A small Saskatchewan town copes with swelling clay problems

R.K.H. Ching and D.G. Fredlund

Abstract: This paper presents the problems and solutions associated with construction on an expansive soil deposit in the Eston area of Saskatchewan, Canada. The results of laboratory testing and records of field investigations are presented. The investigation showed the soil to be extremely expansive in nature and that a school building had undergone approximately one meter of heave during its history. This magnitude of heave is reasonable only if the measured swelling pressures are corrected for sampling disturbance.

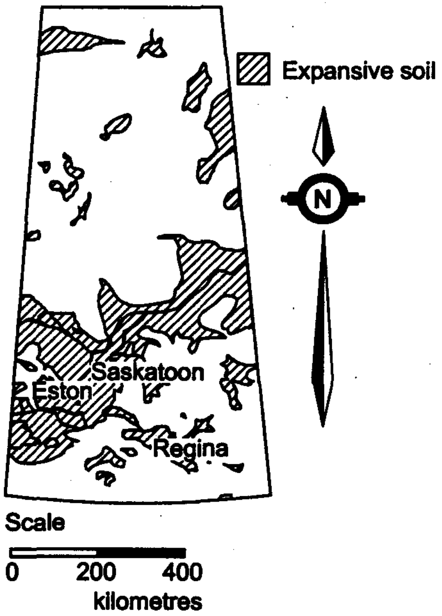
Key words: expansive soils, swelling, foundation, matric suction, heave design.

Introduction

A large portion of the area in Western Canada is covered by expansive soil deposits. Foundation problems are often encountered as a result of swelling of these soils (Hamilton 1966; Fredlund 1975). The soils are unsaturated due to desiccation and the environment is changed when a structure is constructed on the soil. With time, moisture accumulates in the soil as it tends to approach saturation. As a result, the soil undergoes volume change which causes damage to the structure.

A study was initiated in the 1950's to investigate the problems of the swelling soil in the Eston area of Saskatchewan, Canada. This study also included the monitoring of ground movements in the field and the performance of structural foundations. This paper presents the results of laboratory tests and field measurements at several sites. Special construction techniques have been developed for small structures to accommodate the ground movements. These techniques are described in this paper.

Fig. 1. Location of the town of Eston and distribution of expansive soils in Saskatchewan, Canada.



Description of study area and soil material

Eston is situated within the Snipe Lake Plain physiographic region which was a proglacial lake basin (Christiansen 1965) in the south-western part of Saskatchewan. Figure 1 shows the location of Eston and the distribution of expansive soils in Saskatchewan.

The climate in Eston is classified as sub-arid. The monthly precipitation varies widely. The highest precipitation occurs in June and July with an average rainfall of 55 mm. The monthly evapotranspiration over the summer months ranges from 70 mm to 130 mm and usually exceeds the monthly precipitation. As a result, a net moisture deficit occurs. The monthly temperature ranges from −18°C in January to +18°C in July.

The surficial material is a uniform and highly plastic clay known as the Eston clay. The clay is highly overconsolidated due to desiccation. Large shrinkage cracks are present to well below the ground surface. Underlying the lacustrine clay is a layer of calcareous till. A groundwater table is usually not observed during a

R.K.H. Ching. Research Engineer, Department of Civil Engineering, University of Saskatchewan, 57 Campus Drive, Saskatoon, SK, Canada S7N 5A9.
D.G. Fredlund. Professor, Department of Civil Engineering, University of Saskatchewan, 57 Campus Drive, Saskatoon, SK, Canada S7N 5A9.

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subsurface investigation in the general area of Eston. Figure 2 shows a typical soil profile in Eston.

Soil properties and matric suction measurement

Atterberg limits tests, grain size distributions and constant volume oedometer tests were performed to obtain the physical properties of the Eston clay. Filter paper tests were also conducted to give an estimation of the matric suction of the soil (McQueen and Miller 1968).

Classification tests

The average liquid limit of the Eston clay is about 94 percent and its average plasticity index is 63 percent. The Eston clay is classified as a highly plastic clay. The natural water content of the soil ranges from 20 to 35 percent, slightly below the plastic limit of the soil. The void ratio of the soil remains consistent at approximately 1.0 throughout the clay soil profile as shown in Fig. 2.

