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Long-Term Performance of Slab-on-Grade House Foundations in Regina, Saskatchewan

INTRODUCTION

In 2003, CMHC's External Research Program funded a re-examination of a sampling of house foundations in Regina, Saskatchewan, to document their long-term performance. The houses were originally monitored and documented in the 1960s and 1970s by the Prairie Regional Station of the National Research Council of Canada (Division of Building Research) because swelling and shrinking of the deep clay undersoil was affecting foundations of all types, causing visible settling of some floors and other structural effects.

The house building industry in Regina historically has sought economical options for low-cost residential construction, in particular, for construction of economical foundations. Full and partial depth basements have been the predominant choice for single family dwellings in Regina for the past fifty years. Slab-on-grade and crawl-space foundations offer economies of initial construction and ongoing operating costs where basements are not essential. In the mid-1950s, slab-on-grade foundations, combined with other innovations, allowed the construction of 90 m^2 (969^2 ft) houses on 15 m by 37 m (50 ft by 100 ft) lots which sold for under $10,000.

Objective

Although the focus of the 2003 research was principally on slab-on-grade foundations, the ultimate objective was to identify design details that could reasonably and economically be incorporated to improve performance in future construction of low cost foundations in Regina and in other settings where there are deep clay deposits.

Methodology

The research included face-to-face and/or telephone interviews of homeowners and/or occupants (76 participants); detailed measurements of foundation performance (38); and soil moisture investigations on 5 sites.

Typical 1955-1960 Slab-on-Grade Construction in Regina, Saskatchewan

Topsoil was stripped and the lot rough-graded. The base was prepared at 150 mm (6 inches) below finished grade. Base for the interior area of the floor slab was mounded approximately 300 mm (12 inches) with compacted native soil and capped with 100 to 200 mm (4 to 8 inches) of sandy pit run gravel to bring to a base of 89 mm (3.5 inch) thick floor slab. No interior stiffening beams of concrete were placed across central areas of the slab. Polyethylene vapour barrier was placed over the shaped base. Perimeter forms and heating ducts, interior feeder ducts were placed. Perimeter and interior reinforcing steel was installed and tied at the design elevations. Floor slab and perimeter beam concrete were cast monolithically and finished at design grade within +/- 6 mm (0.25 inches). After the perimeter forms were stripped, 50 mm (2 inches) thick insulation board was attached to the perimeter of the concrete slab. 13 mm (0.5 inches) thick cement parging was applied to the outside of the insulation. No perimeter drain tile or coarse gravel fill were placed around the slab. Backfilling to final grade was completed with native clay and topsoil.

Survey of Long Term Occupants

All of more than 100 houses identified in 1960 are still in service. Occupants of the houses were generally tolerant of conditions that might not be accepted elsewhere in Canada where swelling and shrinking subsoil are unknown. Occupants generally expressed reasonable levels of satisfaction for these low initial cost homes even when taking into account relatively high repair and maintenance costs. Accessibility and affordability were the main positive factors cited by occupants. The sloping floor surfaces are tolerated by occupants of varying ages, including several confined to wheelchairs. The remaining original owner/occupants are quite elderly and find easy interior and exterior access without stairs a main reason for remaining in these homes. Newer occupants, both owners and tenants, appreciated the affordability of the houses.

Floor/Foundation Performance

All of the foundations examined in this study, including the slabs-on-grade, have suffered excessive differential movements by all code or engineering standards. Thirty eight floor surveys were conducted in 2003. Of the 35 slabs-on-grade surveyed, all had experienced more than 43 mm (1.7 inches) of differential movement. For purposes of comparison with slab-on-grade, three other types of floors were surveyed. A wood floor over a crawl space experienced less than 20 mm (0.8 inches) of differential over 43 years. A wood floor over a conventional full basement showed 54 mm (2.1 inches) of differential movement over the same time period; while a concrete basement floor slab showed 108 mm (4.2 inches) of differential heaving and 243 mm (9.1 inches) maximum movement over 42 years.

The slab-on-grade floor surveys found differential movements ranging from 40 mm (1.6 inches) to more than 200 mm (8 inches) with a median of approximately 100 mm (4 inches). Attempts by specialist contractors to re-level some of these houses by “mud-jacking” (selectively injecting cement grout into subsoil to raise and re-level above lying slabs) have met with varied success. Several of these homes have been treated more than once since the late 1950s. Owners reported improvements in floor levels for several years followed by return of movements after 7 to 10 years.

Subsoil Moisture and Precipitation

Regina’s climate is semi-arid, with hot summers. Annual precipitation varies considerably and averages 380.55 mm (15 inches) over 113 years of records. Figure 1 shows annual total precipitation above or below the average precipitation for the period 1951 to 2003. The range in annual precipitation for this period was 394.4 mm (15.5 inches) with a high of 602.7 mm (23.75 inches) in 1954 and a low of 208.3 mm (8.20 inches) in 1961. Total annual precipitation 1951-2003 averages 377.6 mm (14.8 inches), which is less than one third of the soil moisture needed to sustain a mix of grass and trees.

Many of Regina’s slab-on-grade houses were built in the period 1955-1960. Prior to construction in the summer of 1955, from 1950 to 1955 the total precipitation received exceeded the normal by an average of 137 mm/yr (5.4 inches/yr) and a total of 689 mm (27.11 inches).

