Soil Movement and Weather

Mouvement du sol et influences climatiques

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Summary

The results of several long-term observations on the movements of the ground under different conditions of soil, weather, vegetation and shelter are recorded. These observations are directed towards a quantitative understanding of water movements and transpiration of vegetation; they provide data for the rational design of house foundations in Britain.

Sommaire

L'auteur donne les résultats de quelques séries d'observations de longue durée portant sur les mouvements du terrain pour différentes conditions de sol, de climat, de végétation et de protection locale. Ces observations ont pour but d'obtenir des données quantitatives sur les mouvements de l'eau et la transpiration de la végétation qui influent sur le comportement des fondations des maisons d'habitations en Angleterre.

Introduction

In Britain there is usually sufficient water in the soil for grasses and crops to grow throughout the year. Occasionally in the drier parts of Eastern England there is no rain for a few weeks in summer and the grasses wilt. In most summers, irrigation will increase the yield of crops in the South and East (*Rothamsted*, 1948–50).

Damage to masonry structures with shallow foundations is widespread on the heavy clay lands that shrink and swell according to the water stored in the soil (*B. R. S. Digest* No. 3, 1949). Nearly all the water deficiency in summer arises from the transpiration of plants, and large trees cause most of the damage (*Ward*, 1948). All masonry houses without basements on the heavy clay lands of the S.E. of England are potentially liable to damage, and paths; roads and shallow drains become distorted with only grasses adjacent. In the absence of vegetation there is no damage.

The above qualitative observations are the results of common experiences, but for the purposes of rational design of foundations quantitative observations on the movements of heavy clay soils have been in progress for several years at different sites on the heavy clays of S.E. England. The variables covered by the observations are weather, type of clay, vegetation—its type or absence, and sheltering of the ground. The results of these observations to date are recorded in this paper.

Extent of Damage from Trees

In the course of visiting and dealing with enquiries of cases of damaged brick dwelling houses near trees it appeared that the height of a tree was a rough guide to the spread of its roots and to the extent of possible damage.

The height (H) of the tree (often roughly estimated) is plotted against the distance (R) between the trunk of the tree and the damaged building in Fig. 1. In this diagram: (*a*) spot points relate to cases not examined and the distance is to the nearest point of the damaged building, (*b*) circle points are cases that have been investigated and are plotted as the distance to the crack in the foundations most remote from the tree. At least 10 feet, and in many cases much more, can be added to the plotted value of the spot point distances to obtain the real extent of the roots. Root competition between adjoining trees and impervious paving over the root system increase the extent of the roots and the damage, see Fig. 1, and note circles marked R, G and P. Most of the trees are poplars and elms, oak is fairly frequent and the others are alder, willow, ash, sycamore, chestnut, birch and hawthorn. The damage is not restricted to fast growing trees, though they are more commonly planted near buildings than other species. All buildings have strip foundations and they vary in depth from about 1 to 6 feet below ground level. The average depth is about 2 feet. The distortion is smaller in buildings more deeply founded.

It has been suggested that buildings with shallow foundations, i.e. most dwelling houses, should be kept away from trees a distance equal to the height of the mature tree (*Cooling*, 1951). This rough rule, see $R = H$ Fig. 1, is not unduly conservative and in the case of dense rows of trees with paved areas adjoining the building $R = 1.5\ H$ can be exceeded. These rules apply only to British climate conditions.

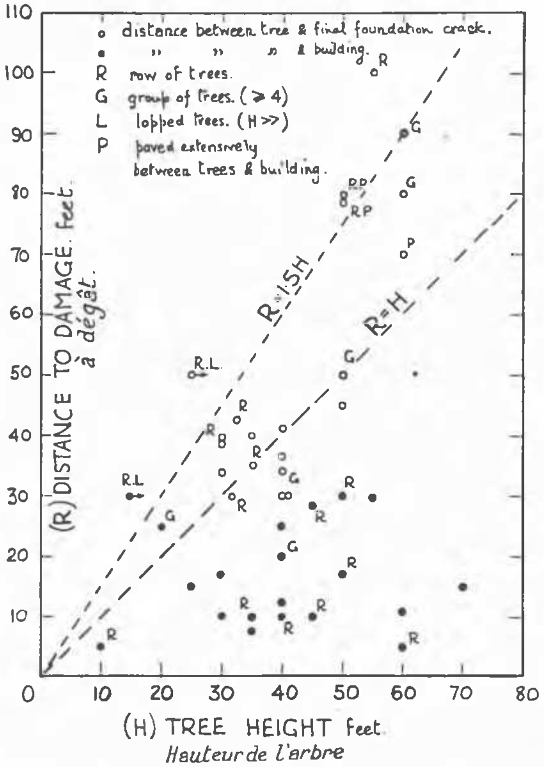


Fig. 1 Relation Between Tree Height in Feet and Distance to Damage
Relation entre la hauteur de l'arbre et la distance des dommages

