Seasonal Movements in some Canadian Clays

Mouvements Saisonniers de quelques Argiles Canadiennes

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Summary

In many countries there are problems resulting from building on clays that undergo differential movements due to seasonal shrinking or swelling. In South Africa, for instance, the problems are mainly caused by swelling whereas in England they are more often due to shrinking of the clay. Both problems exist in Canada.

If the natural precipitation or evaporation at the ground surface is disturbed, as is the case when the ground surface is covered by a structure, the water content of the soil will be affected causing the clay to shrink or swell depending on its initial condition. Ground movements are also related to seasonal climatic conditions, such as precipitation, evapo-transpiration and temperatures which affect the water content of the soil.

In Canada the problem of soil movement has been observed in British Columbia throughout the Prairies and in the Ottawa–St Lawrence lowland. Detailed studies are being carried out at Winnipeg and Ottawa where ground movements are being measured to depths of 8 ft. or more, using multi-rod gauges and concentric telescopic ground movement gauges. Readings have been collected at locations near trees, under flat slabs, in grass plots and on water-mains. Results from these measurements and the correlation of the variables are presented.

Sommaire

Dans plusieurs pays, des problèmes sont soulevés par la construction de fondations sur des argiles sujettes à des mouvements différentiels saisonniers, de retrait et de gonflement. En Afrique du Sud, par exemple, c'est le gonflement qui est le problème principal, tandis qu'en Angleterre, c'est celui du retrait. Les deux se posent au Canada.

Si les précipitations naturelles ou l'évaporation à la surface du terrain sont perturbées, comme cela se produit lorsque l'on couvre la surface de ce terrain en y édifiant un bâtiment, la teneur en eau du sol s'en trouve affectée, et peut produire des retraits ou des gonflements suivant les conditions initiales. Les mouvements du sol sont en relation avec les variations climatiques saisonnières, notamment celles qui concernent les précipitations, 'l'évapotranspiration' et les températures qui, toutes, influent sur la teneur en eau du sol.

Au Canada, ces mouvements du sol ont été observés, en Colombie Britannique, dans les Provinces des Prairies, et dans les terrains bas de l'Ottawa et du Saint-Laurent. Des études détaillées sont en cours à Winnipeg et à Ottawa, où les mouvements du sol ont pu être mesurés à une profondeur de 2·40 m et plus, en utilisant des jauges composées de tubes télescopiques. Des observations ont ainsi été faites en différents endroits: près des arbres, sous des dalles, dans des prés, et sous des fossés d'irrigation. Les résultats de ces mesures sont indiqués, ainsi que les corrélations observées entre les variables.

Canada's vast terrain confronts the engineer with many and often unusual foundation problems. One of these problems results from the excessive shrinking on drying and swelling on wetting, of the clays found in such widely separated regions as the Ottawa–St Lawrence lowland, certain interior regions of British Columbia, and the Prairie Provinces.

The wide variations in Canada's seasonal temperatures and precipitation result in foundation movements of unusual severity. This report correlates certain soil and climatic conditions with soil volume changes, and describes the methods and instrumentation used to measure vertical ground movements, and some of the observed effects of the movements on buildings and water-mains. Detailed information is given for Ottawa and Winnipeg where extensive research has been conducted during the past five years by the National Research Council and the University of Manitoba. Seasonal movements in Saskatchewan have been reported previously (Torchinsky, 1953).

