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Performance of Darke Hall, Regina, Canada, Constructed on a Highly Swelling Clay

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SUMMARY A case history describing the performance of a lightly loaded structure supported by a shallow foundation in an unsaturated expansive soil is presented.

1.0 INTRODUCTION

Darke Hall was constructed in 1928 and provided a centre for the performing arts in Regina (Figure 1). It has been used until recent years by students and the community as a forum for theatre and music. Over the life of the building, considerable deformation of the basement floor and the structural frame has occurred, necessitating frequent adjustment of doors and patching of cracks in walls and ceilings. In 1981, the University of Regina as owners of Darke Hall and other buildings located at the College Avenue Campus undertook the task of determining the condition of the buildings, some dating to 1911, in order to obtain recommendations for the repair and restoration of these architecturally and historically significant structures, with a view of obtaining an additional 100 years of service from them.

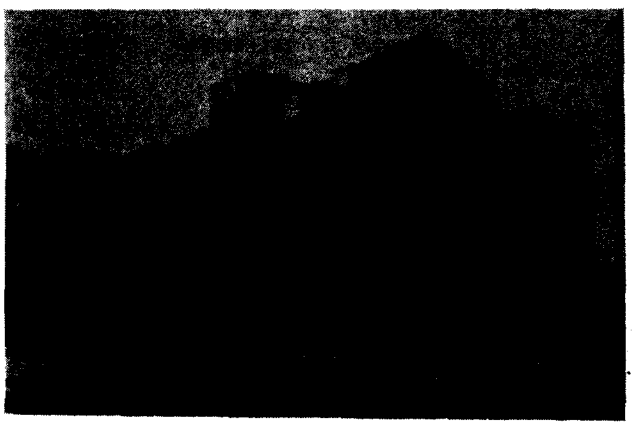

Figure 1 Darke Hall

The case history presented here documents the performance of a lightly loaded structure constructed on shallow strip footings in an expansive clay deposit. Remedial measures proposed for restoration were based on a geotechnical assessment of past and future building performance.

2.0 RECORD OF PERFORMANCE

Darke Hall is a masonry structure with an auditorium on the main floor and practise rooms located on the basement level. The structure is 16.8 m wide by 38.0 m long. An addition built in 1962 increased the length of the structure by 14.6 m. In the original building, exterior bearing wall loads are supported by a reinforced concrete wall placed on a continuous strip footing approximately 1.8 m below grade. Interior loads are supported by bearing walls and strip footings or by columns and square footings (Figure 2). In the 1962 addition, all structural loads are supported on augered shaft, cast in place reinforced concrete piles.

Footing pressures under the original building have been calculated to be approximately 130 to 150 kPa. The reinforced concrete auditorium floor is supported by reinforced concrete beams which span the width of the building. Roof loads are carried by timber framing to steel trusses spanning the exterior walls. The basement floor was originally grade supported concrete on grade.

A network of brass plugs to monitor column movements was installed in 1951 and monitored in 1961, 1962, 1963, 1964 and 1965. Some cracking occurred during all phases of the building's life, but this was generally repaired by normal maintenance. However, increased cracking in the room partition walls in the basement was observed in the early 1960's. The results of a survey and recommendations made at that time suggested that the interior columns were moving downward with respect to the exterior footings. This may represent settlement of the interior columns, heave of the exterior footings or a combination thereof. Since the benchmark was located within the basement, it too was susceptible to movement and thus the magnitude and direction of the movements could never be positively determined. The location of the brass monuments are shown on Figure 2.

Renovations of the basement level in the early 1970's consisted of replacing partition walls, replacing the wood floors in the rooms along the exterior walls with structural concrete floors, and installing weeping tile drains under the rooms. During renovations, a large crack in the soil was observed approximately halfway between the corridor wall and the exterior wall. The soil between the crack and the exterior wall was very moist as compared with the dry soil between the crack and the corridor wall. This observation suggests that heave may have been occurring underneath the exterior footings, and artificial desiccation and possible shrinkage was occurring beneath the interior columns and slab.