The Eston clay consists of approximately 90 percent clay sizes, 8 percent silt sizes and 2 percent sand sizes. The clay has an activity index of 0.7 which indicates a high swelling potential.

Constant volume odeometer test

One-dimensional oedometer tests were performed to establish the volume change properties of the Eston clay. The swelling index and the swelling pressures were obtained for predicting volume change. Two swelling pressures are defined; the corrected swelling pressure, P_s', and the uncorrected swelling pressure, P_s (Fredlund et al. 1980). Figure 3 shows the typical results of a constant volume oedometer test performed on an undisturbed sample. Both the corrected and the uncorrected swelling pressures greatly exceed the overburden pressure. The large swelling pressures indicate the highly expansive nature of the soil.

Figure 4 presents a typical swelling index and swelling pressure profile for the Eston clay. Both profiles exhibit a similar pattern of variations. The corrected swelling pressure varies from 500 and 1400 kPa with an average of approximately 950 kPa. The larger variation in the swelling pressures in the upper strata is possible due to surface effects of infiltration, desiccation and cracking.

Matric suction measurements

The matric suction can be used to indicate the swelling potential of a soil because the volume change associated with a soil is related to the change in the matric suction. Numerous techniques have been devised for measuring soil suction. The filter paper technique seems to be a simple means for estimating the suction (McQueen and Miller 1968). Although further refinement is required for this method, the results can be used as an indication of the negative pore-water pressures in the soil. Figure 5 shows the matric suction profiles obtained from the filter paper technique performed on the Eston clay samples. Soil suction values generally range from 2000 to

Fig. 2. Soil properties and matric suction measurement.

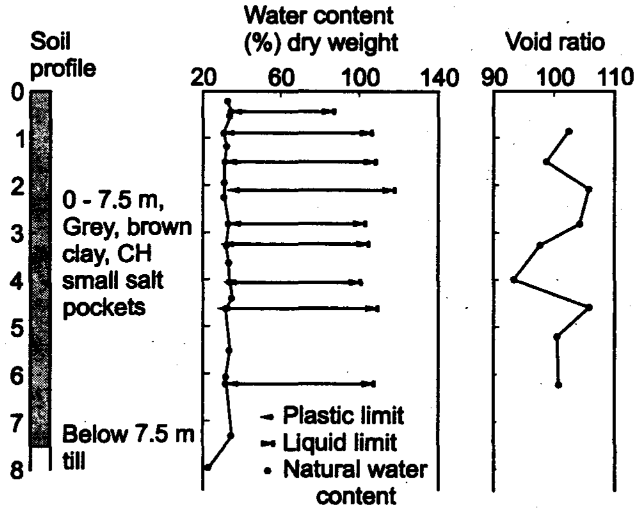


Fig. 3. Typical consolidation results for Eston clay.

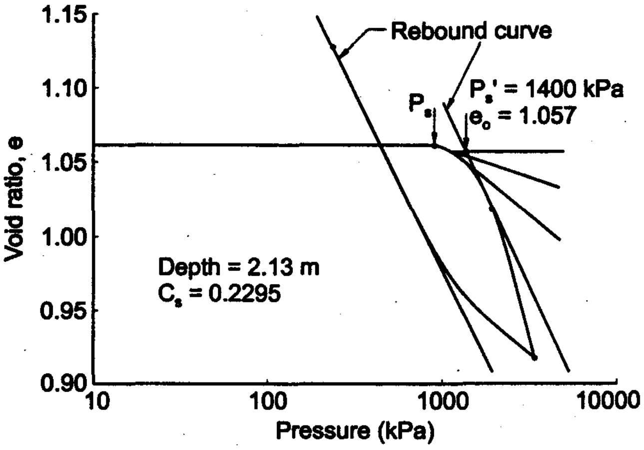


Fig. 4. Profile and swelling properties for Eston clay.

