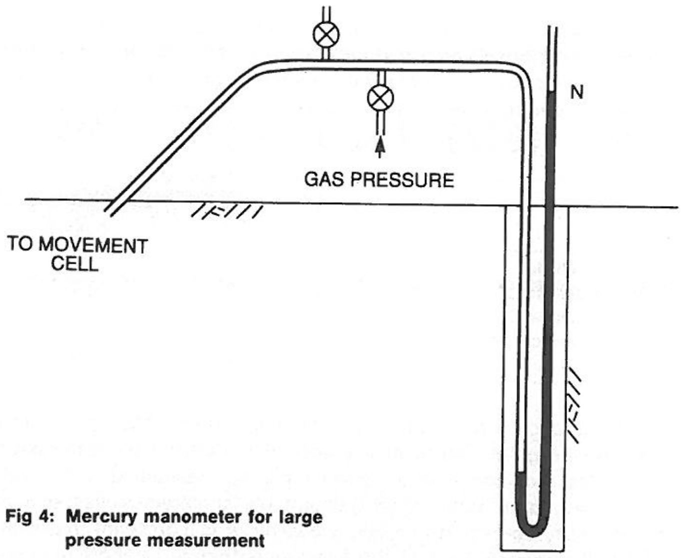


Fig 4: Mercury manometer for large pressure measurement

is slowly opened to vent. This allows the mercury column to fall back slowly. Contact A inside the cell is touched first, followed by B – lighting up globe 1 – and then contact C – lighting up globe 2.

The two circuits and globes are included for two reasons: (1) insurance in case of the breakage of one wire, and (2) the lighting of globe 1 gives warning of the imminent closure of the second circuit, which will light up globe 2. The height of the mercury level *N* in the manometer is read at the instant that each globe illuminates. The movement of the cell is then determined from the change in level *N*, and should be the same for the two sets of readings for the two globes.

Having circumvented the effect of the air bubbles on the electrical circuitry, their effect on the pressure heads of mercury must be considered. The procedure described in this paper enables the change in the level of the movement cell, from some initial level value, to be obtained. Consequently the presence of an air bubble in the mercury column will have a constant effect, providing it does not migrate from one side of the lowest point in the tube to the other side.

Following the procedure described above for filling the tubes with mercury, it is probable that the bubbles will occur at the top end of the mercury column, ie close to point *M* on Fig 5. This being the case, it is not possible for migration past the lowest point to occur.

A further practical problem with the use of mercury is its toxicity. To prevent the possibility of leakage into the ground, the whole system must be proof-tested with gas pressure before the mercury is introduced into it. After the settlement measurements are complete, the mercury must be removed from the system by using sufficient gas pressure to push the mercury out past point *M* on Fig 5.

Example of application

A single mercury settlement gauge of the type described here was developed during the measurement of the settlement of the base of a

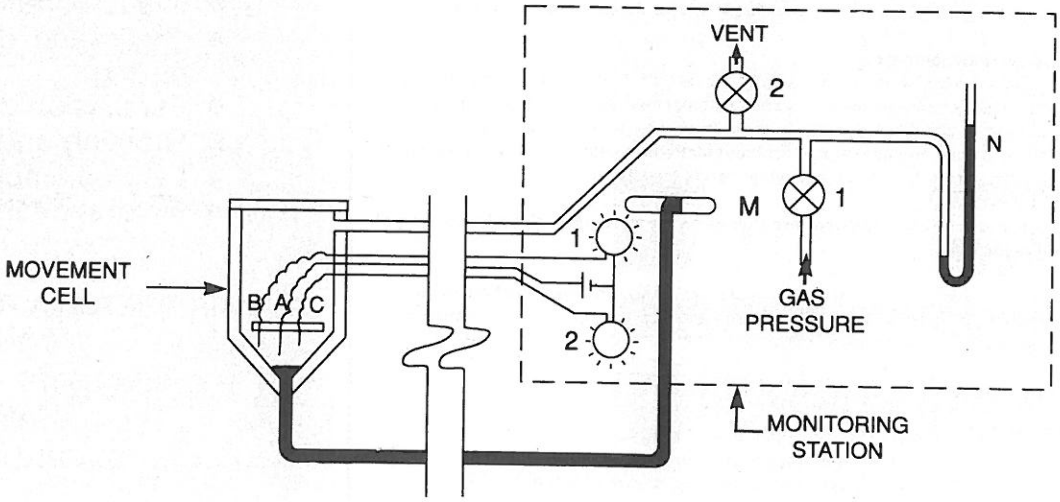


Fig 5: Alternative switch design using mercury

test excavation that was subsequently backfilled and subjected to a surcharge. Three other cells, utilizing the 'overflow level' principle, were installed within a relatively short distance of the mercury cell. The following readings were obtained for two stages of movement in the test:

