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Swelling and Shrinking Subsoils

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Please note

Clay subsoil provides a satisfactory bearing medium for many buildings. Occasionally, however, a combination of circumstances causes changes in the volume of the clay. This swelling and shrinking is sometimes of such magnitude that it, in turn, causes movements in a building, sometimes with disastrous results. This Digest describes some of the common causes of clay volume change and discusses the precautions that must be taken to prevent damage to buildings founded on subsoils that are susceptible to volume change.

Most of the foundation problems of residential, light commercial and industrial buildings, buried pipes, sidewalks and roadways do not result from excessive loading of the subsoil but from swelling or shrinking of the soil itself. In the sub-humid to semi-arid regions of the Prairie Provinces and inland British Columbia, volume changes of clay-rich foundation strata are often caused by the secondary or side effects of man's construction and landscaping activities. In the more humid regions of Eastern and coastal Canada, shallow foundations placed on thick clay deposits may become seriously distorted as deep-rooted vegetation removes soil moisture which cannot be readily restored by infiltration or internal moisture movement (**CBD 62**). In many instances, the cost of correcting these foundation problems greatly exceeds the original expenditure on the foundation. If these problems are recognized in advance by designers, building officials, and owners, it will be possible to provide trouble-free foundations.

Examples of Foundation Failures

Numerous cases of foundation problems arising from swelling and shrinking subsoils have been observed in the field studies of the Division of Building Research. The worst case occurred in the dry grasslands of the central prairies where a floor in a shallow basement heaved at a continuing rate of almost 1 inch per year. When this building was examined by DBR the floor had heaved more than 2 ft. In addition, the wall footings, which are more heavily loaded than the floor, had heaved differentially in excess of 5 inches.

In more humid areas of the northern and eastern prairies, on sites where trees have been removed prior to construction, basement floor slabs may heave by several inches. In one case the floor slab heaved more than 1 foot and wall footings more than 4 inches in less than 5 years. Where this heaving was resisted by partition walls, pressures were of sufficient magnitude to crush 8-inch concrete blocks.

Differential settlements of footings in excess of 1 foot have been observed when trees have grown near foundations on soils that have not previously supported tree growth. Such disruptive settlements may develop in a few weeks during periods of drought or they may occur gradually over the lifetime of a tree when the infiltration of moisture is less than that required by the tree.

Slabs-on-grade upset the natural transfer of moisture to and from the ground and for this reason they are subject to annual as well as long-term movements. Annual cyclic edge movements of an inch or more, and net edge heaves of more than 5 inches over a period of several years, have been observed. Spectacular heaves at rates of 3 inches or more per month have been observed due to plumbing leaks beneath light industrial or residential slabs.

Soil mechanics and foundation engineers now view these problems in the light of a growing understanding of the contributory factors. Completely satisfactory designs are now being made in most instances when the services of these specialists are obtained. They are, however, rarely engaged for the selection of foundations for the majority of buildings in the small to intermediate size range, including single and multiple family dwellings, churches, and light commercial and industrial buildings.

Contributory Factors

The main factors that control the performance of foundations in such conditions are soil, climate and vegetation. The disruption of the natural equilibrium existing between these factors and the compatibility of the foundation structure with present and future subsoil conditions influence the magnitude of the problem.

Most of Canada's surface soils have been shaped and influenced by glaciation. Several western Canadian cities are located on deep deposits of glacial lake clays of high swelling and shrinking potential. Occasionally, glacial clay tills and alluvial clays are also troublesome. The preglacial Cretaceous clay shales are potentially highly swelling are fortunately usually covered with considerable depths of more recent materials and generally only cause concern in large structures and engineering works requiring deep excavations. The marine clays deposited in estuaries in glacial times and which have since risen above sea level present serious shrinkage problems in several coastal areas.

It is possible to delineate the major deposits of troublesome subsoils on pedological and geological maps. Mineralogical investigations have shown that the clay soils of Western Canada are remarkably uniform in mineralogy and that the swelling mineral - montmorillonite - is a major constituent. Also important in the geologic history of a subsoil is its stress history, i.e., whether the soil has been previously stressed above its present conditions by loads since removed or by desiccation.

Climate has a great influence on soil moisture conditions. The engineering behaviour of soils is governed in large measure by their moisture contents. Most clay subsoils exist in an approximate state of moisture equilibrium that may be seriously disrupted by construction, drainage or irrigation. Lawn watering in urban areas can have results equivalent to a substantial increase in rainfall - by amounts estimated to be in excess of 25 per cent for at least one Canadian city. This practice often results in a marked increase in subsoil moisture and volume and brings about new problems for shallow foundations.