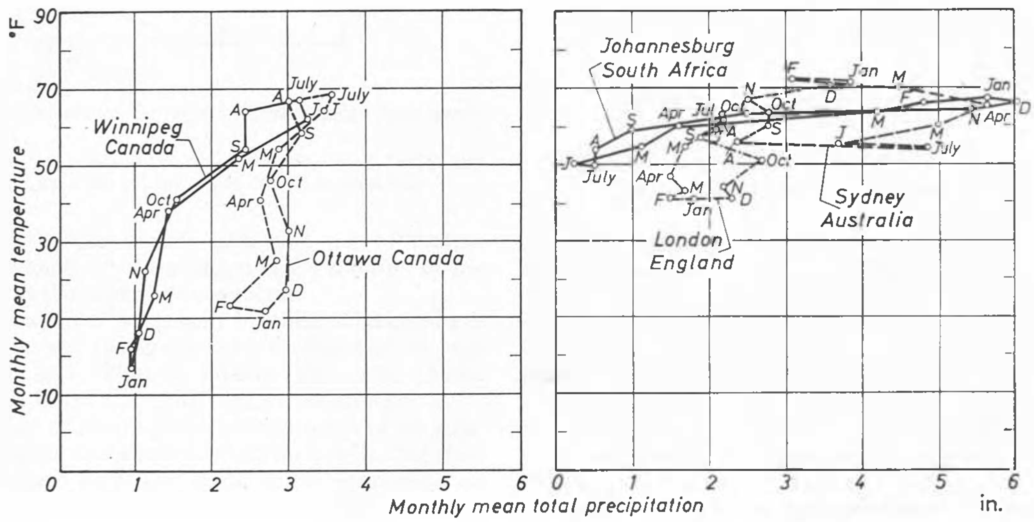

Fig. 1 Hythergraphs for Winnipeg, Ottawa, London, Johannesburg and Sydney
Graphique: précipitations températures (hythercourbes) pour Winnipeg, Ottawa, Londres, Johannesbourg et Sydney

Climate

Mean monthly temperature and precipitation for Ottawa and Winnipeg are shown by the hythergraphs in Fig. 1. Similar records are shown for London, United Kingdom, where SKEMPTON (1954) and WARD (1953) report differential foundation movement from shrinking clays, for Johannesburg, South Africa, where JENNINGS (1955) reports swelling clays, and for Sydney, Australia, where swelling and also some shrinking are reported by TASKER (1954) and ISAACS (1952).

Correlation of Ground Movement and Climate

Visitors to Canada may hear the expression 'the dry thirties', a reference to several hot and dry summers experienced on the Prairies before 1939. Subsequent and proceeding years had much higher precipitation.

In Winnipeg during the 'dry thirties', shrinking clays resulted in severe differential settlements of spread footings and necessitated extensive underpinning of buildings. Many structures constructed on deep piles during the dry years lifted as much as 4 in. off the piles due to subsequent swelling of the clay. Significant seasonal soil moisture changes have been observed to depths of 12 ft. both in Winnipeg and Ottawa and have corresponded to both upward and downward foundation movements. Such general observations led to the development of special instrumentation and to the initiation of continuous readings to establish a correlation between ground movements and their cause.

In clays that extend to considerable depth, precipitation accounts for most soil moisture increases, and evapo-transpiration for soil moisture losses. Such losses and gains for grassed areas may be evaluated by methods proposed by THORNTHWAITE (1948) based on daily weather observations. He assumes that within the root system of grasses, the soil can store up to 4 in. of water. If the amount of water due to high precipitation exceeds this amount, it is called a surplus and is considered to run off. If more than 4 in. of water is lost by evapo-transpiration, a potential soil moisture deficiency occurs. This deficiency can be replaced by rainfall. As shown later, correlation was established in Ottawa between ground movements and soil moisture surplus, storage, and deficiency. This method cannot be used, however, when the ground is frozen and precipitation is in the form of snow. Trees, because of their deeper root system, alter the surplus–storage–deficiency relationship.

Soils

The following is a brief description of two important volume-changing clays found in Canada.

Leda clay—This clay, found in layers up to 200 ft. thick in the Ottawa–St Lawrence lowland region, was deposited during the last ice age in salt water or in fresh water which later became brackish when invaded by the Atlantic (JOHNSTON, 1917; and MACKAY, 1949). Subsequent uplift has raised these deposits to elevations up to 700 ft. above sea level.