Table 1 Conditions at Sites of Vertical Movement Gauges under Rough Grass

Site	Garston Herts	Hilfield Cerne, Abbas Dorset	Bridgewick Southminster Essex
Topography	Gentlesloping field, 245 feet O.D.	Gentle slope below chalk downs, 450 feet O.D.	Flat treeless marsh 1 mile from sea, +7 feet O.D.
Soil type	Stiff glacial clay	Stiff Jurassic (Oxford) clay slightly drifted?	Dried crust of soft sensitive salt marsh clay. Sandy shell bed at 10 feet
Liquid limit	50–70	70	85
Plastic limit	20	25	30
Winter water content (% dry weight)			
1 feet	30	40	30
6 feet	20	30	65
Depth of ground water (feet)	0–10	0–6	0–6
Mean annual rainfall (in.)	28	45	20

Movements of the Ground under Rough Grassland

With the kind assistance of local observers measurements of the vertical movements of heavy clay have been made at three sites for a number of years. The vertical movements at the surface and at a depth of 2 feet are given in Fig. 2. The soil conditions at each site are summarised in Table 1. Roots of the grasses and common weeds extend to a depth of about 5 feet at each site. The measuring equipment installed consists of a rain gauge, a lined borehole for ground water levels, and the vertical ground movement gauge illustrated in Fig. 3. The movement gauge is set in the ground by boring a row of holes 1¼ inches diameter. The outer two rods, joined by a cross beam, form the reference level and the distances between the beam and the tops of the intermediate rods are measured with a ruler.

The movements of the ground are a measure of the water deficit in the ground, but the dryness of one site cannot be compared to another on this basis alone because the relation between the amount of shrinkage and the water deficit varies from site to site. These differences are discussed later. However, the longer duration of the dryness at Bridgewick should be noted. The comparatively large movements at 2 feet depth