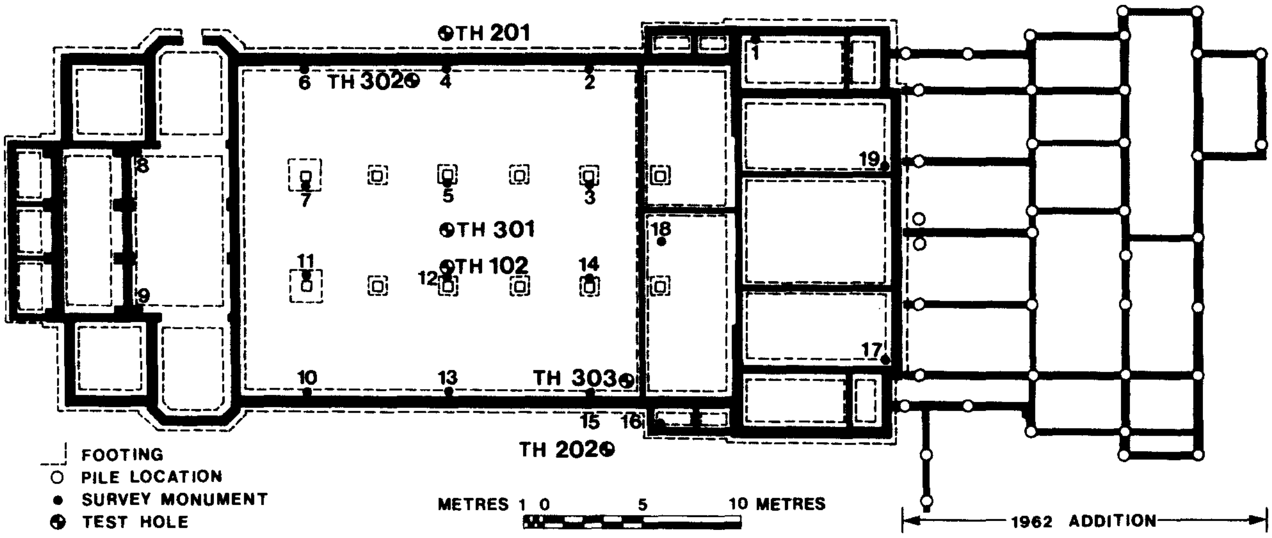

Figure 2 Foundation Plan Showing Locations of Test Holes and Survey Monuments

A level survey was conducted on the few remaining brass monuments in March, 1982. The results indicated that the interior columns have moved upward between 20 mm and 120 mm relative to the exterior walls since 1965. Differential movement of the exterior walls of up to 36 mm was also apparent. The survey results are shown in Table 1. Monument no. 1 was used as a reference point.

Additional surveys including levelling of the basement floor and the underside of the main floor beams, and plumbing of the interior columns were carried out in March and April, 1982. The results are shown in Figures 4 and 5.

The floor survey shows that the corridor floor has heaved as much as 120 mm. The survey of the underside of main floor beams indicated that the interior columns have moved upward between 60 mm and 90 mm with respect to the exterior wall. This could only have occurred as a result of heaving of the interior spread footings. The columns at the southwest end of the corridor were as much as 20 mm out of plumb, with a relative outward displacement at the base of the columns.

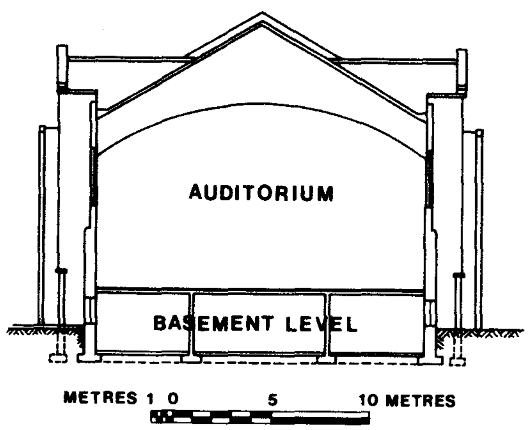

Figure 3 Section Through Darke Hall

Structural distress and cracking at the interior beam to column connections verifies the observation that the interior columns have moved upward relative to the exterior wall. Concern regarding the structural integrity of these members led to the closing of the main floor auditorium in 1983.

TABLE I

MOVEMENT (mm) OF SURVEY MONUMENTS
WITH RESPECT TO MONUMENT NO. 1
FROM 1951 - 1982

MONUMENT NO.	MOVEMENT FROM 1951-1961	MOVEMENT FROM 1961-1965	MOVEMENT FROM 1965-1982
1	-	-	-
3	-5	-8	+73
7	+30	-6	+39
8	-	-6	+3
9	-	-5	+14
11	-6	-9	+74
12	-10	-16	+136
16	+12	+6	+36

3.0 SITE CONDITIONS

Subsurface soil conditions were examined by making a total of seven borings, three on the exterior and four in the interior of the building. The locations of the test holes are shown in Figure 2. These borings were made to establish the geology of the site and to collect disturbed and undisturbed soil samples for laboratory testing. Interior test holes were advanced through the basement concrete floor.

