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Canadian Building Digest, 1977-03

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Canadian Building Digest

Division of Building Research, National Research Council Canada

CBD 184

Foundations on Swelling or Shrinking Subsoils

Originally published March 1977

J.J. Hamilton

Please note

This publication is a part of a discontinued series and is archived here as an historical reference. Readers should consult design and regulatory experts for guidance on the applicability of the information to current construction practice.

Volume-changing clay subsoils constitute the most costly natural hazard to buildings on shallow foundations in Canada and the United States[1]. In the prairie Provinces alone a million or more Canadians live in communities built on subsoils of very high potential expansion. In eastern and coastal regions even larger populations are situated on clays of high shrinkage potential. **CBD 84** discussed the nature of swelling and shrinking soils and gave examples of problems encountered with shallow foundations. This Digest will describe new concepts and details developed from continuing study of the subject and will discuss the selection of appropriate foundations.

Identification of Potentially Hazardous Subsoils

The troublesome clay deposits in Canada can be divided into two main groups, shrinkable clays and expansive clays. Shrinkable deposits, found extensively in the St. Lawrence and Ottawa river valleys, are usually of marine or brackish water origin, have very high natural water content, and contain little or no expanding clay minerals. They display little tendency to expand under reduced stress and freely available water unless they have been previously dried and reduced in volume by as much as 50 per cent below sedimentation conditions. The shallow foundation problems associated with these clays are almost exclusively shrinkage settlements due to the deep-seated drying influence of tree roots (**CBD 62**).

Swelling or expansive clay soils are usually found in lacustrine deposits of Central and Western Canada. Because of their montmorillonite mineralogy and drier initial moisture contents, their usual reaction to changed environmental conditions is to swell or exert large pressures against non-yielding structures; but they may also exhibit a high degree of shrink- swell reversibility with changes in moisture content.

Identification of potential swelling or shrinking subsoil problems is important in the early stages of land use planning and is essential for enlightened foundation selection. A classification (Figure 1) based on percentage clay fraction and plasticity index (**CBD 43**) can be used to categorize probable severity[2]. A soil having clay content in excess of 25 per cent and a plasticity index greater than 30 per cent would be suspected of a very high potential for shrinkage or swelling. Any soil with a clay content and a plasticity index in excess of 10 per cent may undergo at least slight swelling or shrinking with changed environment.

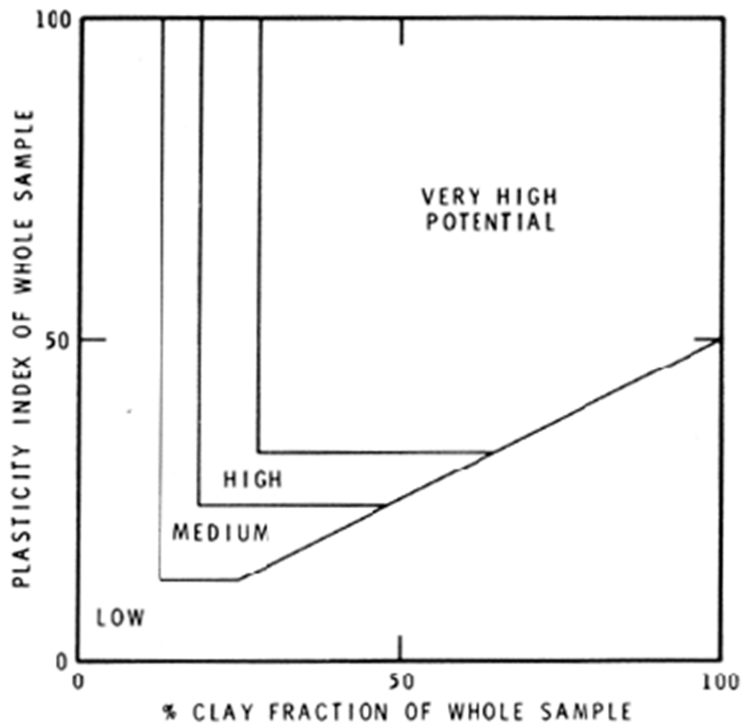

Figure 1. Potential severity of volume change for clay soils. (after Williams (2))

Foundation Selection

The majority of foundations for small structures are selected to meet the minimum requirements of building regulations or standards set by various regulating authorities or financing institutions. Although satisfactory structural safety and first-cost economy are usually achieved, the life cycle costs and performance of shallow foundations on deep deposits of active clay subsoils are often poor.