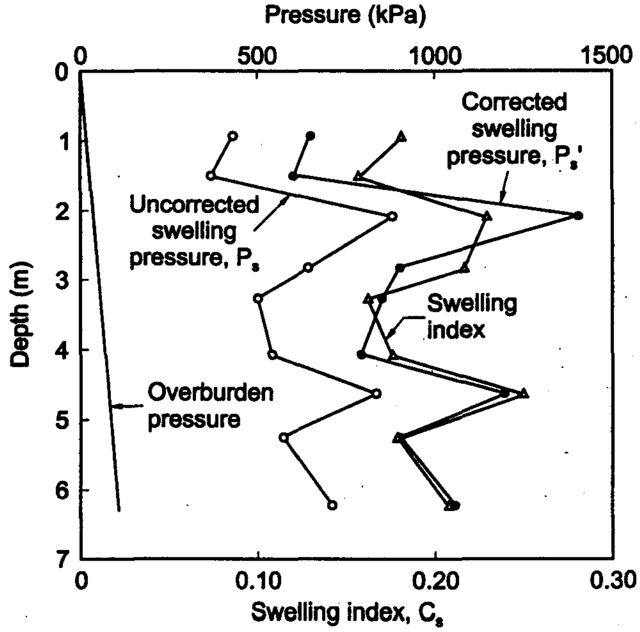
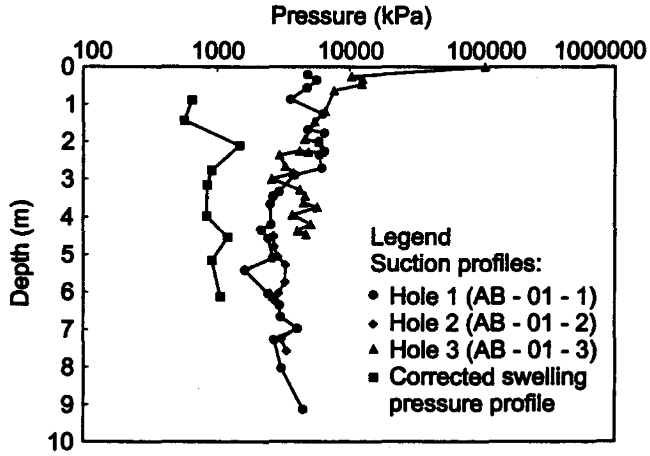


Fig. 5. Matric suction profile for Eston clay.



6000 kPa. A comparison given in Fig. 5 shows that there is a correlation between the corrected swelling pressures and the matric suctions. The matric suctions are higher than the swelling pressures as would be expected. However, the accuracy of the measured suctions is not known.

Results of the laboratory tests for the Eston clay are summarized in Table 1.

Record of swelling soil problems at Eston

A study program was initiated in the 1950's to investigate the problems associated with the swelling soil in the Eston area. Studies included the monitoring of ground movements in an undisturbed field plot and the performance of foundations on the expansive Eston clay. The results of these studies are presented to provide some quantitative measures for the swelling soil problems that have been encountered in this region.

The open field test plot was used to collect field data relating ground movements to climatic factors (Hamilton 1963). Instrumentation consisted of a deep bench mark, a neutron moisture meter access tube, a rain gauge and vertical ground movement gauges. These were installed as illustrated in Fig. 6. Six movement gauges were embedded at different depths below the ground surface. Ground movements were obtained from levelling surveys on the movement gauges with reference to the deep bench mark. The neutron moisture meter did not perform satisfactorily. Instead, the soil-moisture conditions were obtained by gravimetric determination of soil samples. Precipitation was recorded by the storage rain gauge.

Ground movements obtained from three of the movement gauges as well as the rainfall records during the period of June, 1961 to April, 1970 are given in Fig. 7. Maximum ground movements were found to occur during the wet season from March to September. Settlements usually occurred following a long dry period. This pattern of ground movements agreed closely with the precipitation record obtained from the storage rain gauge. The maximum movement recorded is approximately 80 mm.

Table 1. Summary of test results for Eston clay.

Test	Results
Atterberg limits	
Liquid limit	94%
Plastic limit	31%
Plasticity index	63%
Grain size distribution	
Sand sizes	2%
Silt sizes	8%
Clay sizes	90%
Constant volume oedometer test	
Swelling index	0.19
Corrected swelling pressures	500 – 1400 kPa
Matric suction measurement using filter paper	2000 – 6000 kPa

Fig. 6. Instrumentation in Eston test plot.