Disturbed samples were obtained using a hand auger. Undisturbed samples were obtained using thin-walled tubes pushed into the soil using a screw jack. Laboratory testing included the determination of water content, Unified Soil Classification, laboratory vane shear, confined shear strength and oedometer tests.

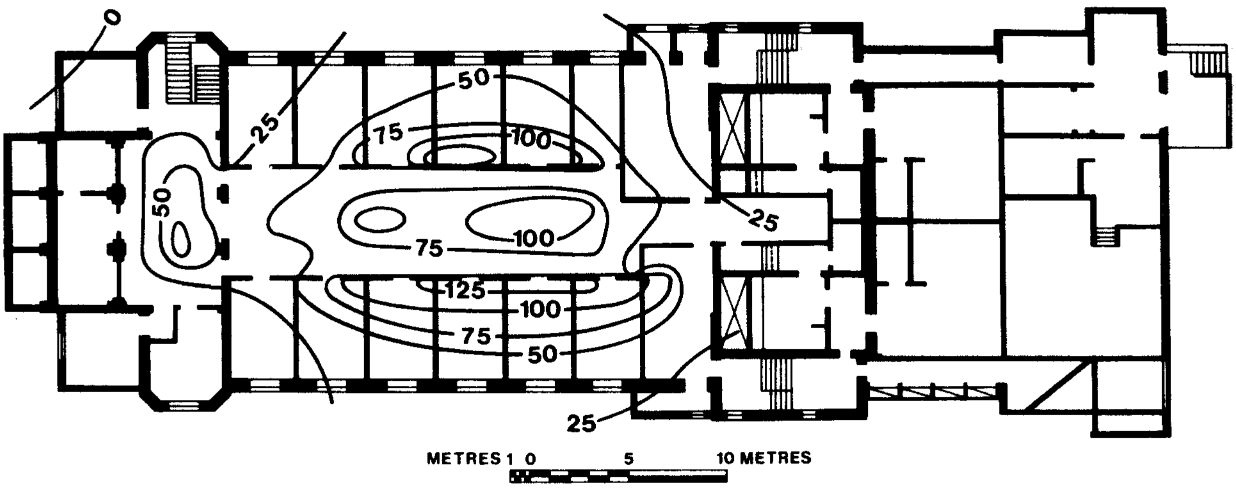

Figure 4 Basement Floor Contours (mm)

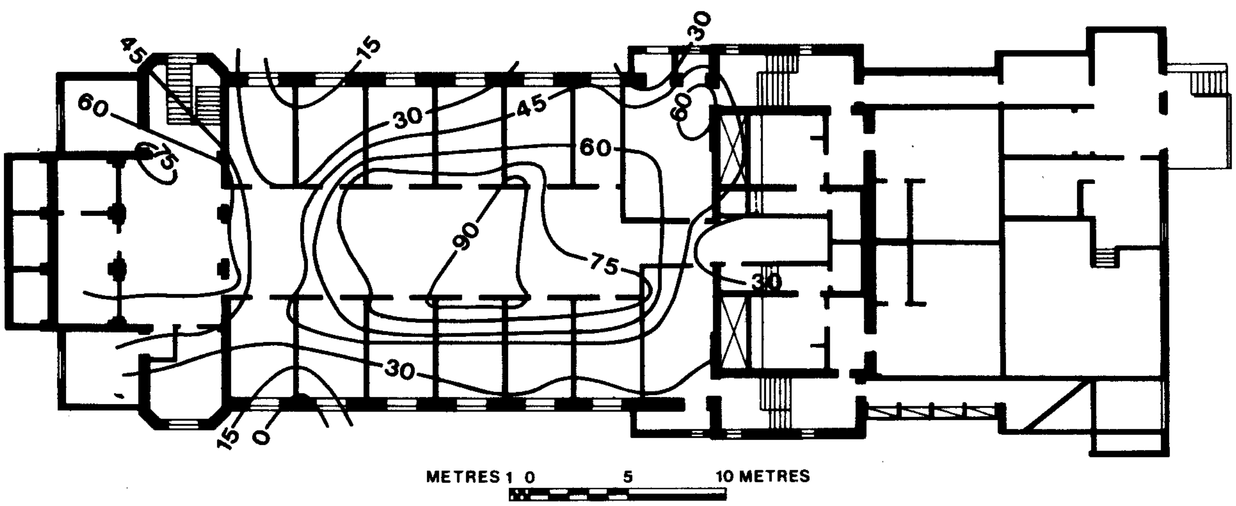

Figure 5 Contours of Underside of Main Floor Beams (mm)

A typical test hole log is shown on Figure 6. The surficial material is highly plastic lacustrine clay 9.4 m in thickness. The lacustrine clay is typically unsaturated, expansive and desiccated near the surface by evapotranspiration. The engineering properties of this deposit have been documented (Fredlund et al, 1980). The clay is underlain by a very silty clay stratum 1.9 m in thickness. Underlying these lacustrine deposits are a very stiff, moist oxidized till and an overconsolidated bedrock clay.