A foundation relies for stability upon the underlying subsoils to depths in excess of twice the width of the structure (CBD 80). The depth of potential soil volume change. either compression or expansion, and the degree of reactivity of the subsoils within this depth are of prime concern in selecting suitable foundations. Depth of frost action is also important for structures that do not lose appreciable heat to the subsoil (**CBD 182**). To date, building codes and standards have been much more specific about the depth of frost action than about the depth of the potentially active zone in shrinkable or expansive clay subsoils.

Active Zone

The active zone is proposed as the term to describe the mass of soil (under and around a structure) that will be appreciably affected by the presence of a structure, its appurtenances, landscaping and neighbouring buildings. The active zone may be thought of as a three-dimensional, dynamic environment influenced by both internally and externally imposed forces. The effects of cyclic or long-term changes in moisture content, temperature and chemistry are often superimposed on the structural stresses and strains to which the soil is subjected. Time, vegetation and climatic variations are important natural factors affecting the extent and activity within this zone. For example, Figure 2 shows the difference between the effects of rooting of uniform depth typical of grasslands and dense forest and the sporadic deepening of the active zone typical of parklands where trees are widely spaced.

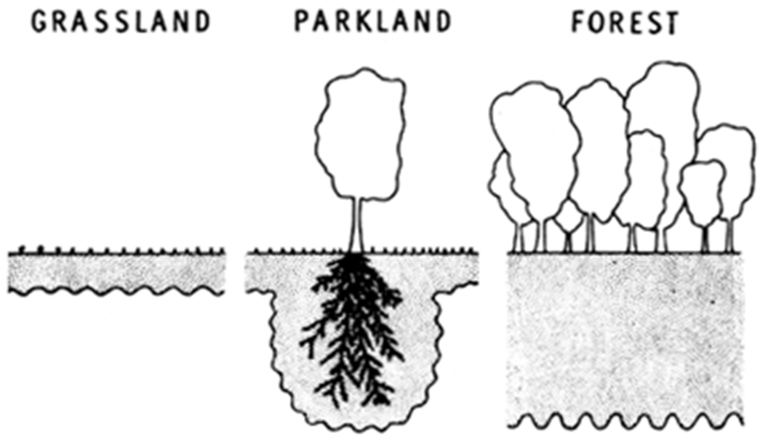

Figure 2. Configurations of the active zone for various vegetation types and densities growing on a deep clay deposit with a deep water table.

Construction and landscaping activities in urban development often have great impact on the natural environment (Figure 3). An excavation of 5 or 6 ft for a house basement results in a net unloading of the subsoil, for the earth removed is usually many times the weight of the completed house. This unloading is conducive of large, non-uniform expansion of subsoils and differential heaving of shallow foundations. Conversely, the weight of a relatively low fill can be far more significant than that of the building placed upon it. Heat flows to or from a building, and subsurface drainage and surface irrigation can cause marked changes in the moisture content, volume or stresses within a subsoil. Paving, landscaping and irrigating large portions of the terrain may also have great impact on deep clay deposits.