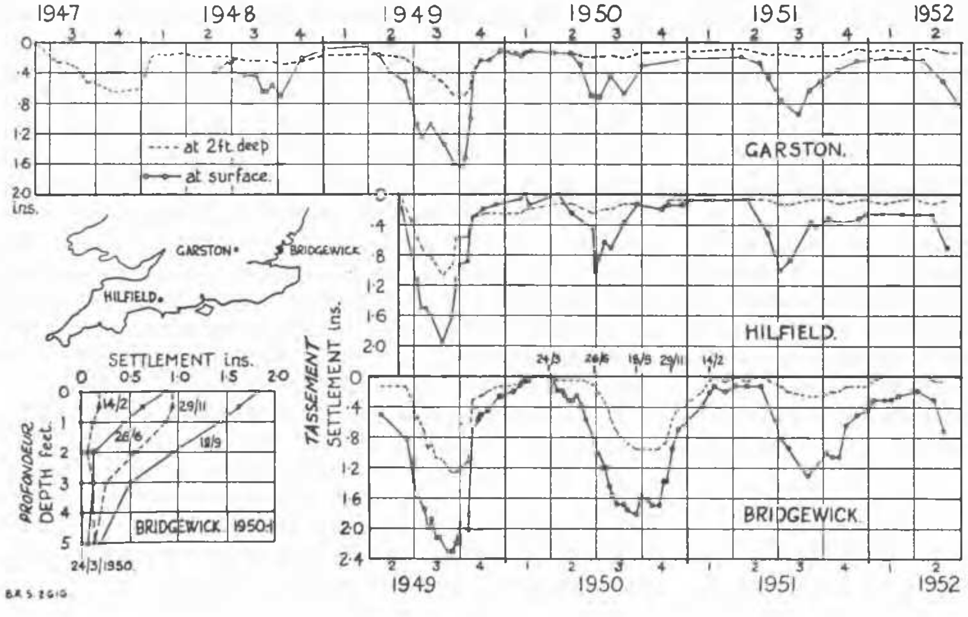


Fig. 2 Vertical Movement of Soil
Mouvement vertical du sol

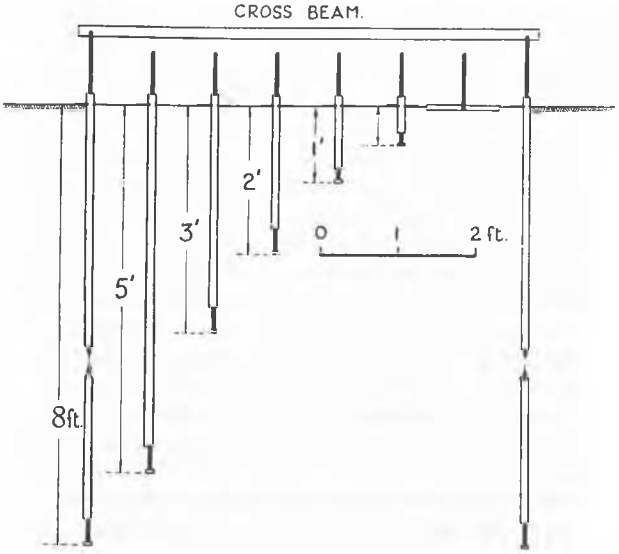


Fig. 3 Vertical Movement Gauge
Indicateur de mouvement vertical

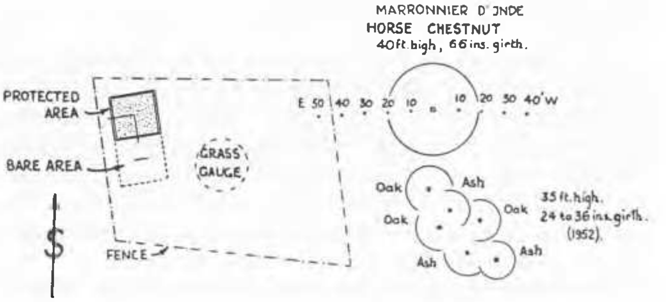


Fig. 4 Ground Movement Site at *Garston*
Emplacement des mesures de mouvement du sol à *Garston*

varying from about ¾ to 1½ inches in the very dry summer of 1949 are of particular interest, since this is a common depth for the foundations of traditional houses. At each of the sites there is only a small movement of about 1/10 inch at a depth of 5 feet in the driest summers. The variation in the vertical movements with depth at Bridgewick for 1950–51 shown in Fig. 2 is typical of the other sites.

Detailed Observations in the Grass Field at Garston

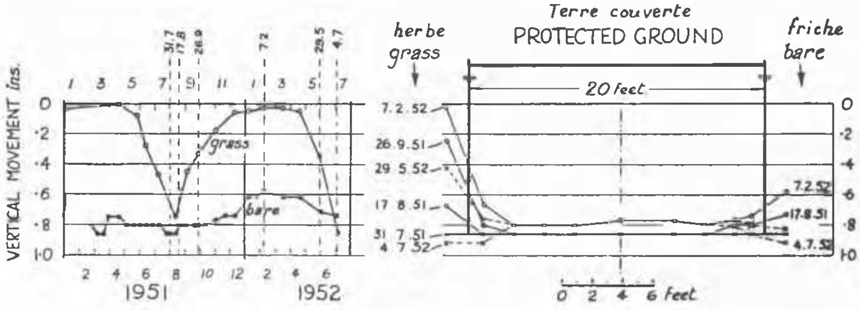
Fig. 5 Protected Area under Construction Showing Bitumous Felt, Coarse Sand, Brick Wall, Concentric Shrinkage Gauges and Reference Beam
Aire de protection en construction

The arrangement of some of the more detailed observations in progress at Garston is shown in plan in Fig. 4. In the centre of the fenced area is the vertical movement gauge recording the effects of the grass on the heavy glacial clay whose results are given in Fig. 2. These records are referred to a datum point at a depth of 22 feet. Also within the fence are two adjacent areas; one, 20 feet square, kept bare of all vegetation, in the centre of which is set another vertical movement gauge, and another area the same size stripped of vegetation and protected from direct rain and evaporation with an impervious sheet of bituminous felt. The felt of the protected area is covered with a 9 inches layer of coarse sand retained within single brick walls. From the centre of the protected area two lines of shrinkage gauges have been set in the ground; one line extends to the bare area and the other extends to the adjacent grassed edge. Two shrinkage gauges are concentrically arranged at several positions along the two lines and record at the ground surface and at a depth of 3 feet. All the rain collected by the bituminous felt is drained into gutters and diverted from the site as it would be by the roof of a house. Fig. 5 is a view of part of the protected area under construction.

