Special Considerations in Design of Foundation in Problematic Soils

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ABSTRACT

The ability of a structure to withstand stresses starts from the nature of the soil on which it is built and the suitability of the foundation adopted for the corresponding soil condition. There are different types of problematic soils mostly encountered in practice such as expansive, collapsible and dispersive soils. Expansive soil is highly problematic due to its high rate of swelling and shrinking when they come in contact with moisture. They range from minor cases to severe cases. The minor cases are situations where the depth of the expansive clay is small and the foundation footing can reach beyond it to more stable strata. The severe cases are situations where the expansive clay is considerably deep and would require most preferably the pile foundation. For the purpose of this study, emphasis was placed on the expansive soil. This type of soil is common in North Cyprus due to the nature of its soil and the extremes in its weather conditions. The Haspolat region in the capital Lefkosa was studied. Relevant data such as soil test data, and other documents related to the research subject were obtained and analyzed. A reconnaissance survey was conducted based on an in depth interview with public officials, private sector entities and the inhabitants of Haspolat. Data was obtained from on the spot observation of the site and recorded for analysis.

The extent of the depth of expansive soil in the soil strata required the use of raft foundations design in expansive soils. Its initial cost of construction is high but the maintenance cost of the building is minimal since the foundation resists any movement of the expansive soil which would have caused failure.

Keywords: Problematic Soils; Foundations; North Cyprus

INTRODUCTION

The ability of a structure to withstand stresses starts from the nature of the soil on which it is built and the suitability of the foundation adopted for the corresponding soil condition. Problematic soils are frequently encountered in engineering practice and the need to continue to anticipate such soils and design to foundations to prevent failure due to differential movement cannot be overemphasized. There are different types of problematic soils mostly encountered in practice such as expansive, collapsible and dispersive soils but for the purpose of this study, emphasis was placed on the expansive soils. This type of soil is highly problematic due to its high rate of swelling and shrinking when it comes in contact with moisture. They range from minor cases to severe cases. The minor cases are situations where the depth of the expansive clay is small and the foundation footing can reach beyond it to more stable strata. In these cases, shallow foundations can be used with minimal differential movement. In order to prevent these unacceptable movements, pad foundations can be used to improve the structural integrity of the foundation. The severe cases are situations where the expansive clay is considerably deep and would require most preferably the pile foundation. This is a situation where concrete piles are driven into the soil until it reaches more stable strata which can conveniently carry the structure's load.

PROBLEMATIC SOILS

Soils in geotechnical engineering can be problematic especially if they become expansive, collapsible, dispersing easily, undergoing excessive settlement upon loading, having a distinct lack of strength or are soluble. These characteristics are likely as a result of their composition, the nature of their pore fluids, their mineralogy or their fabric (Mohsen et al, 2012). The design and construction of foundations on these kinds of soils in Haspolat region poses serious challenges in which the conventional methods become impossible to adopt both from an engineering or economic point of view and hence requires an extensive understanding of the soil characteristics. There are a number of these types of soils which tend to be problematic and they include but not limited to expansive soils (swelling/ shrinking clays), dispersive soils (clays), and collapsible soils (silts).

EXPANSIVE SOILS

Expansive soils as the name imply refer to soils which have the tendency to swell or shrink as a result of changes in environmental conditions. These types of soils are common in the Haspolat region of North Cyprus as shown in Figure 1. Soil samples were obtained by Rotary core drilling with a borehole depth of up to 12m. Peat Soil was observed from the depth of 0 to 0.1m which is regarded as the topsoil. Further penetration from 0.1 to 7.75m revealed varying types of clay with high plasticity which explains its tendency to shrink and swell when exposed to the meteorological conditions of North Cyprus. Foundation types except pile foundations are constructed within these depths which makes them susceptible to failure. When a change in the water content of the soil takes place which is independent of the loading, they experience slow volume changes and these are attributed to the swelling and shrinkage (Bell, 2007). The effects of expansive soils are more obvious in non-load bearing walls, fences, low rise buildings, and roads as they do not have sufficient weight to resist the pressure produced by the expansion (Yenes et al, 2010).

Figure 2 shows an expansive soil and its effect on buildings. Changes in moisture content in expansive clay below a building foundation can result in vertical movements which occurs from the start of the construction, because the vegetation that existed before it was cleared to make way for the excavation of foundation trenches, reduced the moisture content of the soil by absorbing it.

As a result of seasonal moisture changes, alternating wet and dry cycles which are common in North Cyprus further impacts on the moisture content of the soil and results in differential movements below a building's foundation. Differential movements due to expansive clay may also cause problems at the approach contacts at bridges and at drainage structures such as culverts crossing underneath roads.