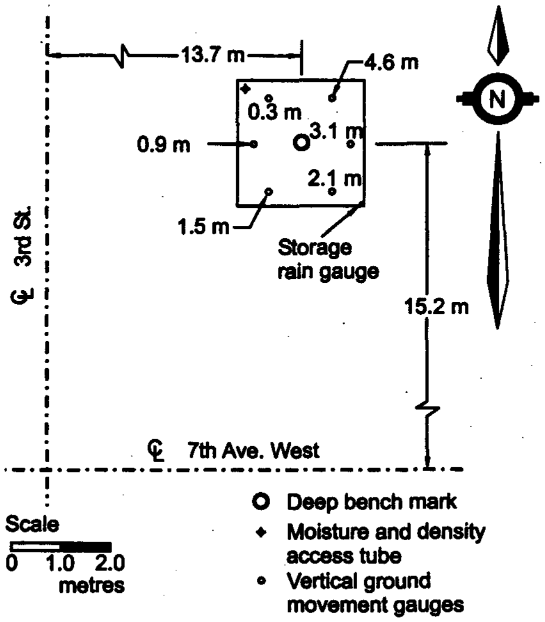
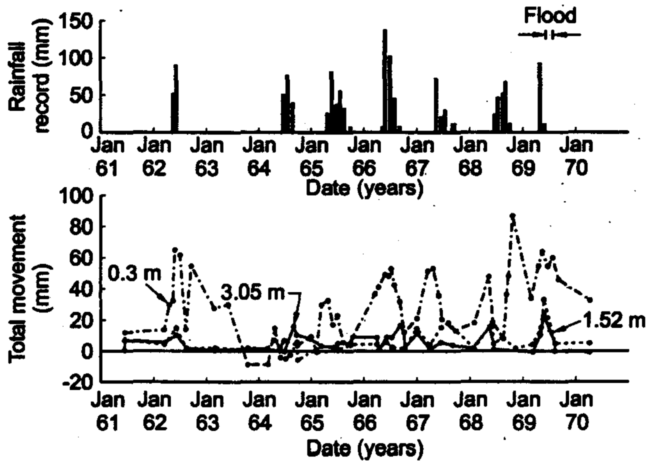


Fig. 7. Ground movements in Eston test plot.

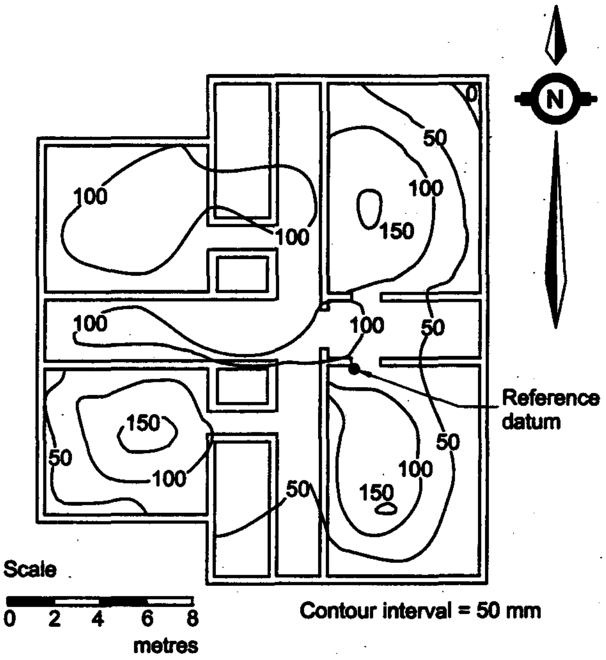


Comparatively large movements varying from 10 to 30 mm were found to take place at a depth of 3 metres. This signifies that the available moisture is effective in penetrating down to a considerable depth. The records of soil moisture contents agreed well with this observation. After a rainfall, the soil moisture contents in the upper 3 metres were usually increased by 5 to 25 percent. This finding is of particular interest because the zone of influence exceeds the common depth used for shallow foundations. Any foundation located within this depth is vulnerable to the effect of soil movements.