To the West of the fenced area observations are in progress on the vertical ground movements adjacent to a horse chestnut tree; unfortunately it is not entirely isolated. The tree circles in Fig. 4 represent the spread of the branches. Concentric gauges recording the ground movements at the surface and at a depth of 5 feet have been set in the ground at intervals of 10 feet from the trunk of the chestnut tree.

(a) Comparison between Vertical Movements of the Ground under Rough Grass and of Ground free from all Vegetation

The vertical movements of the ground surface (*a*) supporting rough grass and (*b*) bare of all vegetation during 1951–52 at



The absolute levels of the above curves are adjusted to correspond with the movements either side of the protected ground.

Fig. 6 Vertical Movement of the Ground Under and Adjacent to the Protected Area
Mouvement vertical du sol au-dessous et à côté de l'aire de protection

Garston are given in Fig. 6. So far these summers have not been very dry and whereas the grass surface movement amounted to about 0.8 inch and the movements extended to a depth of about 3 feet, the total movement on the bare site was only 0.2 inch and extended only to a depth of about 1 foot and was difficult to distinguish, below 6 inches, from thermal movements of the ground. These results show the predominating influence of vegetation and the restricted drying on bare ground.

(*b*) *The Vertical Movements of the Ground under and Adjacent to the Protected Area, with Grass Growing on one side and Devoid of all Vegetation on another side*

The vegetation was entirely removed from the bare area in early February 1951 at a time when the ground was at field capacity (i.e. zero water deficit). The vegetation on the adjoining protected site was not removed until late in May 1951 when there was already a small water deficit, corresponding to a vertical shrinkage of about 0.1 inch. The bituminous felt was laid on the ground and the vertical movement gauges were installed at the end of July 1951; at a time when the water deficit was about at its maximum.

The subsequent vertical movements of the ground surface under and adjacent to the protected area are shown in Fig. 6. The circle points on the right hand side of the figure shows how the swelling of the ground gradually takes place from the edges. The swelling under the centre all occurred during November 1951 when rain caused the ground water level to rise rapidly to the surface and the lifting corresponds to the original water deficit when the vegetation was stripped in late May 1951, namely 0.1 inch movement. No movement has occurred since November. The uplift near the grass edge is greater than in the centre because the drying action of the grass spread sideways during the period between stripping the grass (late May 1951) and placing the felt (end July 1951). The crosses show the downward movements in the early summer of 1952.

No movements were recorded at a depth of 3 feet under or adjacent to the protected area during 1951–52, even though the ground water level rose from a depth of about 8 feet to the surface.

(*c*) *Movements of the Ground Adjacent to a Horse Chestnut Tree*

These observations are only exploratory.

Fig. 7 shows two horizontal profiles of the ground movements during 1951–52 roughly West to East across the tree, the upper profile relates to surface movements and the lower to movements at a depth of 5 feet. Five feet was chosen because practically no movement has ever been recorded below this level due to the transpiration of grasses alone at Garston. The whole of the area under and around the tree is supporting grasses. If the surface movements under grass alone are compared with those around the tree, see left handside of Fig. 7, it will be seen that the effect of the tree extends to at least 40 feet West and about 25 feet East. At 5 feet depth the effect of the tree appears to be less extensive, perhaps only 30 feet West and 10 feet East. The 1951 summer was quite moderate and the rather sudden rise of the ground during November occurred soon after the tree had shed its heavy canopy of leaves and when much rain fell. Clearly many more observation points are needed to resolve the problem quantitatively. *Porter* (1936) showed that a tree trunk in Texas moved up and down according to the seasons by as much as 0.3 foot. It is evident from the Garston results that this movement of the trunk is a simple demonstration of the local water deficit caused by the tree.

The Relation between the Vertical Movements of the Ground and the Soil Water Deficit

One of the unsolved problems in soil physics is a simple and reliable method of estimating the deficiency of water in the ground during the growing season. Clearly, for shrinkable soils, a method involving measurement of ground movement could not be simpler, provided the relation between the water stored and the vertical shrinkage of the soil was simple. It is not as simple as might be thought from general principles, and it has not been completely resolved at present.