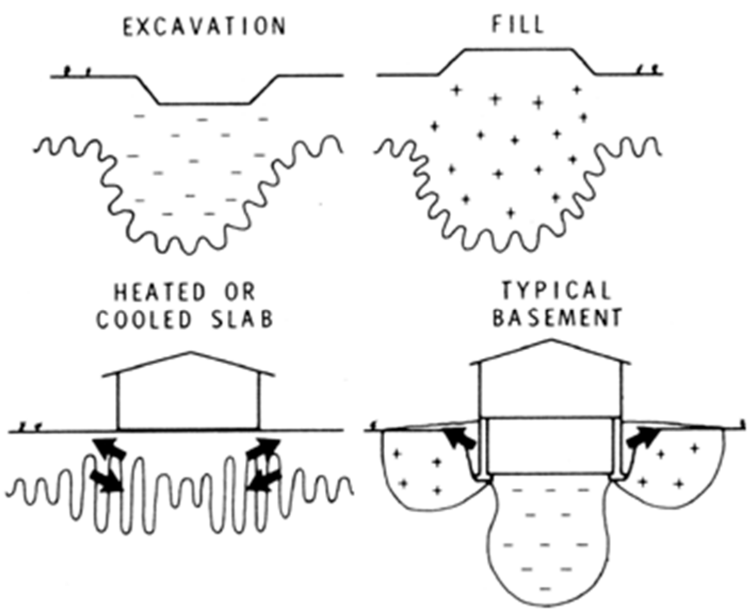

Figure 3. Configurations of the active zone for various structural influences such as: stress reduction -, stress increase +, and heat flow →.

Design of Foundations

There are, basically, two foundation design approaches for swelling or shrinking subsoil conditions. Shallow, spread footings (Figure 4) and slabs-on-grade are most common in traditional practice. Deep foundations, which develop bearing capacity in stable ground conditions below the active zone (Figure 5), are frequently the choice when a design analysis is carried out by geotechnical experts.

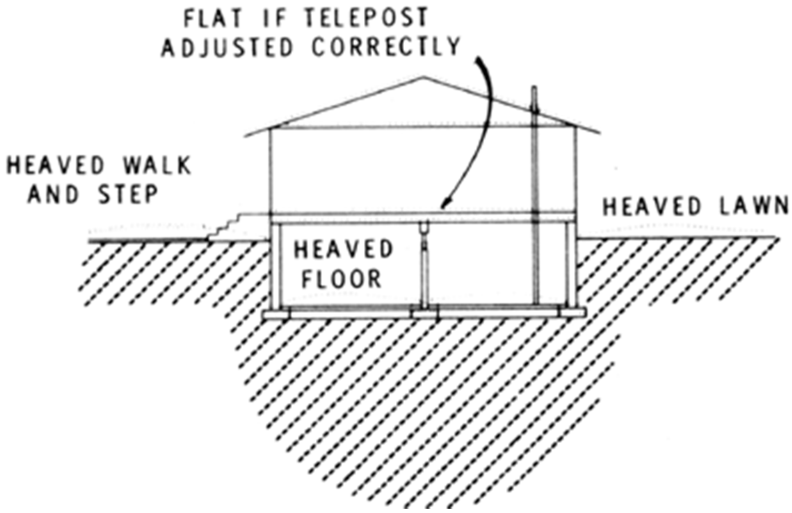

Figure 4. Typical short-term shallow foundation performance on a deep deposit of expansive subsoil.

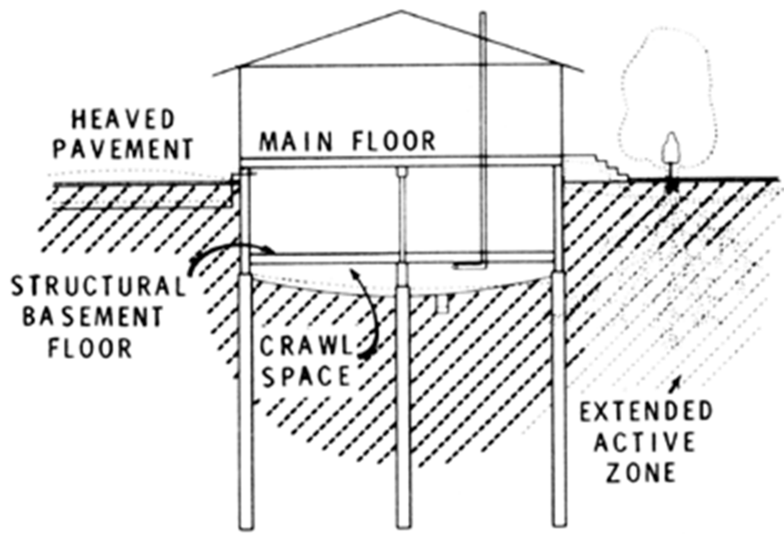

Figure 5. Typical long-term deep foundation performance on a deep deposit of expansive subsoil, including effects of tree growth.