Water contents of 32 percent to 35 percent were encountered to a depth of 4.6 m in exterior test holes drilled immediately adjacent to the footing. The water contents adjacent to the footing in interior test holes was 32 percent to 37 percent, indicating that the water content of the soil across the exterior footings is relatively constant. The water content adjacent to an interior column was 20 percent at the surface, increasing to 30 percent at a depth of 0.8 m, indicating that the soil immediately beneath the slab has likely been desiccated as a result of interior heating. At the centre of the corridor, approximately 1.0 m of highly plastic clay and sand is present. The water contents in this area ranged from 33 percent to 38 percent with free water being evident. Water content profiles across the building are shown in Figure 7.

The results of a constant volume consolidation test are shown on Figure 8. The corrected swelling pressure is P'_s = 155 kPa with a swelling index, C_s = 0.09 and a compressive index, C_c = 0.21. This specimen was obtained from the exterior of the building at the footing level. Although no consolidation testing was conducted in the area of the interior footing, testing at other buildings in the vicinity indicate that a corrected swelling pressure, P'_s = 600 kPa can be estimated for a water content of 25 percent. For a saturated clay, a water content of approximately 35 percent is typical.

4.0 ANALYSIS

Since the construction of Darke Hall in 1928, the foundation has undergone movement due to shrinking and swelling of the foundation soil. Initially, the exterior foundation members were moving upward as the soil swelled in response to an increase in the water content and an attendant decrease in the matric suction. However, desiccation in the interior, likely due to drying from interior heating, resulted in shrinking of the soil with an increase in matric suction. Although there has been an upward movement of the exterior walls relative to the interior columns prior to the early 1965, there has been subsequent upward movement of the interior columns of up to 150 mm since that time. The high water contents measured at the exterior foundation would indicate that the soil was saturated, and that presently there was little additional tendency for swelling. The high water