Vegetation also plays an important role in affecting soil moisture content. It may be visualized as a very efficient pump capable of extracting great volumes of water from relatively impermeable soils. Natural grasses and other similar vegetation may be capable of removing moisture from depths greater than 8 ft and at a rate of ¼ inch of water per day. Large trees have been known to extend their roots to depths in excess of 25 feet and horizontally to distances greater than 1½ times the height of the tree. Competition of shallow and deep-rooted plants in the same soil profile tends to accelerate soil moisture depletion.

Nature of Swelling and Shrinking Clay Soils

The physical dimensions, or volume, of coarse-grained soils, such as sand, are governed solely by loading stresses. In contrast to this, the volume of a clay soil is governed not only by external stresses (loading) but also by internal stresses.

The weight of overburden and foundation loads are the principal external forces acting on a subsoil. The internal stresses arise from physico-chemical forces which increase as the soil dries. A clay which has long existed in an environment where abundant moisture has been available, will have small internal stresses and has little tendency to take up more moisture. Roots of plants, however, may induce internal stresses much greater than the stresses applied by building foundations!

In humid areas natural clay soils with high initial water contents and which have not previously been subjected to drying or consolidation by loading will tend to shrink on drying or loading more than they will tend to swell on wetting or unloading. Under other climatic conditions, clays that have been subjected to cyclic moisture change or previously subjected to higher loading may tend to swell greatly when allowed access to water under light loading. Their rate of swelling is governed by the rate at which water can move into the clay, i.e., the permeability of the clay. Because of small pore size and thus their low permeability, clays may take years to reach new moisture equilibrium conditions.

The magnitude of heaving or shrinkage is dependent on the amount and type of clay minerals present, the previous stress history of the deposit, the magnitude of water content change from initial to final equilibrium conditions, and the thickness of the soil strata affected in addition to elapsed time. Although clays are complex materials, those that will be troublesome can be identified and rates and magnitude of volume change estimated from standard laboratory tests.

Seasonal and Long-Term Effects

The vertical movements of various natural subsoil strata have been measured at several test sites in Canada to establish the effects of natural grass, cultured grass, summer fallow, pavement cover, and large trees. Both annual and long-term trends have been measured. Under sub-humid climatic conditions, annual movements under grass cover usually have a maximum range of approximately 4 inches at the ground surface. In very dry years, shrinkage of over ½ inch has been measured at the 8-foot depth. The annual range of movements under summer fallow may be somewhat smaller than for grass cover.

Some of the serious problems created by the encroachment of deep tree roots into foundation strata have been described in **CBD 62**, particularly with reference to the Leda clay of the St. Lawrence and Ottawa valleys. On many tree-lined streets in several cities in Western Canada, the tell-tale bowl-shaped depressions in sidewalks, roadways and landscaping, and foundation distortions give evidence of progressive shrinkage settlements, often of a foot or more. Conversely, the removal of heavy tree growth from a building site prior to construction has resulted in some of the most spectacular heaves experienced by shallow foundations.

Paved surfaces cut off evaporation, and progressive heaving due to an increase in moisture may continue for several years after construction. A heaving rate of 1 inch per year is not uncommon. Landscape irrigation also has long-term cumulative effects on the volume change of clay subsoils. Uncontrolled roof runoff and excessive lawn watering have precipitated foundation problems in many small buildings. Localized shrinkage due to moisture migration caused by heat loss from structures has also had serious consequences.

The most devastating heaving occurs when the reduction in external stresses caused by excavation is combined with an abundance of subsoil moisture. This swelling results in cracked basement floor slabs so common in several urban centres on the Prairies. These cracks are usually evidence of the greater rate of heave of lightly-loaded, central floor areas and footings as compared with the slower rate of heave of more heavily loaded wall footings. Measurements in a large number of new house basements have proved that both the footings and floor slab continue heaving for several years after the time of construction. The rate of heaving of some floor slabs and central footings is of the order of 1 inch per year; that of the perimeter footings is approximately one-half of this rate. Plaster cracking, binding of doors, and superstructure damage often do not become serious in the first year after construction.

Foundation Designs

The selection of foundations for small buildings is usually based on local convention (**CBD 12**). Many of these local designs have evolved through modifications to traditional designs brought from other areas. Rarely do these have the benefit of individual site investigations and design by specialists. In newly settled areas of Canada, the art of these foundation designs has been based on a relatively short span of experience. Many of the original foundations are still in service but their performance life to date is shorter than the effective period of some of the variables that have significant effects on their performance, e.g., growth of trees to maturity, or long-term effects of irrigation or drainage. Evolutionary changes in designs of house foundations have been made in an attempt to reduce the capital expenditure to the bare minimum. Some of these modifications are the adoption of cast-in-place concrete to replace stone masonry for basements, the inclusion of longitudinal reinforcement in long foundation walls, and the use of keyways and reinforcing tie-bars at the connection of walls and footings. These modifications have helped to increase the rigidity and have reduced the frequency of cracked foundation walls, but have not solved the problem of differential heaving or settlement of the footings or floor slabs.