The geology and geotechnical properties of leda clay are discussed in another contribution to this conference by EDEN and CRAWFORD (1956).

Lake Agassiz clays—The swelling and shrinking clays found in the Red River Valley consist of varved lacustrine deposits laid in glacial Lake Agassiz which covered a large area of southern Manitoba toward the end of the last ice age (UPHAM, 1896). They consist of two layers of approximately equal thickness: a top layer of brown varved clay underlain by a softer and siltier grey layer. In Winnipeg their combined thickness ranges between 40 and 60 ft. They are generally overlain by a few feet of more recent fluvial silts and clayey silts, organic soils or clays modified by vegetation and weathering. Swelling pressures of about 1 ton/sq. ft. are commonly shown during consolidation tests on undisturbed samples. Swelling pressures up to 20 tons/sq. ft. on re-wetting have been measured in the laboratory on air-dried samples. The composition of the brown clay is approximately 30 per cent montmorillonite and the remainder practically all illite.

Ground Movement Gauges

Two types of gauges were used for measuring vertical soil movements in the ground. The multi-rod gauge (WARD, 1953) uses a series of rods with shoes, placed on undisturbed soil at predetermined depths, in a line of vertical holes. The holes, spaced a foot apart, are lined to permit the rods to move freely when the soils supporting the shoes shrink or swell. The tops of the rods project above the ground surface so that elevation readings can be taken with reference to a level beam spanning the line of gauges or by using a precise engineering level. These readings are referenced to a deep bench mark.

A telescoping concentric gauge has been developed for use where space is limited (BARACOS and MARANTZ, 1953). Steel tubes of various lengths and diameters telescope loosely over one another with the longer tubes fitting inside the shorter tubes. Each tube is fitted with a 10- by 3-in. flat steel plate at its lower end to form horizontal vanes. The tubes are placed one at a time, after being greased, into an elliptically shaped hole, around a ½-in. diameter reference rod. They are then turned forcing the vanes into undisturbed soil at predetermined depths. The hole is carefully backfilled and compacted as each tube is installed. The centre rod has a steel foot founded at the bottom of the hole and is referenced to a permanent bench mark. Measurements are made on the tops of the tubes, which extend above the ground surface, using an Ames dial or rule with reference to the centre rod.

Ground Movements in Grass Plots

Since 1951, multi-rod and concentric telescoping ground movement gauges have been used in Winnipeg and Ottawa in grass plots located outside the influence of trees. The magnitude of the movements in both cities is comparable. As an example, Fig. 2 illustrates the recorded seasonal ground movements, the soil moisture surplus–storage–deficiency curves and also water-table elevations for Ottawa.

The Ottawa results show that the maximum settlements occur during the summer at the height of the vegetation growing season when high temperatures and evapo-transpiration resulted in a peak moisture deficiency. Rains and reduced evapo-transpiration toward the end of September favoured increased soil moisture and swelling. By November the soil was recharged. Frost heave during winter caused the ground surface to rise while movements were insignificant at depths below frost penetration. The range of movement of the ground surface, excluding frost heave, is almost 1·5 in.

The movements recorded in Winnipeg showed marked differences from year to year. Downward movements were observed during December, January and February of 1952 and 1953. It is believed that ice lenses, forming at shallow depth, removed sufficient moisture to cause excessive shrinking of the underlying partially saturated clay to cause a net downward movement of the ground surface. During the following years freezing resulted in a small upward movement of the ground surface followed by additional rising during the spring thaw. Melt water during the spring generally resulted in large upward movements. A rise of 1·4 in. of the ground surface accompanied the spring thaw in 1953. A downward movement of 1·4 in. occurred during the relatively dry summer of 1955. In other years the summer downward movement has been as little as 0·2 in. Upward and downward movements of as much as 0·3 in. have been measured at the 8-ft. depth with the 12-ft.