The results from the test plot indicate that ground movement problems can occur even under undisturbed conditions. The problem is expected to be greatly aggravated if a change in the soil environment is introduced by the construction of a structure. As a result, moisture will gradually accumulate in the subsoil and cause a reduction in the soil suction and an increase in the soil volume.

The excessive ground displacements associated with a change in the soil environment can be illustrated by the record of the foundation performance of the old Eston school building. This structure was monitored as part of the study program. The basement floor of this building continued to heave since the completion of construction. Figure 8 shows the basement floor heave when the initial measurements were made in August, 1960. Although the maximum differential movement was only about 150 mm, a much larger total heave of approximately 600 to 800 mm had already taken place before the commencement of the monitoring program (Hamilton 1966). The maintenance records indicate that the deformation was severe. As a result, the concrete floor slab had to be removed and approximately 300 mm of the subsoil had to be excavated. The soil was then levelled to allow the reconstruction of the floor slab. This upgrading operation was executed twice before the building was finally demolished in 1969.

Fig. 8. Floor heave in old Eston school building.



Using the prediction method for heave proposed by Fredlund et al. (1980) and the results from the constant volume oedometer tests, a total heave of 780 mm can be computed. Detailed calculation procedures are outlined by Yoshida et al. (1983). The computed total heave agrees well with the actual heave that had taken place at the structure.

The data collected from the monitoring of this structure indicated the severe ground movements that can be caused by environmental changes. Ground movements of such large magnitude can inflict serious damages to structures and are difficult to take into account in the design.

Special construction techniques used in Eston

Special construction techniques for small structures have been developed by residents of the area to accommodate the problem of swelling soils. These methods have been derived largely on the basis of experience. Both deep foundation and shallow foundation are used. The type of foundation selected is usually based on the loading requirements and the importance of the structure. The unit costs of the two foundation types are approximately the same.

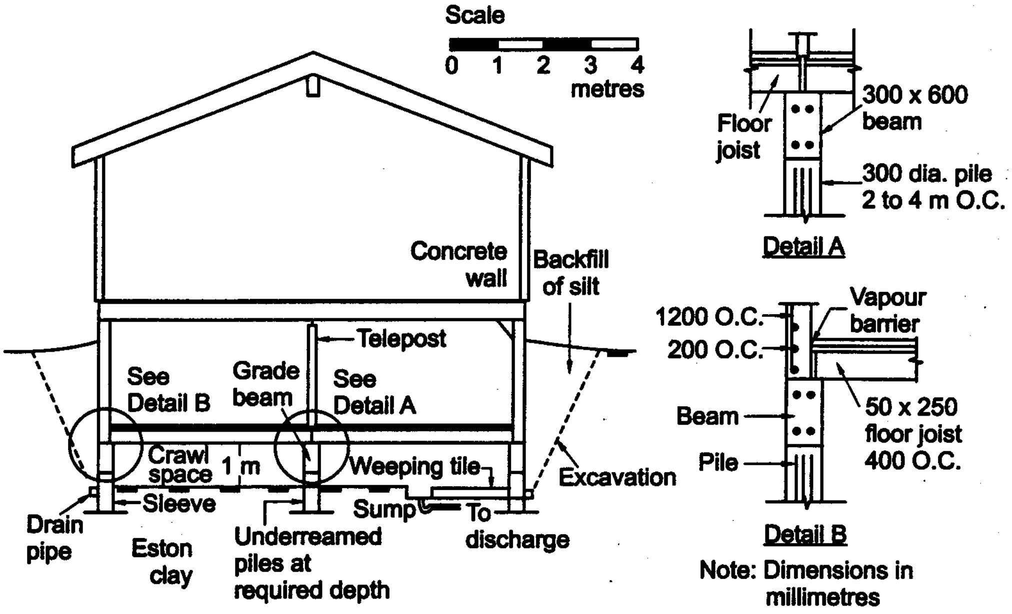
Numerous other foundation treatments have been tried with poor success. For example, tin cans, tires and straw bales placed beneath the concrete slabs have not proven effective in eliminating the heave problem.

