Performance of Concrete Foundation Slabs on Canadian Clays

Comportement de dalles de fondations en béton au contact d'argiles canadiennes

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Summary

To study the performance of concrete slabs placed directly on the ground as foundation units for small structures, the Division of Building Research constructed two slabs in Ottawa and one in Winnipeg. These two locations represent wide variations in soil and climate conditions. In both locations the slabs were constructed on clay subsoils with well-known swelling and shrinking characteristics. This paper describes the performance of the slabs during several years of operation.

Sommaire

Dans le but d'étudier le comportement de dalles de béton au contact du sol, utilisés comme éléments de fondations pour charpentes légères, la division de Recherche en Bâtiment a fait construire deux de ces dalles à Ottawa et une à Winnipeg, sites où le régime climatique et l'état du sol présentent des fluctuations importantes. En ces deux endroits, les dalles furent construites sur des sous-sols argileux dont les caractéristiques de gonflement et de retrait sont bien connues. Le présent travail décrit les observations qui ont été faites sur le comportement des dalles au cours de plusieurs années.

One of the post-war developments in Canadian housing has been a trend toward eliminating the conventional full basement under single-family dwellings and erecting the superstructure on a concrete slab placed on the ground. Although apparently introducing some economy into house construction, the use of basementless houses has not developed as widely as had been anticipated since real economies are found to be small. Enough houses without basements, however, are being constructed in Canada to require a better understanding of the action of concrete foundation slabs, when placed either directly on the ground or on a low fill.

One of the first locations in which this type of house was proposed for extensive use was the City of Winnipeg, where soil conditions have long been known for their trouble-some characteristics in relation to building. Little was known about the forces to be expected upon such slabs in use. Building officials, however, had the responsibility of determining acceptable standards for the design of such foundation slabs. The lack of necessary information was brought to the attention of the Division of Building Research of the National Research Council and a comprehensive research program was planned in 1951.

It was decided that the only satisfactory way to determine the performance of concrete slabs on ground would be to construct slabs in typical areas to a scale that approximated those in use under actual houses. Two slabs were built in Ottawa, Ontario, and one in Winnipeg, Manitoba, on clay soils well known for their shrinkage and swelling characteristics. The slabs were made 20 ft. square since it was thought that this size would effectively eliminate "scale effects". On each of the three slabs, which were of unreinforced concrete 6 in. thick, a standard prefabricated hut, electrically heated by cables embedded in the slabs, was built.

In the absence of adequate design information, most slabs for basementless houses have been built using very conservative assumptions. To increase the possibility of observing failure, the test slabs were built to minimum or even subminimum standards. One of the slabs located in Ottawa (Slab A) was constructed directly on the ground surface after the removal of a few inches of top soil ; Slab B was placed on a compacted crushed rock base 18 in. thick on top of the original ground. Short fibre pipes were provided through the slabs to accommodate ground movement gauges and to allow for the removal of soil samples from under the slab. The slabs were provided with 1 in. thick edge insulation. The superstructures consisted in each case of a prefabricated Army hut of insulated plywood panels slightly over 3 in. thick. A cross-section of Slab B in Ottawa is shown in Fig. 1. The slab constructed in Winnipeg was placed directly on the ground and was therefore similar in design to Slab A in Ottawa.

The general objective of the project was to determine the structural and thermal performance of unreinforced concrete slabs on clay soil. The specific structural objective was to determine the changes of elevations of the slabs during a number of years and to correlate these movements with the soil and climatic conditions. This paper summarizes the findings of the structural investigation.