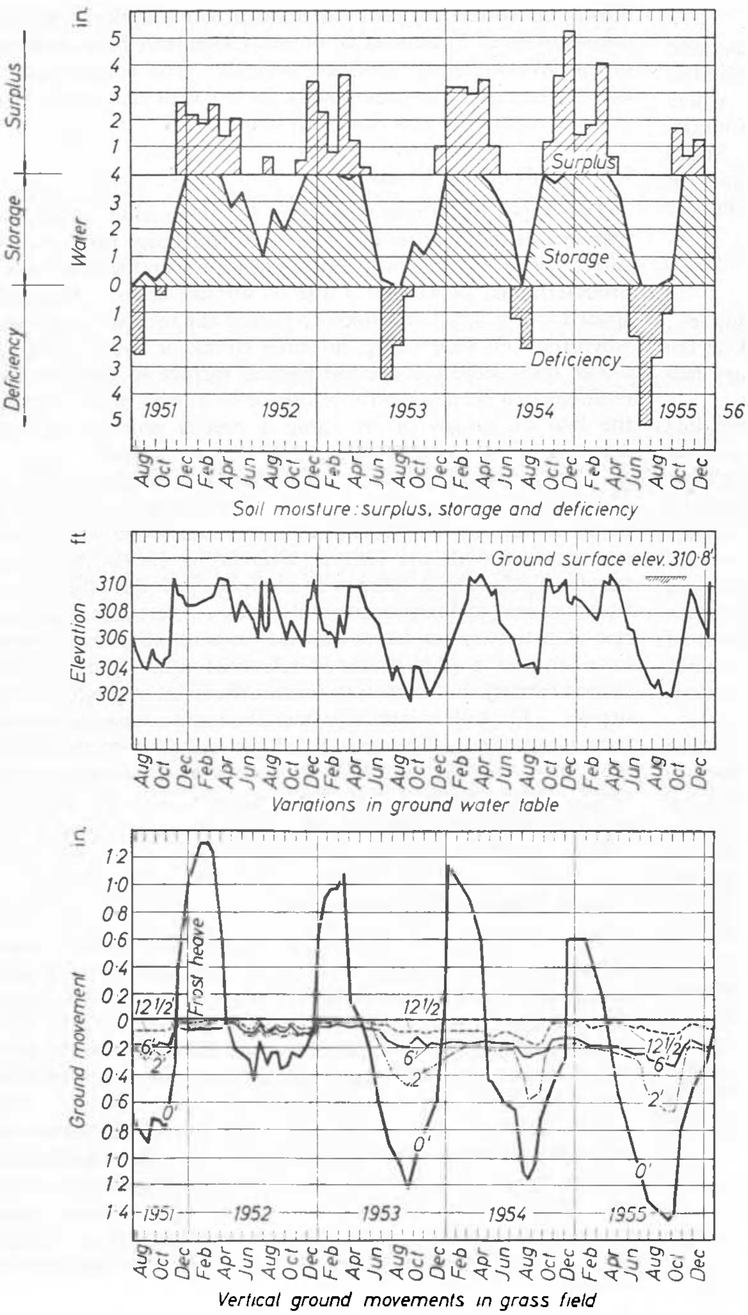

Fig. 2 Ground movements and soil moisture conditions in grass plot

Mouvements de terrain et teneur en eau du sous-sol d'un pré

depth remaining practically stationary. Following dry weather, when the clays fissure and permit rapid entry of water, rains have resulted in very rapid upward ground movements.

Ground Movements near Trees

Large settlements have been directly attributed to soil moisture demands of trees adjacent to foundations. To study these movements multi-rod and concentric telescoping gauges were installed in Ottawa during 1954 adjacent to a line of elm trees approximately 60 ft. high at distances of 5, 10, 20, 30 and 40 ft. from the trees and extending to depths up to 15 ft.