Spread footings placed at depths ranging from 6 to 8 feet below original grade are commonly selected as foundation units for small buildings with basements. The root penetration of large trees and drought-resistant plants may go well below this level and eventually affect the soil volume and foundation performance. In at least one major Canadian city (Winnipeg), during periods of prolonged droughts, a great number of shallow spread footings have undergone serious differential settlements requiring extensive repairs. The complete prohibition of trees and deep-rooted plants within distances of up to 100 feet from such foundations on clay would be most unsatisfactory from the owner's point of view. One solution is to use foundation designs that carry building loads to deeper strata. Alternatively, one might consider measures for maintaining constant soil moisture conditions. This is not usually successful because of the difficulty in supplying and distributing enough water through the relatively impermeable clay to meet the tremendous demands of trees. On the other hand, the effects of a few years of intensive lawn and garden watering in more arid areas has effectively raised the level of the subsoil moisture around buildings, and induced heaving of previously stable soils. The long-term effects of this practice are yet to be felt in some prairie communities where water supplies are becoming more abundant. The removal of trees from a site prior to construction can have similar effects.

When severe differential movements of spread footings have been anticipated, excellent results have been obtained through the use of pile foundations. In such designs, exterior basement walls and partitions can be designed as deep beams spanning the piles, with space provided below the bottom of these beams to allow for the predicted heave. Structural basement floors spanning these foundation units are used in this design to combat the most severe conditions. Pile foundations with various structural floor systems over crawl spaces have been successfully used in many buildings without basements. Complete isolation of the structure from volume-changing soil is the key to good performance of this type of foundation. A void space of dimension greater than the anticipated heave should be provided beneath all beams and structural units. Heaving soil can develop pressures more than ten times greater than design floor loads. With the exception of those few cases where swelling pressures are unusually small, it is uneconomical to design spanning members in contact with the soil to resist uplift forces.

Perimeter walls and grade beams must be designed to resist lateral swelling pressures of backfill soils. Extremely high pressures can develop against these units if clay backfill is compacted to a high density in a dry condition and later becomes wet. An effective tile-drain system and free-draining granular backfill, extending almost to exterior grade elevation, should be included in perimeter backfill design.

In some cases the movement of shallow spread footings may be tolerated and the superstructure damage minimized through use of adjustable columns supporting the beams above. The problem of differential heaving of a basement floor may be avoided by providing a structural basement floor clear-spanning between foundation supports.

Although still not commonly adopted for small buildings, raft foundations might be considered in some cases. For a full basement beneath light, one- and two-storey buildings, the weight of soil excavated is considerably greater than the total weight of the building. This results in a net unloading of the subsoil and contributes to the swelling problem. For partial basements in which excavation is approximately 4 feet deep, the weight of soil removed more nearly equals the weight of the structure and the principle of a "floating foundation", as described in **CBD 81**, might be employed. The shallower the foundation, the more vulnerable it becomes to subsoil moisture changes due to surface influence.

Slabs-on-ground for small basementless buildings have met with varying success in different areas of Canada. In areas of humid climate, slabs lightly reinforced to resist small edge deflections have usually performed well. Some difficulties have occurred when part of the slab is not heated and the superstructure has been damaged by frost heave, or where nearby trees have caused subsoil moisture changes. In more arid areas of Western Canada, the short-term performance of similar lightly reinforced slabs has not been good. The more marked effect of lawn watering and plumbing leaks on subsoil moisture conditions has resulted in many problems. In soil and climatic conditions similar or more severe than those of Regina, it is advisable that concrete slabs-on-ground be stiffened by beams and reinforcement. They may be required to span up to two-thirds the long dimension of the slab in the event of edge heaving at diagonally opposite corners, or up to one-third the length dimensions in the case of centre heaving. This heavy stiffening requirement will probably make ground-supported slabs uneconomical, compared with pile and crawl space construction, for all but small buildings.

Summary

The swelling and shrinking of subsoils of high clay content create serious problems in shallow foundations in many areas of Canada. Differences in performance of shallow foundations arise from small differences in climate and the extent of disturbance of natural conditions due to man's construction activities. Methods of identification of potentially troublesome conditions and various foundation design alternatives to cope with these problems are now available to foundation specialists. The value of new foundation designs, based on a fuller understanding of the various factors affecting performance, has been established by their improved long-term performance. It is to be hoped that changes in local practice for small building foundations, which are rarely designed by a specialist, will include the adoption of these improved foundation schemes.