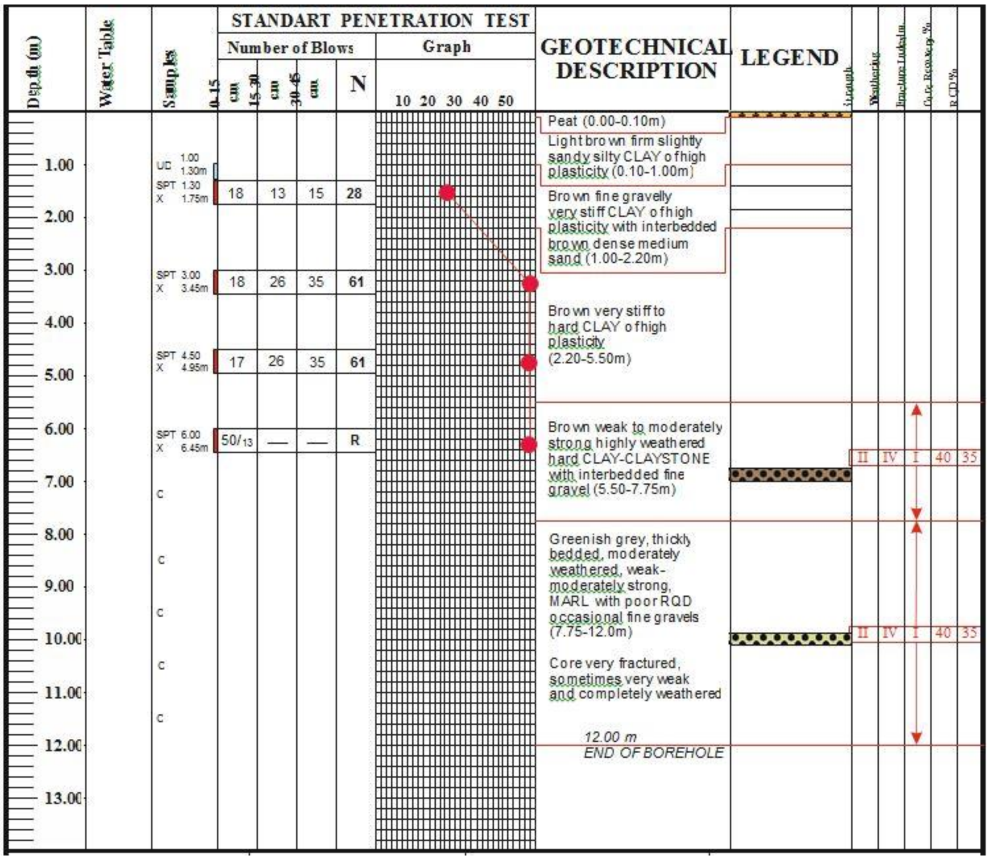

Figure 1 Standard penetration test in Haspolat region

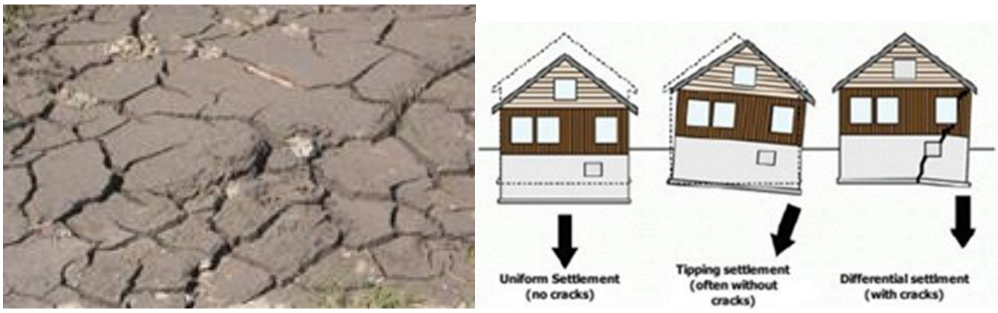

Figure 2 Expansive soil and its effect on buildings

Tables 1 and 2 show the mineral and chemical components and content of expansive soil.