There are three independent ways of estimating the amount of water lost from the ground for a measured vertical movement:—

(i) measure the loss in weight of water from samples of the ground before and after it has shrunk;

(ii) take large samples of the ground at field capacity and dry them in an oven and measure the vertical shrinkage;

(iii) calculate the loss of water from the ground under grass from the weather data by the method developed by *Penman* and compare the field measurements of vertical movement.

The first method is the least satisfactory and is suitable only if the soil is homogeneous in type—a rare phenomenon. The ratio: $\left(\frac{\Delta w}{\Delta z}\right)$ (called the water-shrinkage factor) between the

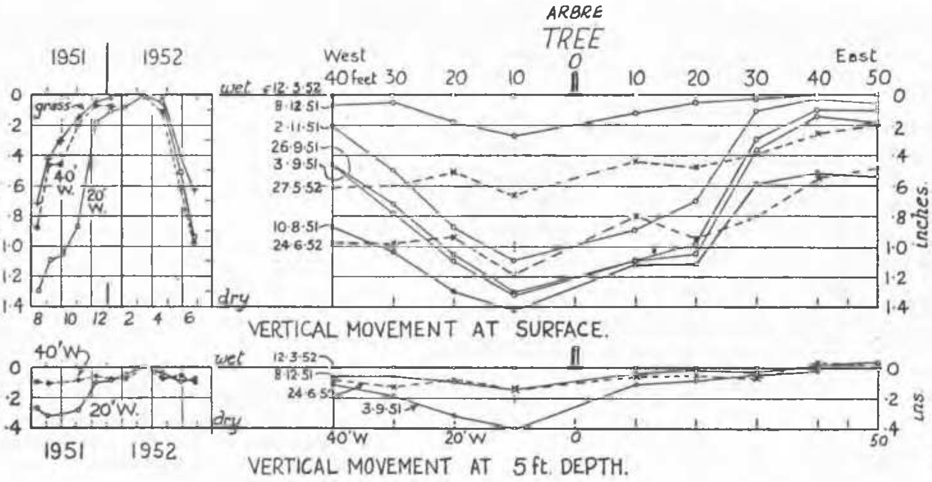


Fig. 7 Ground Movement 1951–1952
Mouvement du sol 1951–1952

Table 2

Site	Garston						Hilfield			Bridgewick		
Dates	24.6.–15.9.47			15.9.47–31.1.48			2.6.–26.8.49			24.4.–12.8.49		
Depth (feet)	Δw	Δz	$\frac{\Delta w}{\Delta z}$	Δw	Δz	$\frac{\Delta w}{\Delta z}$	Δw	Δz	$\frac{\Delta w}{\Delta z}$	Δw	Δz	$\frac{\Delta w}{\Delta z}$
0–0.5	—	—	—	—	—	—	1.7	0.18	9.0	0.77	0.19	4.0
0.5–1.0	—	—	—	—	—	—	1.5	0.25	6.0	0.57	0.13	4.4
1–2	1.7	0.53	3.2	2.2	0.58	3.8	1.9	0.44	4.3	1.2	0.37	3.2
2–3	1.2	0.19	6.3	1.4	0.10	14.0	1.5	0.62	2.4	1.4	0.44	3.2
3–4	0.8	0.27	2.2	0.5	0.24	2.1	—	—	—	—	—	—
3–5	—	—	—	—	—	—	1.2	0.38	3.2	1.8	0.44	4.1
Sum	3.5	0.99		4.1	0.92		7.8	1.87		5.7	1.57	
Mean $\frac{\Delta w}{\Delta z}$	3.5			4.5			4.2			3.6		

Notes: Δw is change in water deficit in inches of water estimated from water content of samples.
Δz is vertical movement of ground in inches as measured.
Specific gravity of soil assumed 2.7.

The *Garston* values of $\Delta w/\Delta z$ are unsatisfactory, because the vertical movement points are scattered over a larger area and in more variable soil than the other two sites.

change in the number of inches of water (Δw) stored in the ground (measured like rainfall and calculated from two water content surveys) to the corresponding vertical movement (Δz) in inches under grass at Garston, Hilfield and Bridgewick is given in Table 2 for various intervals of depth (z). There is a large variation in the values of $\frac{\Delta w}{\Delta z}$ particularly at Garston, due to successive samples at the same level being dissimilar in soil type.

The second method is not entirely satisfactory because soil dried in the oven may not shrink in the same way in the field. Large vertical samples about 8 inches diameter and 12 inches long have been taken in tubes only at Garston and Bridgewick to date. They are dried in a ventilated oven from the top surface only, at temperatures of about 70° C. The loss in weight and the length of the samples is measured at intervals during drying. The relations between Δw and Δz are plotted in Fig. 8, together with the slopes of the linear portions $\left(\frac{\Delta w}{\Delta z}\right)$.

