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The movement of soil moisture under a government subsidy house

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ABSTRACT: The South African government's attempts to provide affordable, subsidised housing for the very poor has suffered from a large number of structural failures, many due to heaving foundations. These houses are particularly susceptible to damage by heaving clay because they are exceptionally light and clay can lift them very easily. Rational design requires knowledge of the pattern of heave which will occur under the foundation. The pattern of heave depends on the pattern of moisture movement. Currently available methods of rational design rely on assumptions about the shape of the mound which will develop due to moisture movement under the foundation. The shape assumed is largely guided by measurements made on test foundations. Instrumentation has been installed under a Government Subsidy house in the Free State and moisture movement is being monitored. The actual pattern of moisture movement observed is substantially different to what is normally assumed and could point to more reliable estimates of the heave which needs to be designed for.

1 INTRODUCTION

Since 1994 the South African government has built more than 2.68 million subsidised houses throughout the country (Government Communication and Information System 2015).

The construction of raft foundations for Government Subsidy housing has become common in areas affected by expansive soils as is the case in much of the Free State and Northern Cape. The intention of raft foundations on active soils is to limit the differential movements of the underlying soils to a level which can be tolerated by the superstructure (Day 1991). The large number of failures suggests that the problem of providing sufficient stiffness to the foundation has not yet been solved. This impression is reinforced by the observation that many houses are being built on "stock design" rafts which bear only general correspondence with the likely heave potential of the soils involved. There is the impression that there may be inadequate understanding of the actions which need to be designed for. In many cases, when structures have become structurally unsound due to heaving foundations, it is more economical to demolish than to attempt repair. The seriousness of this problem therefore merits a search for a solution.

Current raft design relies on assumptions about the shape of the mound or dome which will develop due to moisture movement underneath the foundation. The shape which is assumed is often based on heave measurements on simulated foundations (Pidgeon 1987), (Pidgeon and Pellisier 1987) or foundations simulated by sheet covers (Fityus et al. 2004), (Miller et al. 1995), (de Bruijn 1973). Such test foundations do not take account of two important factors concerning the influence of a building constructed on the foundation—the influence of the building on the temperature regime under the slab and the influence of the building on solar radiation reaching the soil surrounding the raft. Both of these factors can have a profound effect on moisture movement under the foundation. (Fityus et al. 2004) found that over a period of measurement lasting seven years, temperature appeared to have a greater effect than rainfall on moisture movement and consequent heave of clayey soils at their test site.

2 SITE DESCRIPTION AND INSTRUMENTATION

The location of the study area is in Botshabelo section K, which forms part of the Mangaung Metropolitan area and is situated 45 km east of Bloemfontein. Each year many government subsidy houses are built throughout Botshabelo. A significant number of them experience structural distress well short of their design lifetime.

Botshabelo is underlain by mudstones, shales and sandstones of the Beaufort Group, with frequent intrusions of dolerite. All of these rocks frequently produce expansive clays when weathered in the semi-arid conditions of the central Free State. The area is therefore likely to be very suitable for the study being undertaken. A Government

Subsidy House (GSH) was selected based on the soil conditions and the fact that it has a raft foundation of a very common "stock" design. Continuous Logging Soil Moisture (CLSM) probes were installed to measure water content at various depths under the house. Measurements are being taken automatically at hourly intervals. The installation layout is from east to west and north to south in direct alignment with the house.

The CLSM probes allow measurement of temperature and water content at depths of 150 mm, 300 mm, 450 mm, 600 mm, 800 mm and 1000 mm. The soil profile underneath the house has a thin layer of dark brown clayey sand with a thickness of 150 mm. This is underlain by a layer of black transported clay and a layer of olive residual clay. Both clays were assessed by Van der Merwe's method (Van der Merwe 1964) as having medium expansiveness. Rock is found at a depth of approximately 1.1 meter. The first clay layer is from 150–900 mm, the second clay layer is from 900–1100 mm. Figures 2 and 3 illustrate the layout of the CLSM probes inside and below the house.

3 RESULTS AND DISCUSSION

3.1 *Moisture content seasonal change models*

Results of hourly measurement of water content taken over a period of two years were analysed. The following figures illustrate moisture content values measured in summer and winter at each depth recorded by the probes. These graphical representations of the data were produced using the programme "3D field". The scale was selected as a best fit for each specific model. Areas of dark gray/black have higher moisture content. A grey scale is shown next to each figure.