Table 1 Mineral components and contents of expansive soil (%)

Component	Montmorillonite	Illite	Kaolin	Quartz	Feldspar
Content	13	39	31	9	8

Table 2 Chemical components and contents of expansive soils (%)

Component	Na_2O	MgO	Al_2O_3	SiO_2	K_2O	Fe_2O_3	SiO_2/Al_2O_3
Content	3.2	6.7	19.5	47.3	8.4	12.8	2.1

DISPERSIVE SOIL

Dispersion occurs usually in soils with a considerably high exchangeable sodium percentage (ESP), resulting in internal erosion. The tendency for dispersive erosion in a given soil depends upon different variables such as mineralogy. Chemistry of the clay and the dissolved salts in the soil water play a vital role in its tendency to disperse upon loading. Dispersion also occurs when the repulsive forces (electrical surface forces) between clay particles exceed the attractive forces (Van der Waal forces), the clay particles progressively detach from the surface and become suspended, so that in the presence of relatively pure water the particles repel each other to form colloidal suspensions (Umesh et al, 2011).

Most soils with clay fractions composed mainly of the smectite and other 2:1 clays (for example, montmorillonite), and some illites (1:2 clays) are highly dispersive.

COLLAPSIBLE SOILS

These types of soils are moisture sensitive because increase in moisture content is the primary triggering mechanism for its volume reduction (Mohsen et al, 2012). When the in-situ moisture content remains low, small settlements are expected since the soil can withstand relatively large stresses being imposed on it. It will also show a decrease in volume and increase in settlement with no increase in the applied stress if the moisture content increases. The change in volume is mainly associated with a change in the soil structure resulting in the collapse of the grain structure. Figure 3 shows the relation between dry density, liquid limit and collapsibility of soils (Das, 2009).

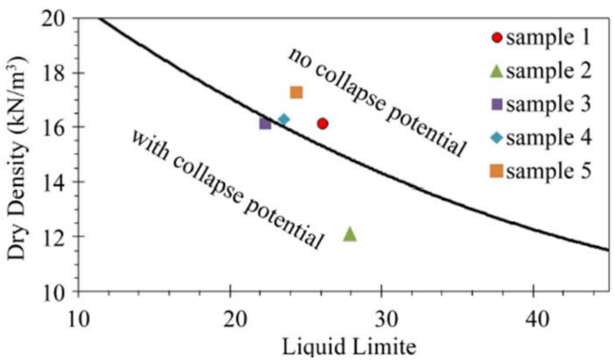

Figure 3 Collapse potential to Liquid Limit and Dry Density

From experience, alluvial and windblown deposits are known to geotechnical and geological engineers as having the potential to collapse especially in arid regions (Yakov, 2007).

Collapsible index of soils can be calculated by Equation 1 (Ozer et al, 2011):

$$I_c = \frac{H_1 - H_2}{H_1} \times 100 \qquad \text{Eq. 1}$$

Where I_c is collapsibility index, H_1 is initial soil sample thickness (before saturation), and H_2 is the final thickness of the soil sample (after saturation).

Table 3 shows the potential severity of collapse of soils.

Table 3 Collapse percentage as an indication of potential severity

Collapse (%)	Severity of problem
0 – 1	No Problem
1 – 5	Moderate Trouble
5 - 10	Trouble
10 - 20	Severe Trouble
Over 20	Very severe Trouble

CONSIDERATIONS IN FOUNDATION DESIGN FOR EXPANSIVE SOILS

Nature of Expansive soils

The most suitable foundation to be used on soils is largely influenced by geological and environmental conditions and these require special consideration during design to avoid eventual failure. Table 4 shows some problem conditions of different types of problematic soils which require special considerations. In this study, emphasis was more on expansive soils which is common in the Haspolat region of North Cyprus.

The change in the moisture content in soil which creates vertical movement of expansive clay below a foundation usually commences when construction begins and this is due to the clearing of bushes, shrubs and cutting down of trees before excavation begins. This increases the moisture content in the soil as the seasons change between fall, winter, summer and spring. The time related nature of these moisture content changes results in a differential movement in the soil which can cause considerable damage to the foundation and subsequently the structure itself.