Deep foundation

Deep foundations are generally used for more heavily loaded structures where unsightly structural damages are of major concern to the public. Cast-in-place augered piles with diameters of 250 mm or larger are commonly founded on the underlying till layer. The upper portion of the pile is encased with a sleeve to avoid the development of skin friction which may be reversed due to soil expansion. Piles are reinforced with several vertical bars of 12 to 25 mm diameter to resist the tensile forces produced in an uplift action. The lower portion of the pile is generally bell-shaped. Structural concrete beams are constructed spanning across adjacent piles. Styrofoam boards are utilized to fill the gap beneath the perimeter structural beams. These boards may be crushed as the swelling pressure of the soil develops.

Structural walls are built with concrete heavily reinforced in both horizontal and vertical directions to resist the tensile forces caused by differential movements. Wooden floor joists are simply supported on structural beams and a wooden floor is laid on these floor joists. Typically, floor unit is not rigidly affixed to the load carrying members. In this manner, the entire structure is flexible and can tolerate large distortions without detrimental results.

Fig. 9. Structure with deep foundation.



A building can be constructed with or without a basement. In either case, an unusually large crawl space of approximately 1 metre is provided beneath the lower floor to allow room for the anticipated soil expansion. If a basement is needed, the basement walls must be reinforced to provide resistance against the lateral swelling pressures. Typical horizontal and vertical reinforcement spacings are 200 mm and 1200 m, respectively. Heated air outlets have been sometimes installed in the crawl space. Hot dry air can be periodically circulated in order to maintain a consistent environment for the foundation soil. A weeping tile system is constructed around the building at the lower floor level for collecting larger volumes of water that may infiltrate through the soil. The water is drained into a sump in the crawl space where it is discharged into the public storm sewers. The excavation is backfilled with a non-swelling silt, which is locally referred to as river clay, borrowed from the nearby region. The compacted backfill is less permeable compared to the fissured clay and is more effective in reducing the infiltration of water. Figure 9 illustrates a typical structure supported on piles.

Shallow foundation

For lightly loaded structures, a shallow foundation is preferred. The basic foundation unit is a continuous strip footing of approximately 0.5 metres wide by 0.2 metres high. The footing is heavily reinforced to increase its flexural strength in resisting the detrimental effect of differential movements. A wood form is then constructed for the perimeter structural wall on the spread footing. Slots are cut in the wood form approximately 1 metre above the footing level. Joists are inserted into these slots. Concrete is cast *in situ* to form the structural walls. A wood floor is placed on the top of the structural floor joists. Using this procedure, the floor and walls form a single, integral unit. The wall unit is locally called a stub wall. The stub wall may require two form works and concrete pours to attain the desired height for the foundation wall. Figure 10 shows a typical structure using this construction technique.

A variation in the shallow foundation construction technique shown in Fig. 11 has also been used. The basic foundation unit is also a continuous strip footing of 0.5 metres wide by 0.2 metres high. In addition, another strip footing of smaller dimensions (i.e., 0.4 metres wide by 0.2 metres high) is constructed on top of the larger strip footing. The wood floor unit used in this construction is laid on the bottom spread footing instead of bonding it to the structural walls.

In both shallow foundation types, a crawl space of 1 metre is provided beneath the lower floor to allow room for possible soil heave. The underground drainage system and backfilling operation are essentially the same as those for the deep foundation described previously.

Observations of performance of different types of foundation

Performance records for the Eston school building are cited to show the effectiveness of deep foundations to overcome the swelling clay problem. The Eston school was erected in 1954–55. Its construction made use of deep foundations along with a crawl space, as described in the previous sections. Attention was given to the design and construction of this building in an attempt to reduce the detrimental effect resulting from the anticipated soil movements. The boiler room was built on a mat foundation to support heavy boiler machinery and vibrations induced by the boiler operation.

The deep foundations with the one-metre crawl space performed satisfactorily and no structural movement oc-

Fig. 10. Structure with stub wall construction.