During the summer of 1955, the fourth driest year recorded in Ottawa since 1890, settlements ranged from 3·5 in. at the ground surface to 0·5 in. at the 15-ft. depth. Fig. 3 shows the maximum recorded vertical ground movement at different depths. To permit comparison with trees of the same species but of different size, the distance from the trees is expressed as a ratio to tree height. The influence of the trees was greatest at distances having a ratio of less than 0·2; for greater distances the influence decreases becoming negligible at a ratio of 0·8. Beyond this, the ground movements are identical to those in grass plots.

Flat Slab Foundations

Monolithic reinforced concrete slabs placed on a prepared gravel bed on the ground surface are being used in increasing numbers for house foundations in Canada. The slab supports the walls, forms the floor, and often contains heating coils.

As part of an extensive study of this form of construction, two experimental slabs were constructed in Ottawa and one in Winnipeg. They were 6 in. thick, 20 ft. square, of non-reinforced concrete, supporting a small prefabricated building electrically heated by cables embedded in the slab. The programme included the measurement of movements of the slab and the supporting soils by means of multi-rod gauges at the 2- and 5-ft. depths.

Fig. 4 shows the movement recorded on equally spaced points along the two diagonals of the Winnipeg slab which was supported directly on clay. Points A_1, F_6, A_6, and F_1 are respectively the south-east, north-west, north-east and south-west corners of the slab. Maximum seasonal upward and downward movements of 1¼ in. of the slab occurred.

Differential movements up to ½ in. have resulted in the top of the slab being concave. This is attributed to the dry soil conditions at the time the concrete was placed and subsequently increased soil moisture contents near the slab perimeter. The gauges showed that, to a depth of at least 5 ft., soil shrinking and swelling occurred accompanied respectively by downward and upward movement of the slab. Corresponding decreases and increases in moisture contents were observed. Similar movements occurred in the Ottawa slabs, but one of the slabs which is supported on 18 in. of gravel showed less movement.

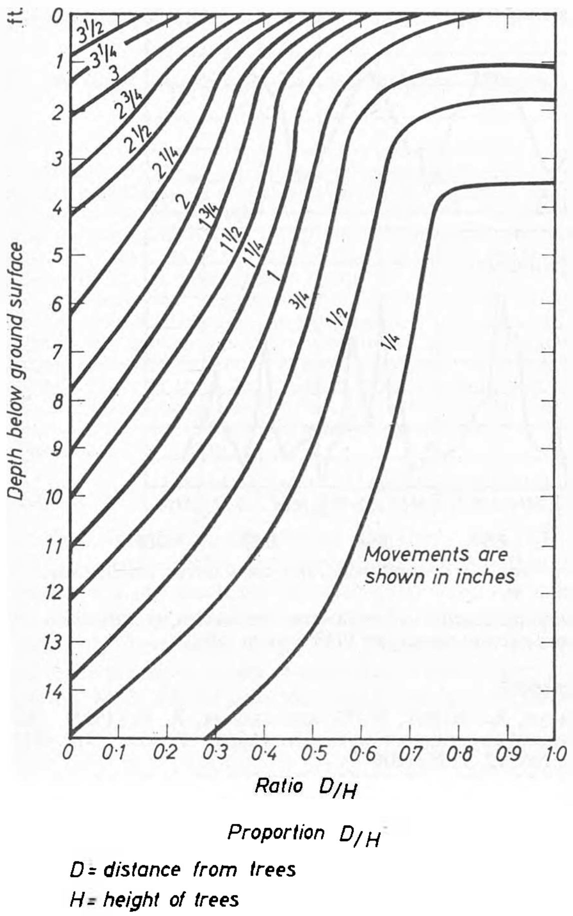

Fig. 3 Vertical movements in Leda Clay soil near 60 ft. high elm trees in Ottawa in 1955

Mouvements verticaux du terrain près d'un groupe d'ormes de 18 m de haut à Ottawa en 1955

Water-main Failures

Extensive damage to water-mains in the City of Winnipeg has been caused by ground movements (Baracos, Hurst and Legget, 1955). Soluble sulphates in the soil have caused rapid corrosion of cast-iron pipe which, once weakened, fails in flexure as a result of seasonal soil movements. It has been noticed that the number of failures per month greatly increases during September following a hot dry summer (Fig. 5).