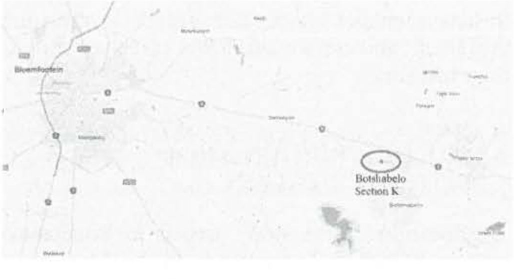

Figure 1. Botshabelo section K.

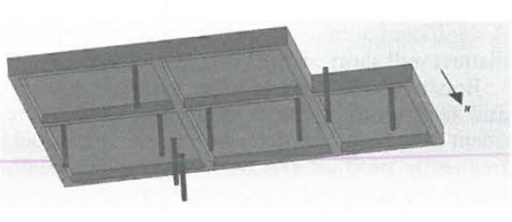

Figure 2. 3D layout of CLSM probes.

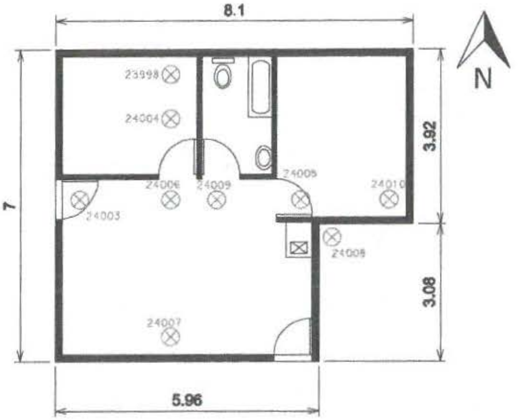

Figure 3. CLSM probe layout in raft foundation: dimensions m.

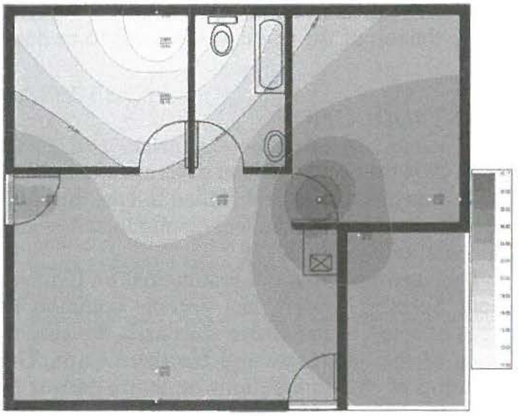

Figure 4. Summer: 150 mm w = 10%–32%.

From the figures it can be observed that the north side consistently shows the lowest moisture content compared to the rest of the house. This is almost certainly due to the fact that solar energy reaching the ground on the northern side is more intense than that reaching the other sides of the building. When rainfall occurs the north side is prone to rapid moisture change. This is probably due to the fact that the dry, cracked soil allows immediate access to rainwater. At the north side water contents range from less than 5% to 25%. In contrast, water content near the south east re-entrant corner remains within the range 31%

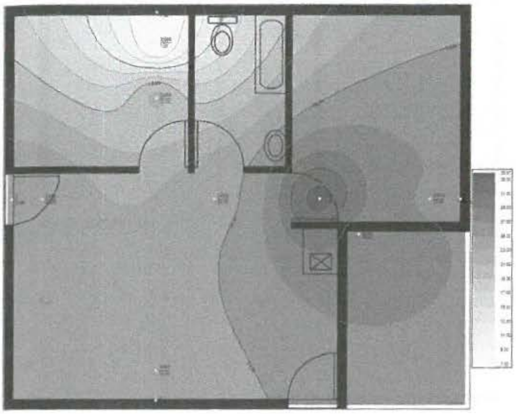

Figure 5. Summer: 300 mm w = 7%–33%.

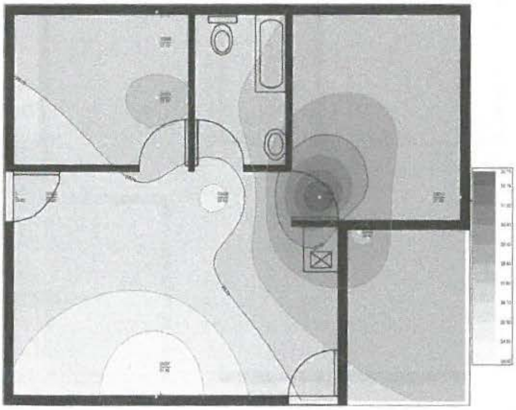

Figure 6. Summer: 450 mm w = 24%–33%.