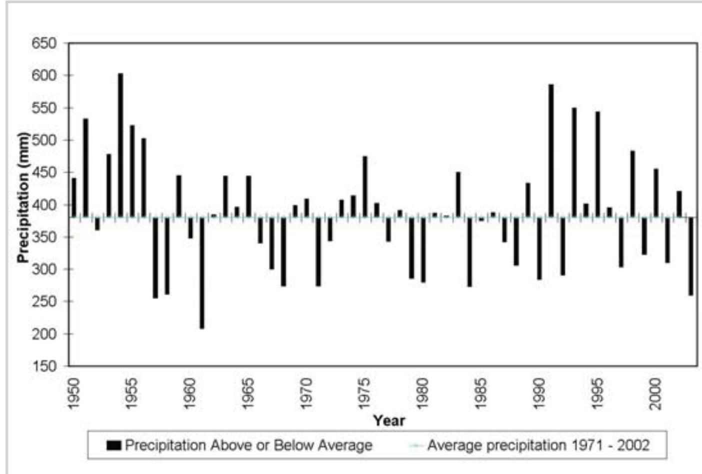

Figure 1 Annual Precipitation for 1951 through 2003
Regina A Station Records, Environment Canada

Data from the studies conducted by the NRC in the 1960s indicate that by the third or fourth winter, slabs-on-grade that had been placed on soil profiles that were wetter than normal (due to several summers of above normal rainfall) had experienced sagging that ranged from 30 to 80 mm (1.2 to 3.1 inches) below the perimeter of the floor slabs.

For slabs-on-grade constructed too low, or on a lot with surface drainage towards rather than away from the house, occasional flooding and/or subsoil seepage impinging under one or more sides has caused differential heaving and sloping from one side to the opposite side or more complex compound slopes.

The 2003 soil moisture surveys found that for several of these houses, the soil moisture conditions around the perimeter of the slabs was much drier than measured in the 1960s and 1970s. The deepest and most severe drying was found within the zone of influence of tree roots. In general, the region experienced several years of below normal precipitation since 2000.

Impacts of Construction and Landscaping

Water infiltration is affected by water ponding, melting of drifted or piled snow, and high variability of precipitation received at the ground surface. Manmade constructions and practices such as pavements, roofs and shaping of the land surface further distort these patterns, as they tend to increase run-off and reduce and reshape the natural infiltration of moisture from the relatively uniform conditions of a flat prairie agrarian landscape. Plantings of deep-rooted perennial vegetation and landscape irrigation add further to the complexity of the infiltration/evapo-transpiration budget of deep soil profiles. Leaks from plumbing and municipal services, and heat loss from structures, are other causes of variability of subsoil moisture.

During extended drought periods and under sealed surfaces such as pavements and slabs, tree and shrub roots extend in search of moisture and cause deep-seated shrinkage.

Foundations placed in 1955 and 1956 experienced some central area settlements with perimeter area heaving resulting in maximum dishing in central areas in the first four or five years. Exterior area settlements and/or heaving became more pronounced through the 1970s. The effects of orientation to drying sun and prevailing wind-driven precipitation, irrigation and drainage patterns, and the proximity of large trees and shrubs were increasingly significant. From 1979 through 1990 a general climactic drying trend accentuated the settlements experienced in the 1970s, with exceptions where local flooding or heavy irrigation caused heaving. 1989, 1991, 1993, 1995, 1998 and 2000 all had above average precipitation, which could have reduced or reversed the settlement trends with the exception of deep seated settlements due to trees and shrubs. 2001 and 2003 were drier than average.

The largest distortions observed in the 2003 research were attributable to the combined influences of drying by deep roots and wetting, usually from external sources around slabs.

Conclusions

Slabs built from 1955 through 1960 experienced initial differential movements of settlement in central areas and heaving at perimeters caused by subsoil moisture redistribution imposed by heat flow.

This was followed by continuing perimeter heaving as landscaping and gardening irrigation augmented precipitation and reduced moisture deficits. Deep and wide spreading roots from trees and large shrubs gradually reduced subgrade moisture, causing clay shrinkage and settlement of the overlying ground surface and shallow foundations.

It must be noted that excessive movements were noted for all foundation types built on Regina's deep clay soil during this period. Short term wetter than average conditions could have serious impact where surface drainage away from foundations is inadequate or reversed because of ground heaving or settlement. Long term drier than average periods coinciding with deep rooted tree growth present worst case conditions for shallow foundations.

Occupants of the houses examined in the 2003 study expressed generally high levels of satisfaction with the homes, despite the maintenance and repair costs over the years associated with foundation movement. The main factors for their satisfaction were accessibility and affordability.

Information gathered in this study will be useful to designers and contractors contemplating the use of slab-on-grade construction for houses or other light structures in areas of deep clay soil and climactic conditions similar to those of Regina.

Recommendations

Geotechnical and foundation engineering capabilities have advanced greatly during the past five decades. Experienced specialists should be retained to advance the state of construction technology. To improve shallow foundation performance, the 2003 study recommends that climate information, in particular Cumulative Departure (CD) from long term average precipitation, be verified to provide an index point with which past and future moisture profiles could be compared as part of the construction planning process.

Soil moisture content and volume changes should be minimized by maintaining initial moisture content conditions over the area and depth of influence of new structures. Water flow towards foundations should be regulated or eliminated by techniques such as root barriers, perimeter drainage systems and adequate surface grading. Plumbing leaks and heat loss, and lateral heat flow under and beyond slabs, should be minimized.

If clay expansion and/or shrinkage are inevitable, construction should take this into account. Heaving against foundation slabs could be minimized by using long term shrinkage and vegetation. Engineered fill could be used to elevate slabs 0.5 m. (1.65 ft) or more to increase subgrade loading. Void forming techniques could eliminate heaving pressures against thin slab areas and increase bearing pressures under perimeter and rib stiffening beams.

Chemical slurries could be pressure injected into dry and fissured subsoils to reduce swelling potential and to seal against moisture.

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