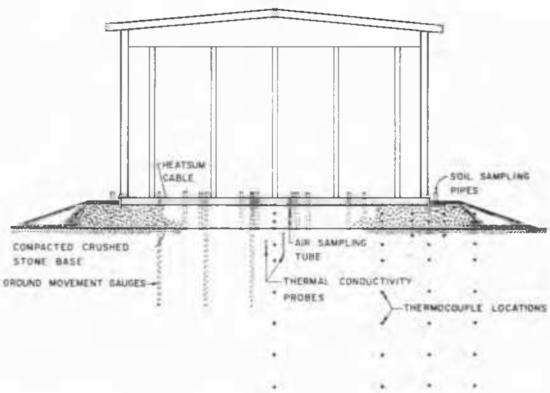

Fig. 1 Section through slab B
Section transversale de la dalle B

2. The Sites

Ottawa slabs were built on a flat grassed area on the grounds of the Montreal Road Laboratories of the National Research Council. An 8 ft. deep test pit at the site revealed about 3 ft. of friable, brown clay above brown, highly fissured and brittle clay of blocky structure. Below a depth of 10 ft. unweathered marine clay is encountered as described by EDEN and CRAWFORD (1957). The annual average natural water content increases from about 30 per cent at the surface to 45 per cent at a depth of 8 ft. Seasonal variations range from about 7 to 35 per cent at the surface but at a depth of 3 ft. little seasonal variation has been measured (CRAWFORD 1960). Frost heaving of the upper soil is common and ice lensing may increase the water content seasonally to 70 per cent. Snow-cleared roads in the vicinity commonly heave about 6 in. but very little frost penetration has been observed in soil under natural snow cover. In the upper 8 ft. the plastic limit averages about 28 per cent and the liquid limit ranges from 60 to 70 per cent. The undisturbed shrinkage limit averages about 25 per cent; for remoulded clay the shrinkage limit is slightly lower. The soil contains about 65 per cent of clay-size particles ($< 0{\cdot}002$ mm). Swelling and shrinking of the upper clay has been observed in the laboratory and in the field. In the upper region, the process appears to be reversible; at depth the shrinkage appears to be only partly reversible. Vegetation, particularly trees, has been shown to have a great influence on shrinkage (BOZOZUK and BURN 1960).

The Winnipeg slab was located on the campus of the University of Manitoba on glacial lake clay, typical of the area. The upper 8 ft. of soil is a highly plastic silty clay overlain by about a foot of organic top soil. The natural water content averages 30 to 35 per cent. The liquid limit averages about 100 per cent, the plastic limit about 35 per cent, and the shrinkage limit about 15 per cent. The clay contains approximately 30 per cent montmorillonite, the remainder being predominantly illite (BARACOS and BOZOZUK 1957).

3. Environmental Influences

The Ottawa and Winnipeg sites typify two entirely different soil and climatic regions of Canada. Ottawa, with a mean annual temperature of 42° F, receives a well distributed annual precipitation of 35 in. Winnipeg, with a mean annual temperature of 37° F receives only 20 in. of precipitation, more than 60 per cent of which falls during the five summer months. This contrast in climate is shown in Fig. 2.

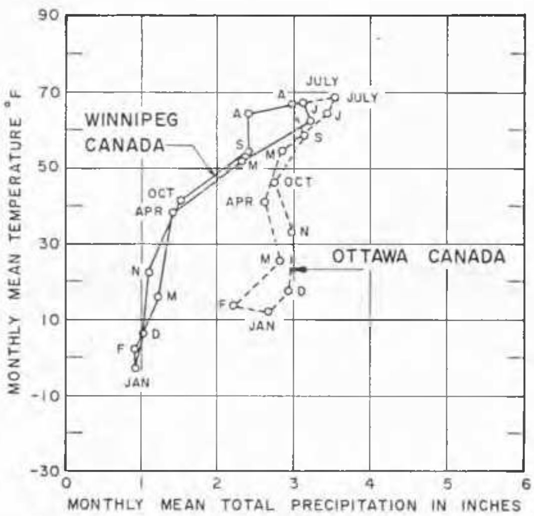

Fig. 2 Hythergraphs for Winnipeg and Ottawa
Hythercourbes pour Winnipeg et Ottawa

The soils of the two regions have reached equilibrium conditions under their respective climatic environments. In the Ottawa region the soil is almost always saturated during the spring and autumn seasons and usually is severely desiccated during the summer. On the prairies, long-term climatic effects appear to exert more influence on soil moisture conditions. Laboratory studies on the two clay types have shown the Ottawa marine clay to be particularly susceptible to shrinkage with only partial volume regain possible and the prairie clay to be capable of complete volume reversibility on drying and wetting (WARKENTIN and BOZOZUK 1960).

Field studies have revealed surface settlements greater than one foot in the marine clay (BOZOZUK 1959) with a possible recovery of about 50 per cent due to wetting (LEGGET 1954). On the prairies seasonally reversible ground movements have been reported (BARACOS et al 1955).

4. Observations of Slab Movements at Ottawa

Movements of the Ottawa slabs were measured on a grid of points, spaced approximately 4 ft. apart, inside the huts. The readings were taken with a precise optical level and referenced to a deep benchmark installed nearby. The movements were observed initially at approximately monthly intervals and later at greater intervals. Maximum and minimum movements recorded in Fig. 3 were taken at the