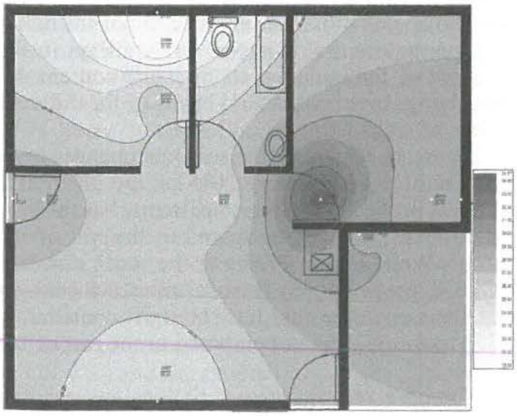

Figure 7. Summer: 600 mm w = 20%–35%.

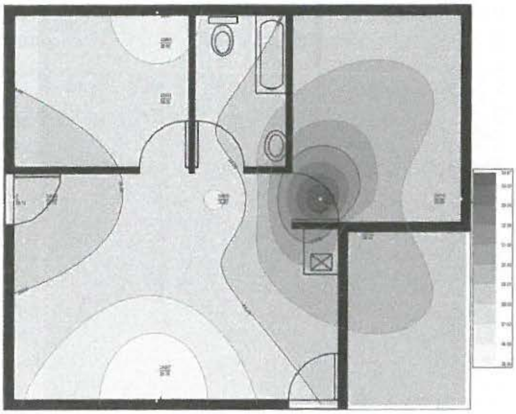

Figure 8. Summer: 800 mm w = 25%–35%.

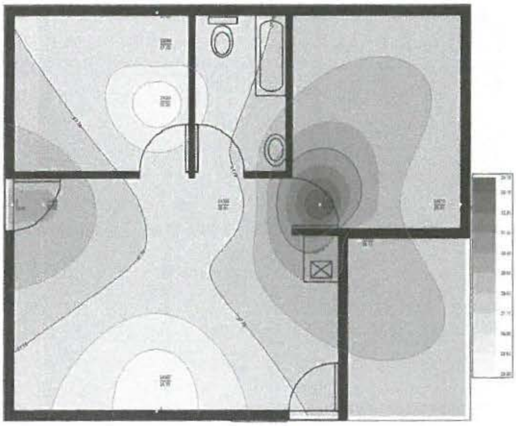

Figure 9. Summer 1000 mm w = 25%–34%.

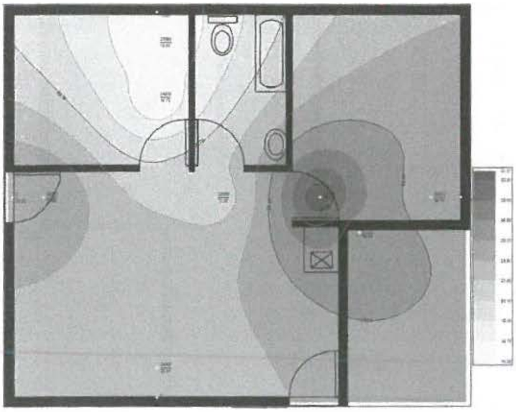

Figure 10. Winter: 150 mm w = 15%–31%.

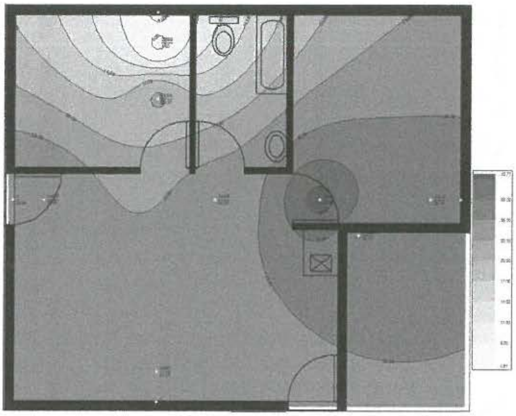

Figure 11. Winter: 300 mm w = 5%–33%.