	Movements in mm	
	Stage 1	Stage2
Overflow cell No 1	75	30
Overflow cell No 2	83	28
Overflow cell No 3	54	33
Mean of overflow cells	71	30
Mercury cell	74	35

The variation in the overflow cell readings was probably caused by the very irregular nature of the ground underlying the excavation (backfilled rock and soil from surface mining operations). This variation unfortunately makes the test unsuitable for a precise evaluation of the mercury cell's performance. However, it is significant that even though the upper 2,5 m of both the movement cell and manometer tube were exposed to direct sunlight, and the rest of the manometer tube was in the open air but sheathed in hose-pipe, the readings obtained were reasonably close to the means of the overflow cell values, even without any temperature corrections. The difference was certainly within the bounds of acceptable error for bulk earthworks settlement measurement.

Conclusions

1. Where easy access, for the monitoring station, is available at the same level as the movement cell, then the water overflow level cell can be used without any need to generate or measure pressures, and then this type may well be the easiest to set up and operate. However, Irwin initially developed the mercury gauge because air locks can form in a water gauge, and he suggests that the mercury type enables readings to be taken faster because of the need with the water overflow type to produce de-aired water and to flush out the overflow tube with it.
2. Temperature effects on the mercury switch type of cell, when used with nylon tubing, have been shown to be acceptably small for the measurement of settlement of bulk earthworks.
3. A mercury manometer tube, where only the higher level of the mercury is accessible for reading, can be used to measure the changes in pressure produced by the changing level of the mercury-switch movement cell.
4. The mercury column in the mercury switch movement cell does not need to be used as an electricity conductor, hence small breaks in the continuity of this column can be shown to be unimportant. Platinum contacts within the cell can work as well as, and possibly better than, the conducting mercury column.

Reference

1. Irwin, M J. A mercury-filled gauge for the measurement of settlement of foundation. *Civil Engineering and Public Works Review,* March 1964, p 358.

Acknowledgements

I wish to thank Mr John Wates of Wates and Wagner for the opportunity to develop the mercury switch cell on an actual test site, Mr Graham Bailey of the Department of Civil Engineering at the University of the Witwatersrand for assistance in the manufacture of the cell and Mr Peter de Hahn of Terramonitoring for his assistance in providing facilities for its installation.

Appendix: Effect of temperature change on the mercury level read on one leg of a manometer

With reference to Fig 6, the volume of mercury shown cross-hatched equals the difference in the volumes of nylon tube and mercury after a temperature rise, ie

$$2.\delta H a_o = 3(\alpha_n - \alpha_m) \times 10^{-6}\,\Delta T V_o$$

where a_o = initial cross-sectional area of tube
V_o = initial volume of tube and mercury
α_n = linear coefficient of thermal expansion of nylon
$= 80 \times 10^{-6}/°C$
α_m = linear coefficient of thermal expansion of mercury
$= 60 \times 10 \times 10^{-6}/°C$

Substituting values and rearranging the equation:

$$\delta H = 30 \times 10^{-6} \frac{V_o\,\Delta T}{a_o}$$

But $V_o = \ell_o a_o$ where ℓ_o = initial length of the mercury-filled part of the tube

$$\therefore \delta H = 30 \times 10^{-6}\ell_o\,\Delta T$$

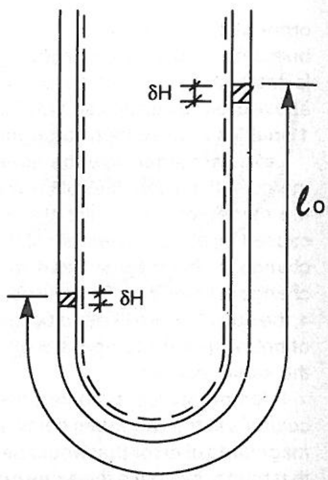


Fig 6: Effect of temperature change on a manometer

Discussion on papers

Written discussion on the papers in this issue will be accepted until 30 April 1991. This, together with the authors' reply, will be published in the August 1991 issue of *The Civil Engineer in South Africa*, or later. For the convenience of overseas contributors only, the closing date for discussion will be extended to 31 May 1991. Discussion must be sent to the Directorate of SAICE.

The discussion must be submitted in duplicate, should be in the first person present tense and should be typed in double spacing. It should be as short as possible and should not normally exceed 600 words in length. It should also conform to the requirements laid down in the 'Notes on the preparation of papers' as published in the October 1983 issue of *The Civil Engineer in South Africa.*

Whenever reference is made to the above papers this publication should be referred to as *The Civil Engineer in South Africa* and the volume and date given thus: **Civ Engr S Afr, Vol 33, No 2, 1991.**