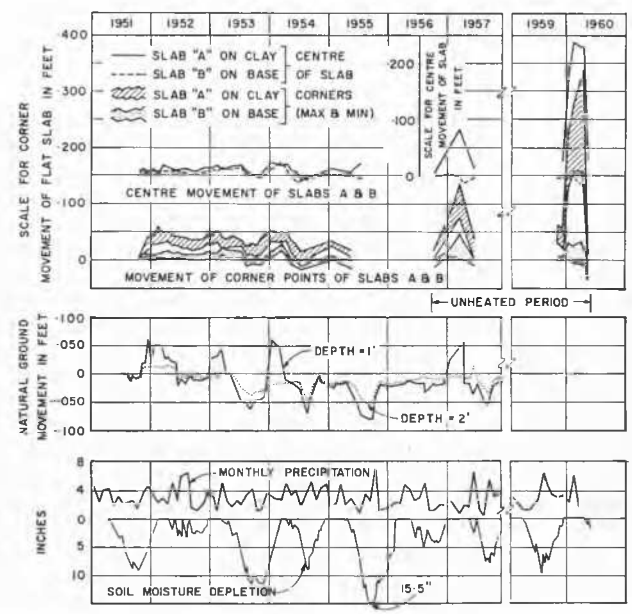

Fig. 3 Movements of Ottawa slabs and climate data
Mouvements des dalles et données climatiques d'Ottawa

slab centre and corners. The vertical ground movements at the 1 ft. depth were measured just beyond the influence of the slab. Monthly precipitation and soil moisture depletion for the corresponding periods are shown for comparison. " Soil moisture depletion" is the amount of water drawn from the soil to make up the difference between water used in evapo-transpiration and that available from precipitation during a dry season. It is based on the method of THORNTHWAITE (1948); its use has been described by BOZOZUK and BURN (1960).

Shortly after the slabs were constructed, the precipitation at Ottawa increased resulting in an upward movement of the corners which reached a maximum in one corner of Slab A of approximately 0·06 ft. (3/4 in.). A significant difference in the movements of Slabs A and B soon became apparent; this trend continued throughout the observations. Ground movement gauges located at depths of 2 and 5 ft.

beneath the slabs showed vertical movements less than half that observed at the slab surface.

Measured movements in undisturbed ground near the slabs were significantly greater than under the slab; even at the 1 ft. depth (Fig. 3) seasonal vertical movements amounted to nearly 0·15 ft. Part of this total movement may be due to winter frost heaving. At the 2 ft. depth, where frost heaving is not a factor, seasonal movements are about equal to slab movements. The slabs can therefore be seen to have a moderating influence on ground movements.

The most significant result of these studies is that the seasonal movement of the slabs has been relatively so small (except for the frost heaving described later). Vertical movements of shallow footings in this soil greater than 1 ft., reported by Bozozuk (1925), introduce an apparent anomaly. Two independent reasons may explain this. Firstly, large movements reported by Bozozuk can be attributed to local soil desiccation due to vegetation, especially trees. There were no trees adjacent to the site of the slab foundation. Secondly, at the site of the slabs the natural water content is relatively low, on the average not much above the shrinkage limit. The soil has obviously reached fairly stable equilibrium with its environment at a water content that will allow only small volume changes. In the locations studied by Bozozuk, on the other hand, it has been observed that invariably the clay on which the footings rest is covered by several feet of sand which seems to preserve the clay in a moist condition. It is therefore liable to greater volume change than the soil at the test site.

Of particular interest is the heaving observed during the two winters 1956-57 and 1959-60 when the huts were not heated. The maximum corner heaves in Slab A were approximately $1\frac{1}{2}$ in. and 4 in. respectively with the heave at the centre, 1 in. and 3 in. respectively, equalling approximately the average of the four corner heaves. The heave of Slab B was very much less and only reached values of the order of 1/2 in. at one corner, with no heave in the centre.

The corner with the greatest heave in both slabs was that to the northeast. This corner was most exposed to the cold because of reduced solar radiation and also because the snow was frequently swept clear at this point. A greater amount of frost heave was observed in the winter of 1959-60, in spite of the fact that this winter was milder than 1956-57. This may be attributed to the precipitation during the autumn of 1959 being greater than the normal. Perspective views of the extreme conditions of the two slabs (maximum frost heave April 1960, maximum shrinkage July 1954, and maximum swelling February 1952) give a vivid impression of the relative magnitude of the movements observed (Fig. 4).

Relatively little cracking has been observed in the Ottawa slab, partly because, as also for the Winnipeg slab, the concave shape of the deformed slab tended to keep the cracks closed on the slab surface. Owing to a very high groundwater level in the spring of 1960, cracks in Slab A showed moisture from capillary action. The cracks seem to have had no adverse structural effect on the slab. No cracks could be found in Slab B.