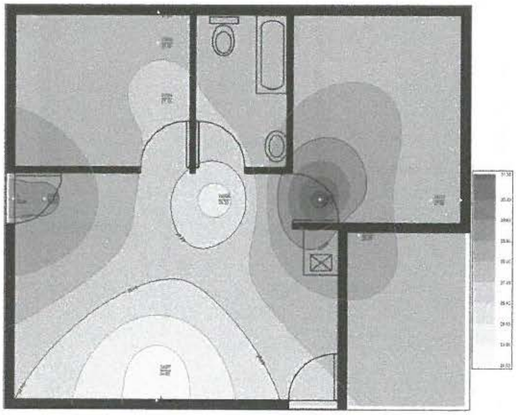

Figure 12. Winter: 450 mm w = 24%–31%.

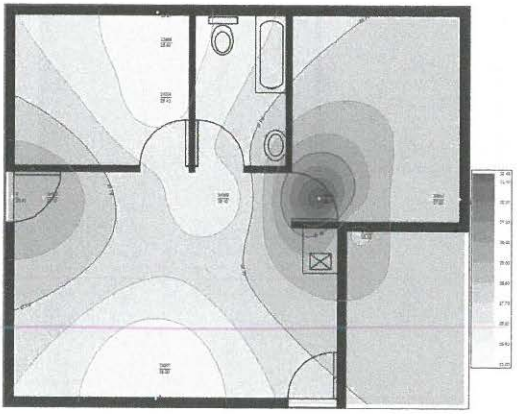

Figure 13. Winter: 600 mm 25%–33%.

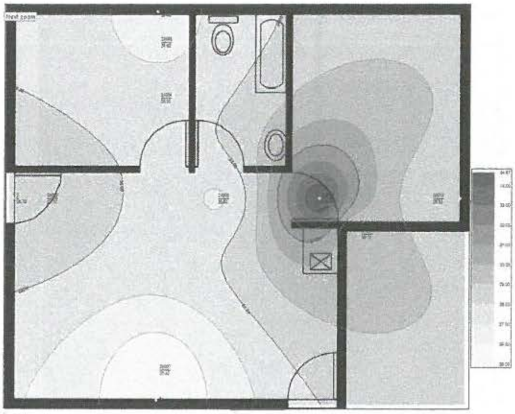

Figure 14. Winter: 800 mm w = 25%–35%.

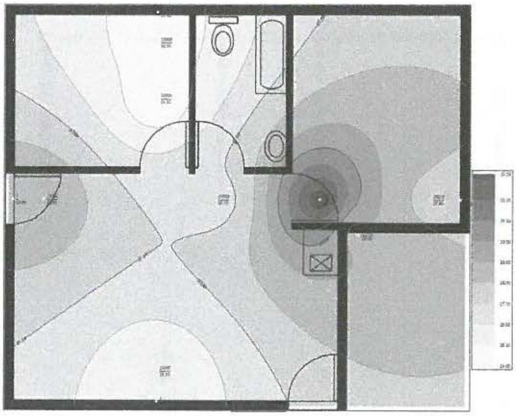

Figure 15. Winter: 1000 mm w = 24%–33%.

to 34% at all depths in both summer and winter. This re-entrant corner never receives any significant solar radiation. The architecture of the building guarantees that it is practically always in the shadow of the building. Its moisture content did not change by more than 3% in any of the different layers of soil.

Figure 16 illustrates the seasonal changes from March 2014 to February 2015 of the north side (CLSM probe 23998) that consistently has the lowest moisture content compared to the rest of the house. While Figure 17 shows the south east side (CLSM probe 24005) seasonal moisture changes for the same time that has the most consistently high moisture content compared to the rest of the house.

The observed moisture variations suggest that an approximately symmetrical dome-shaped heave pattern, centred roughly on the centre of the

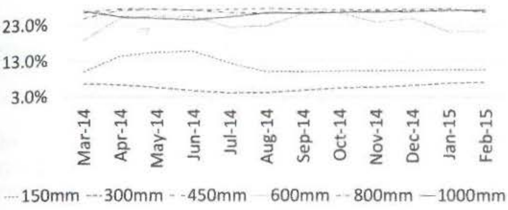

Figure 16. Probe 23998 moisture content 5% to 25%.