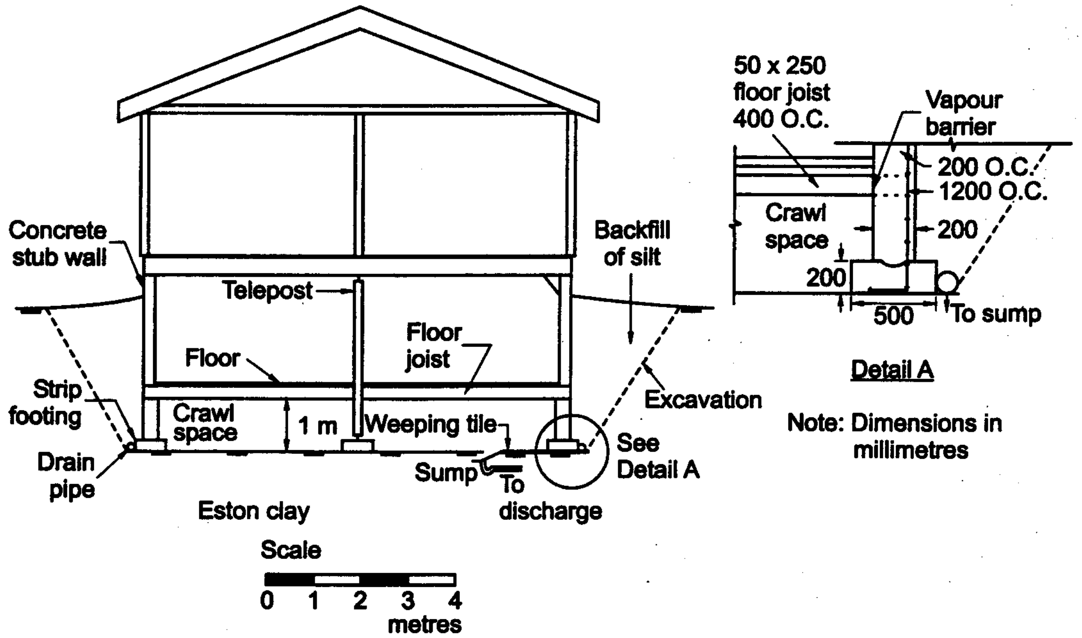
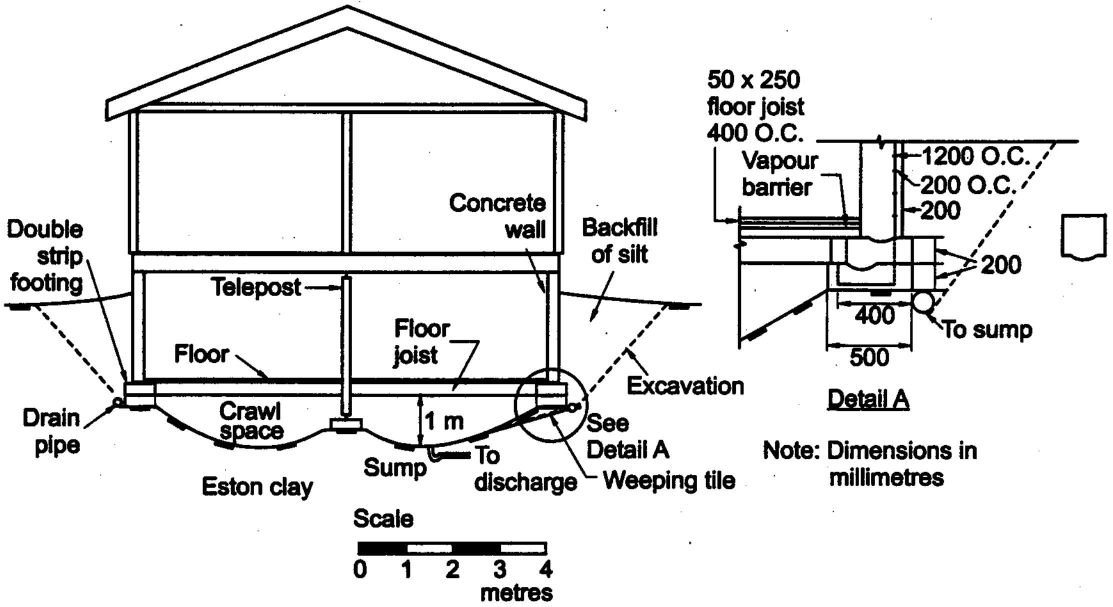