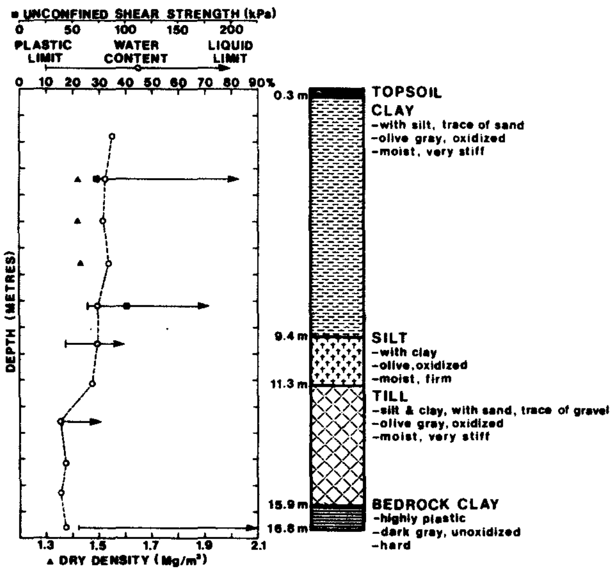

Figure 6 Typical Test Hole Log

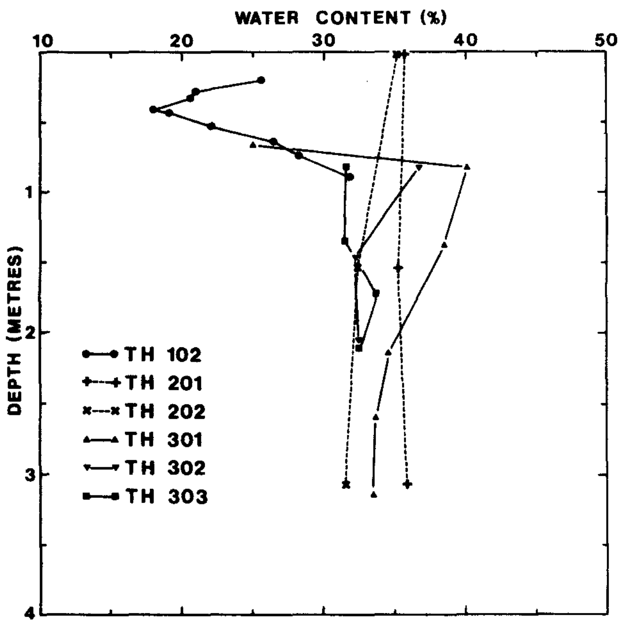

Figure 7 Comparison of Water Contents Across Building

contents in the centre of the basement floor corridor indicate a plentiful source of water that has caused swelling of the interior columns that is continuing to date. Although the source of this water is unknown, it is suspected that drains installed under the floor slab, as well as a drain installed during original construction, has hastened the transport of water to the formerly dry interior of the building.

The current desiccated nature of the soil near the interior columns suggests that additional heaving will take place. Using techniques described by Yoshida et al (1980) it has been estimated that an additional 25 mm of heaving may occur. Higher water contents around the exterior of the building have been attributed to the degree of irrigation that is employed by groundskeepers. Future differential movement due to drying, perhaps due to the growth of trees near the foundation, is of greater concern than additional swelling of the exterior foundation soil.

5.0 REMEDIAL MEASURES

Environmental changes have caused and continue to cause differential swelling and shrinking of the soil, movement of the shallow foundations and subsequent structural damage to Darke Hall. The remedial measures recommended were to underpin the exterior and interior foundation to isolate the structure from the effects of volume changes in the soil as completely as possible. The sensitivity of the structure to additional movement, the uncertainty regarding the construction and construction materials used in the building and the uncertainty surrounding possible environmental changes (principally landscaping) that could result in future movement of the exterior foundations justified the underpinning recommendations.

The basement floor will be removed and replaced by a crawl space and structural floor slab. Adequate vapour barriers will be included to ensure that desiccation of the soil will not occur. Exterior perimeter drains will ensure that water will be directed away from the footing. Insulation placed outside of the footing and grade beam will decrease the thermal gradients and the degree of moisture movement that will normally take place as a result of steeper thermal gradients (Hamilton, 1969).

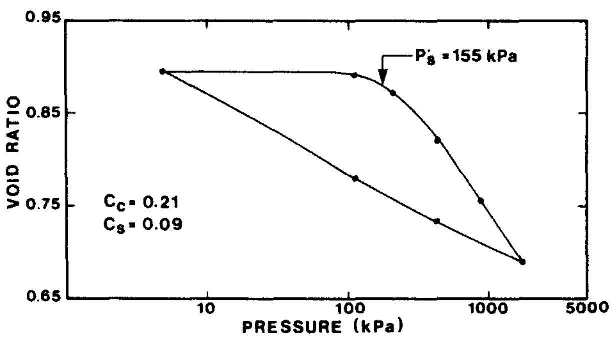

Figure 8 Constant Volume Consolidation Test Result

6.0 CONCLUSIONS

Over its 55 year life, Darke Hall has experienced large differential foundation movements. The movements of the shallow foundations have been the result of environmental changes, primarily movement of moisture, and volume changes in the expansive unsaturated soil. In excess of 100 mm of heave has been observed on the slab-on-grade floor. Differential movement of the interior columns and the exterior footings has resulted in structural damage. In order to restore the building for a further 100 years, it has been recommended that the structure be completely underpinned to transfer loads to more competent soil strata and to isolate the foundation from the effects of future environmental changes of the expansive clay soil as completely as possible.

The field evidence accumulated from Darke Hall has provided a valuable case history regarding the long-term performance of a structure founded on spread footings on highly expansive soil. The performance of the structure has been shown to be related to the control of and changes in the subsoil environment.

7.0 ACKNOWLEDGMENTS

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8.0 REFERENCES

Fredlund, D.G., Krahn, J. and Hasan, J.U. (1980). Variability of an expansive clay deposit. Proc. Fourth Inter. Conf. on Expansive Soils, Denver, Colo., Vol. 1, pp. 322-338.

Hamilton, J.J. (1969). Effects of environment on the performance of shallow foundations. Canadian Geotechnical Journal, Vol. 6, pp. 65-80.

Yoshida, R.T., Fredlund, D.G. and Hamilton, J.J. (1983). The prediction of total heave of a slab-on-grade floor in Regina clay. Canadian Geotechnical Journal, Vol. 20, No. 1, pp. 69-81.