Shallow foundations may undergo large absolute (total) and differential movements on subsoils of moderate to high swelling or shrinking potential. Distortions often do not reach damaging magnitudes for a year or more after construction, but they continue to grow and cause maintenance problems throughout the life of the structure. Once a structure's tolerance to distortion has been exceeded, maintenance problems often foreshorten its service life.

Deep foundations can completely eliminate absolute and differential movements within the main structure. For equal depths of basements, however, the net unloading influence of excavation to subfloor level can be somewhat greater than with shallow foundations. This is because the weight of the superstructure is transmitted to great depths instead of tending to compensate for the weight of excavated soil. It is therefore not unusual for ground-supported components such as basement floor slabs and buried plumbing and appurtenances on or near grade (for example, driveways, sidewalks, service conduits and door steps) to undergo accentuated differential movements in relation to the stationary main structure. Free-spanning structural members over adequately sized and drained voids and crawl spaces, structural or stable fill transitions between the main structure and surrounding native subsoils, and flexible connections for conduits all require expert design and carefully controlled construction to ensure successful long-term performance.

On subsoils of moderate to high shrinkage potential the magnitude and rate of shallow foundation movements are directly related to the location and activity of tree roots. During drought conditions deep rooted trees have been responsible for severe differential movements of several inches in a single growing season[3,4]; and over longer periods of time, cumulative differential movements within a single dwelling have exceeded a foot[5].

Clay Soils as Backfills. Clay-rich soils often present long-term problems as backfill materials. Their lumpy, cohesive nature, as produced by common excavation techniques, makes it difficult if not economically and practically impossible to recompact them to states of uniform moisture content and density that will ensure minimum future settlements, minimum swelling potential or minimum lateral earth pressures. Beyond the obvious problems of large and protracted surface settlements, clay backfills require significantly stronger retaining structures such as basement walls to withstand the larger horizontal earth pressures than are exerted by non-clay backfills.

Slabs-on-Grade. Although much progress has been made recently in developing design procedures for providing sufficient slab stiffness to minimize damaging distortions, no assurance can be given that such slabs will not suffer excessive tilt when non-uniform subsoil volume changes take place. Thick layers of non-clay subsoils overlying clay deposits may reduce differential movements of superimposed slabs or footings. Unfortunately, in Ottawa and Winnipeg tree roots have sometimes penetrated the deeper strata so that the resulting drying shrinkage has caused damage to foundations and structures placed higher in the profile. *Spread Footings*. The desirability of placing spread footings as deep as possible to minimize the dangers from deep rooted vegetation is counterbalanced by the desirability of keeping basement excavations as shallow as possible to minimize the unloading-heaving effect. If reactions to changed environment can be predicted to be exclusively shrinkage or swelling, the most desirable depth for spread footings and basement floors can easily be selected. "Floating" foundations (**CBD 81**) incorporating thick, heavily reinforced concrete mats have been successfully used to keep superstructure distortions to acceptable levels (**CBD 54**, **CBD 148**).

Deep Piles or Pier Foundations. Provided sufficient attention is given to isolating pile caps, beams and all other structural elements from the subsoil by adequate voids or crawl spaces, deep piles or pier foundations are most effective for subsoils of high potential for swelling or shrinkage. Although apparently simple in design and construction, their good performance potential can be lost if expert attention is not given to these and other details such as positive drainage and humidity control in all voids and crawl spaces and flexible connections for plumbing and other ground supported appurtenances.

Conclusions

A number of effective alternatives to traditional foundations can be developed from the knowledge and concepts now available relating to swelling and shrinking subsoils. Geotechnical experts in most major cities can assist in the development processes that will result in economic solutions. Planning and building authorities should require geotechnical hazard reports as part of submissions for approval of subdivisions or development plans; and such reports should include evaluations of the hazards to various structures and recommendations on the most suitable design and construction practices to ensure economic long-term performance.

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