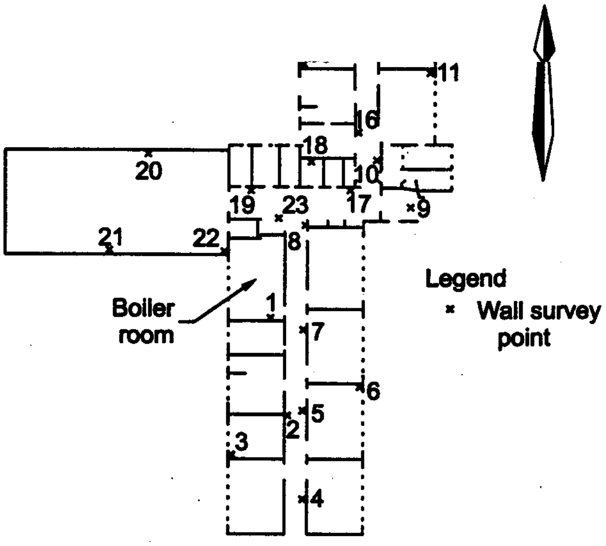
Fig. 11. Structure with double strip footings.



curred on the main floor. However, the structural floor slab in the boiler room was observed to heave continuously after construction. The movements were monitored by means of levelling surveys. Survey points were installed on the walls in the main building and on the floor in the boiler room. Figure 12 shows the locations of the wall survey points. Large differential movements took place in the floor slab of the boiler room. Slab movements amounting to 75 mm were measured in the middle of the floor. The structural grade beams around the perimeter of the boiler room restrained the floor movements along the edges of the room. As a result, the floor slab bulged upward toward the middle of the room.

As a result of the heaving of the boiler room floor the structures neighbouring the boiler room tilted. Some structural members were badly damaged and continuous repairs were required. Figure 13 illustrates the movements observed from several of the survey points. Structural movements in excess of 50 mm occurred in the main floor area adjacent to the boiler room. Only slight movement was observed in the main floor area which was further away from the boiler room.

Fig. 12. Survey points in Eston public school.



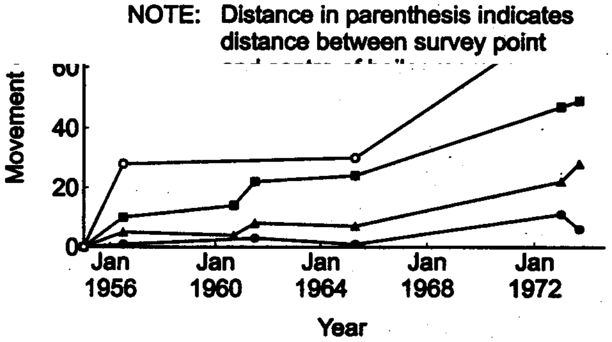
The record for the Eston school building provides a history typical of the performance of the deep foundations in the Eston area. The deep foundations minimize the effect of environmental changes in the swelling subsoil since the structural loads are transferred down to the underlying till layer. The provision of the crawl space appears to be effective in reducing the amount of soil movement.

Discussion

The expansive Eston clay is highly desiccated. A change in the soil moisture conditions can cause substantial volume change to occur. From the investigations in the open field test plot, it is evident that substantial ground movements can occur even under the natural cycles of drying and wetting. The ground movement problem is greatly magnified due to the construction of a structure. This is verified from the monitoring of floor movements in the old school building in Eston. In this case, an estimated heave in the range of 600 to 800 mm had occurred during its service life.

Foundations in direct contact with the swelling soil generally suffer excessive structural damages due to soil movements. When designing structures in the Eston area, the potential of large volume change of the clay must be taken into consideration. Special construction techniques have been developed for small structures. Both deep and shallow foundations are used in these designs. The key elements involve a large crawl space beneath the floor and flexible connections between structural members. The crawl space is used to isolate the superstructure from the expansive soil. The building can tolerate some differential movements to occur without harmful consequences. A relatively less permeable silt backfill has been used to reduce excessive seepage into the cracked subsoil. Adequate subsurface drainage around the outside perimeter of the foundation is provided to divert seepage water from the subsoils. These measures are essential in minimizing the magnitude of the soil movements.

Fig. 13. Wall movements due to boiler room floor heave.



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