Multi-rod gauges modified to measure vertical movement of buried pipe showed a 2-in. upward movement following the spring thaw, of a poorly backfilled water-main buried about 7 ft. below the ground. Differential movements of as much as ¾ in., resulting in ½-degree rotation of tightened joints, have been measured on water-mains consisting of 6-ft. lengths of 6-in. diameter universal cast-iron pipe.

Discussion

It is evident from experience in Canada and elsewhere that swelling and shrinking clays introduce foundation movements that so far can only be predicted on the basis of experience. These clays can be identified by their high plasticity index and liquid limit and by their high content of active clay minerals, particularly montmorillonite. From these studies it may be inferred that foundations constructed on Winnipeg clays during dry periods are subject to heaving in subsequent wet periods, and those constructed during wet periods will undergo settlement in subsequent dry weather. The clays behave differently in Ottawa. Only downward movements have been observed in foundation walls of buildings constructed during either wet or dry periods.

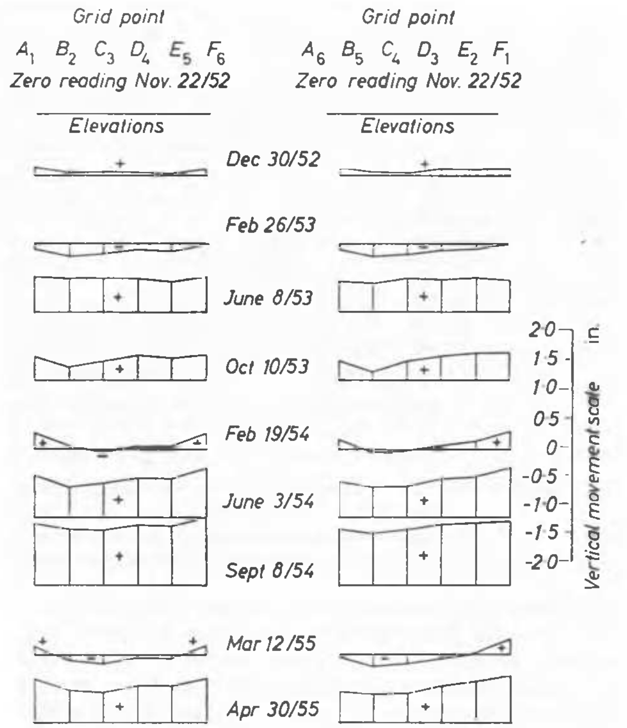

Fig. 4 Flat slab—Winnipeg, plots of typical vertical slab movement (points on diagonals of slab)

Dalle plane à Winnipeg. Graphiques typiques de mouvements verticaux (en des points situés sur les diagonales de la dalle)

Correlation of seasonal climatic changes and ground movements is possible for grass plots as shown for Ottawa. For building sites other factors must also be considered, as indicated by the following examples.

In Vernon, B.C., which is in a relatively arid area, new houses on shallow foundations on a hill-side site intercepted the downhill snow melt. This water entered crawl spaces under the houses and percolated to the clays supporting the foundations and the resulting swelling caused severe differential movement. Without the interception of surface flow by the buildings, such changes in moisture content would not have occurred.