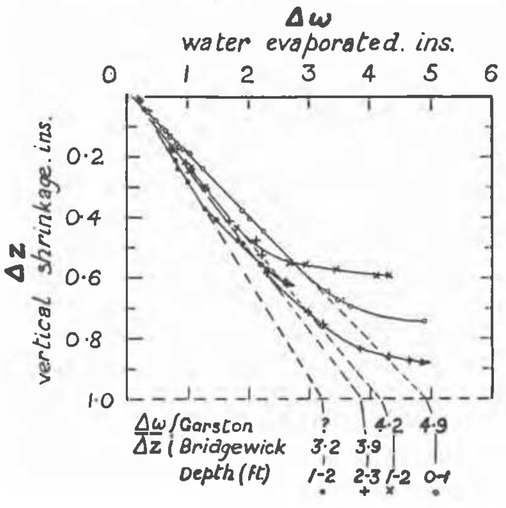


Fig. 8 Loss in Weight and Length of Dried Samples
Réduction en poids et longueur d'échantillons secs

The third method based on the weather data is probably the most general way of estimating the total water deficit in the ground and it has been shown to be reasonable in many climates. *Penman* (1948) first estimates the evaporation from a hypothetical open water surface by an ingeneous combination of the usual type of evaporation "sink" formula, involving the wind speed and the vapour pressure gradient, and the evaporation as part of the heat budget of the energy exchange between the atmosphere and the water surface.

At present the relation between evaporation from an open water surface and transpiration from a grass surface is largely empirical, and will vary with the ease with which grass can obtain water. When the grass suffers from lack of water, growth and transpiration become reduced. *Penman* (1949) has suggested the concept of a "root reservoir" of a certain number of inches of water that is readily available to the roots and which is removed from the ground at a rate proportional to the open water surface evaporation and referred to as the *potential* transpiration. When the root reservoir is exhausted, the *actual* transpiration is reduced as if the potential transpiration was applied to bare soil initially at field capacity. This stage of the drying process is assumed to follow a drying curve obtained experimentally. Clearly, the size of the root reservoir may have to be adjusted from year to year according to grass husbandry and the rainfall in the early part of the growing season.

Penman has calculated the potential transpiration for the sites on which vertical movements were measured. The complete link between shrinkage and grass transpiration will depend upon knowledge of the root reservoir, but the water-shrinkage factor $\frac{\Delta w}{\Delta z}$ for the top few feet can be deduced without this knowledge, by making the reasonable assumption that the first stages of drying in spring and the first stages of wetting in autumn affect only the top layer of soil. When potential transpiration is plotted against vertical shrinkage of the ground surface the slope of the drying curve from zero water deficit up to about 3 inches is the same as that from maximum deficit down to about 3 inches less than the maximum. The values of these slopes, $\left(\frac{\Delta w}{\Delta z}\right)$, rounded off because of scatter in the points, are: Garston 5.5; Hilfield 4.0; Bridgewick 4.0. The depth over which these are average values is not known but the corresponding vertical movements are, in order, about 0.6; 1.0 and 1.2 inches.

The values of the water-shrinkage factor $\left(\frac{\Delta w}{\Delta z}\right)$ obtained by the three methods are in reasonable agreement considering the nature of the factor. The minimum possible value of $\frac{\Delta w}{\Delta z}$ is 3, but it is generally greater than 3 according to the number of horizontal cracks and anisotropy of the clay causing less vertical than horizontal shrinkage. The results, so far, encourage further work with the second and third methods and give promise to the measurement of vertical movement as a simple method of estimating the soil water deficit.

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References

Cooling, L. F. (1951): Building Research Congress, London. Division I papers, p. 157.

B.R.S. Digest No. 3 (1949). Building Research Station Digest No. 3. H.M.S.O. London.

Penman, H. L. (1948). Proc. Roy. Soc. A., 193, 120.

Penman, H. L. (1949). J. Soil Sci. (Oxford), 1, 74.

Porter, H. C. (1936). Proc. First Conf. Soil. Mech. II, 256.

Rothamsted (1948–50). Annual Reports, Rothamsted Experimental Station.

Ward, W. H. (1948). Proc. Conf. Biology and Civil Eng. Inst. Civil Engrs., 181.