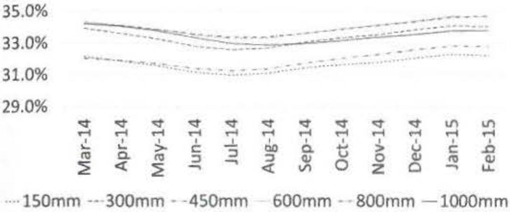

Figure 17. Probe 24005 moisture content 31% to 34%.

foundation, as found by Pidgeon (1987), Pidgeon and Pellissier (1987), Fityus et al. (2004) etc. in simulated foundation tests is not likely to develop. Simulated foundation tests take no account of the influence of shadows cast by the building. It appears that the south east re-entrant corner will remain in a high water-content, highly expanded state (varying by only about 3%) whereas the northern wall will assume a lower water-content, less expanded state with far more variability. This tends to confirm the findings of Fityus et al. (2004) that temperature can have a more pronounced effect than rainfall on swelling patterns in active soils.

3.2 *Further considerations*

It has been noted (Fityus et al. 2004) that heave predictions commonly ignore the effect of the loads applied by the building, though this may not be true in all cases. The load applied to the soil directly under a raft foundation by a completed GSH house is approximately 10 kPa. The three layers of material under the instrumented foundation were tested to assess their ability to heave against constraining pressures. The clayey sand of the thin upper layer was found to be able to expand against a pressure of 11 kPa up to a water content of slightly above 28%. The transported clay, of the second layer, was found to be able to expand against a pressure of 14 kPa up to a water content of 35% and the residual clay of the third layer could expand against a pressure of 14 kPa up to a water content exceeding 45%. These pressures were measured by apparatus under development by the CUT Soil Mechanics Research Group. At lower water content far higher pressures can develop. Assuming a unit weight of 2 000 kg/m^3 for all layers, the maximum pressure exerted at the base of the lowest layer would be approximately 21 kPa. It would therefore appear that the loads applied by overburden and structure might cause a restriction to heave in the thin upper layer in the wettest area only (around the south-east re-entrant corner). The lowest layer of clay would probably experience no restriction to heave, and the lower part of the middle layer would probably be restrained in the area of maximum water content.

4 CONCLUSIONS

The measurements of moisture content under a very common type of Government subsidy house built on clayey soil suggest that currently accepted patterns of heave are unlikely to provide good guidance for foundation design. The instrumentation used in this investigation has proved itself convenient and reliable. It is hoped that it will be possible to instrument several other light structures in order to work towards a general modeling procedure. This should enable reliable predictions of the moisture conditions which need to be designed for in the general case. This in turn should allow reliable and economic design of a wide range of raft foundations with the prospect of fewer failures. In the meanwhile, by applying the findings of this investigation it should be possible to at least obtain better estimates of moisture pattern development and to estimate more realistic heave patterns than are currently being employed.

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REFERENCES

Day, P.W. 1991. Design of Raft foundations for houses on expansive clay using Lytton's method. *Course on design of foundation to suit various soil conditions. SAICE Structural Division 1991*.

De Bruijn, C.M.A. 1974. Moisture redistribution in Southern African soils. *Proceedings of the 8th International Conference on Soil Mechanics and Foundation Engineering. Moscow. Vol2.2.1973, pp. 37–44. (NBRI Reprint No R/Bou 442,1974)*.

Fityus, S.G., Smith, D.W. & Allman, M.A. 2004. Expansive soil test site near Newcastle. *Journal of Geotechnical and Geoenvironmental Engineering. ASCE. July 2004 pp. 686–695.*

Government Communication and Information System. 2015. *Housing delivery in South Africa—How have we fared?* Government Communication and Information System (http://www.sanews.gov.za/south-africa/housing-delivery-sa-how-have-we-fared).

Miller, D.J., Durkee, D.B., Chao, K.C. & Nelson, J.D. 1995. Simplified heave prediction for expansive soils. *Unsaturated soils/sols Non Satures, Alonso & Delage (eds).* Roterdam: Balkema.

Pidgeon, J.T. 1987. The results of a large scale field experiment aimed at studying the interaction of raft foundations and expansive soils. *International Conference on soil structure Interactions. Paris. May 1987.* Paris: ENPC Press.

Pidgeon, J.T. & Pellissier, J.P. 1987. The behaviour of an L-shaped raft subjected to non-uniform support conditions. *International Conference on Soil Structure Interactions. Paris. May 1987.* Paris: ENPC Press.

Van der Merwe, D.H. 1964. The prediction of heave from the Plasticity Index and the percentage clay fraction. *The Civil Engineer in South Africa Vol.6.No.6 June 1964.*