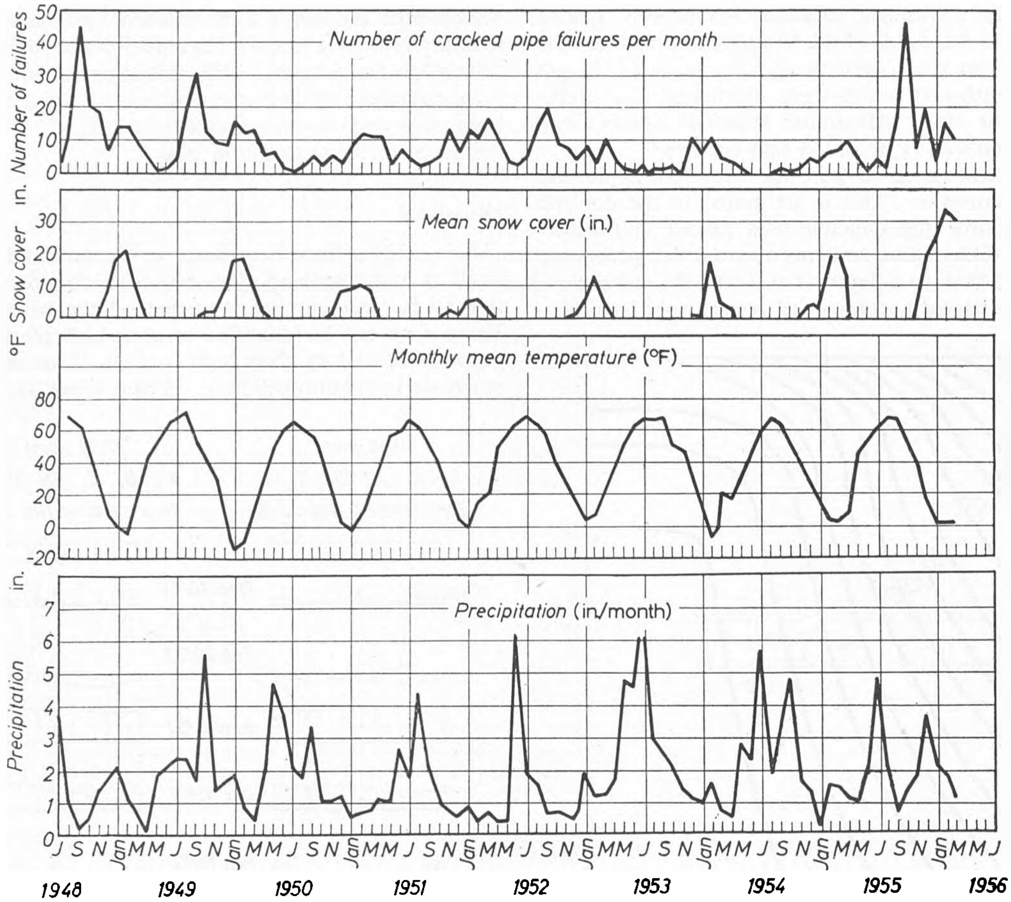

Fig. 5 Number of cracked pipe failures, monthly mean temperature, monthly precipitation, and snow cover, *versus* time, July 1948 to March 1956

Nombre de ruptures de conduites d'eau, température moyenne mensuelle, précipitations mensuelles, et variations de l'épaisseur moyenne de la couche de neige, en fonction du temps, de juillet 1948 à mars 1956

Differential settlements of 3 to 4 in. and occasionally as much as 1 ft. of brick dwellings have taken place in Ottawa with the maximum settlement always in the vicinity of trees. Tests in such areas have shown significantly that the soil is much drier in the vicinity of trees and streets. Paved streets affect soil moisture by improving surface drainage and reducing evapotranspiration.

Experience with water-mains and with spread footings illustrates that poorly compacted backfill and inadequate surface and underground drainage can materially increase the depth to which clays are subject to seasonal volume changes.

Records of vertical ground movements under a variety of conditions in areas where volume-changing clays are encountered are considered an invaluable aid to shallow foundation design. The writers believe that the Canadian experience with ground movements will be valuable where similar soils are found not only in areas having comparable climatic conditions but elsewhere where soil moisture changes may be caused by environmental changes accompanying land development.

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