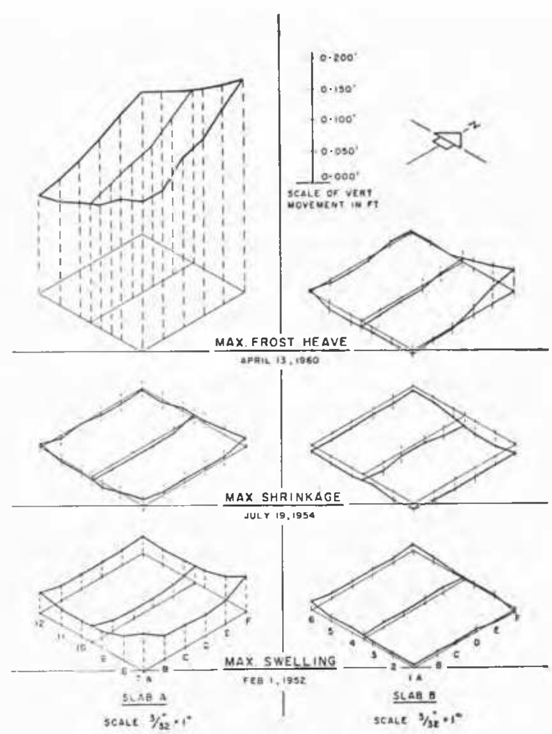

Fig. 4 Movements of Ottawa slabs
Mouvements des dalles d'Ottawa

5. Observations of Slab Movements at Winnipeg

The method used for level measurements on the Winnipeg slab was similar to that used in Ottawa. The slabs were observed continuously for approximately three years (October 1952 — June 1955) from the time of construction under fairly dry soil conditions (Baracos and Bozozuk 1957). No winter of unheated operation was possible and at no time was there frost penetration under the slab.

Considerable heave due to swelling of the clay was recorded. In contrast to the Ottawa slabs, the greatest heaves occurred in the summer, during the rainy season. The maximum heave was observed in September 1954, when the corners heaved by almost 1 in., the centre slightly less. During winter months the heated slab showed a net settlement below the original zero elevation in the central portion (approximately 1/4 in.) whereas the corners generally remained slightly higher than their original zero elevations. This condition led to the maximum differential movement observed of approximately 1/2 in.

Two hairline cracks were observed in the Winnipeg slab but the concave deformation tended to keep the cracks closed in the top surface of the slab. One of these cracks was perpendicular to the north wall at approximately the slab centreline, where the slab is weakened by thermocouple sticks.

6. Summary and Conclusions

(a) The Ottawa and Winnipeg slabs were subjected to a range of soil movements due to swelling and shrinkage of the underlying clay soils, and also due to frost heave in the case of the Ottawa slabs.

(b) The maximum changes in slab levels due to soil swelling were significant : in Ottawa Slab A, placed directly on clay, 3/4 in.; in Ottawa Slab B, placed on a crushed stone base 18 in. thick, 3/8 in. ; and in the Winnipeg slab, 1 in. The maximum movements due to frost heave were 4 in. in Slab A and 1/2 in. in Slab B when they were unheated during the winter. The maximum "dishing" or warping measured along a diagonal due to swelling and shrinking amounted to 3/8 in. in Ottawa Slab A, slightly less than 1/8 in. in Ottawa Slab B, and 3/8 in. in the Winnipeg slab. The maximum "dishing" due to frost heaving in the Ottawa slabs was relatively small (less than 3/8 in.) in spite of the large absolute movements.

(c) The crushed rock "cushion" under Ottawa Slab B was effective in substantially reducing the changes in slab levels.

(d) The slabs in Ottawa appeared to have a moderating influence on natural ground movements; the smallness of the measured movements of the slabs could be attributed to absence of vegetation and the nature of environmental influences.

(e) Some cracking occurred in Ottawa Slab A and the Winnipeg slab, but none in Ottawa Slab B. The cracks were very small on the slab surface due to concave deformation and had little effect on the usefulness of the slabs as foundations. Differential movements of similar slabs can be reduced by introducing a crushed stone bed of a thickness appropriate for the particular swelling and shrinkage characteristics of the underlying clay.

(f) The greatest swelling observed in Ottawa occurred in the winter whereas in Winnipeg it occurred in the summer. This variation can be attributed to differences in climate and soil.

(g) In low-lying, flat areas in clay soils where the ground water table may be expected to be near the surface during some periods of the year, a crushed stone base under the slab has the added advantage of improving the general drainage conditions around the house by raising the slab over the general ground elevation.

(h) The Ottawa and Winnipeg slabs were constructed to what were considered minimum or subminimum design standards, since they were only 6 in. thick and not reinforced. Although they underwent appreciable movement (even if frost heave is disregarded) they did not suffer structural damage of any consequence.

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