Table 4 Problem conditions requiring special consideration

Problem Type	Description	Comments
	Organic soil; highly plastic clay	Low strength and high compressibility
	Sensitive clay	Potentially large strength loss upon large straining
	Micaceous soil	Potentially high compressibility (often saprolitic)
Soil	Expansive clay/silt; expansive slag	Potentially large expansion upon wetting
	Liquefiable soil	Complete strength loss and high deformations due to earthquake loading
	Collapsible soil	Potentially large deformations upon wetting (Caliche; Loess)
	Pyritic soil	Potentially large expansion upon oxidation
	Laminated rock	Low strength when loaded parallel to bedding
	Expansive shale	Potentially large expansion upon wetting; degrades readily upon exposure to air/water
	Pyritic shale	Expands upon exposure to air/water
Rock	Soluble rock	Soluble in flowing and standing water (Limestone, Limerock, Gypsum)
	Cretaceous shale	Indicator of potentially corrosive ground water
	Weak claystone (Red Beds)	Low strength and readily degradable upon exposure to air/water
	Gneissic and Schistose Rock	Highly distorted with irregular weathering profiles and steep discontinuities
	Subsidence	Typical in areas of underground mining or high ground water extraction
	Sinkholes/solutioning	Karst topography; typical of areas underlain by carbonate rock strata
Condition	Negative skin friction/ expansion loading	Additional compressive/uplift load on deep foundations due to settlement/uplift of soil
	Corrosive environments	Acid mine drainage; degradation of certain soil/rock types
	Permafrost/frost	Typical in northern climates
	Capillary water	Rise of water level in silts and fine sands leading to strength loss

APPROPRIATE DESIGN ALTERNATIVES FOR FOUNDATIONS IN EXPANSIVE SOIL

The area covered by the expansive clay can be excavated and replaced with gravelly materials if the thickness is small. It can be removed in strips below the foundation though this may still produce some unacceptable movement which could result in some degree of failure. Some foundation design for expansive clay may include raft foundation, shallow foundation footing and pile foundation.

A raft foundation can be designed to withstand the large differential movement, depending on the size and layout of the structure. This method is not economical but it is very effective since the load from the structure is imposed on a mass of concrete with sufficient thickness (Figure 4).

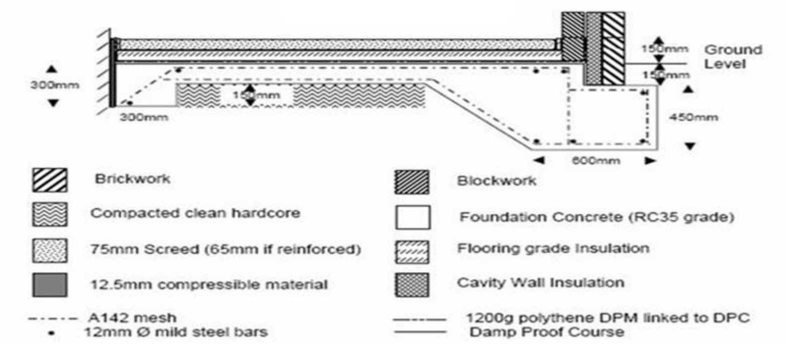

Figure 4 Raft foundation on expansive soil

A shallow foundation footing design can be adopted where the expansive soil stratum is relatively thin which allows the footing to be placed in a low expansive stratum. Small movement may still occur. This can be prevented by the use of pad foundations which would increase its structural integrity (Figure 5).

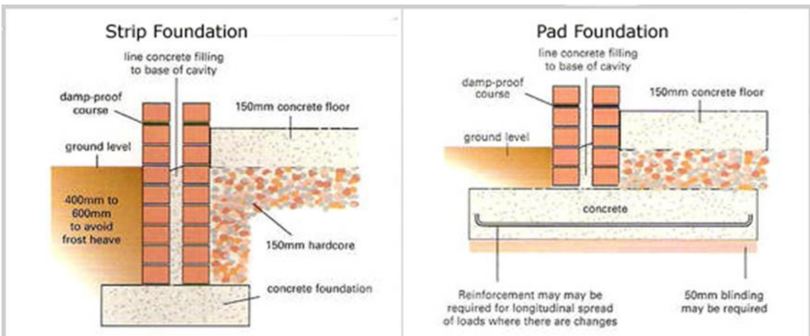

Figure 5 Strip and pad foundation for expansive soil

Pile foundations in expansive soils are used to transmit the structure’s load to a more stable stratum below the clay (Figure 6). They have a very high potential to reduce differential movement in expansive soils and this is mainly because of their ability to resist uplift forces due to swelling of clay layers in the upper soil when properly installed (Ahmed, 2005).

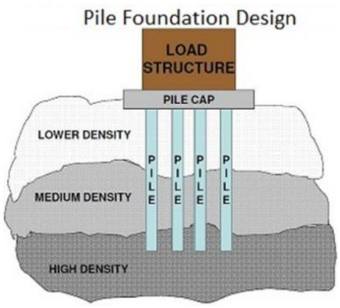

Figure 6 Pile foundation in expansive soils

Factors affecting the selection of a suitable foundation in expansive soil

There are a number of factors which should be considered in the selection of a suitable foundation and they include but not limited to the following.

The swelling nature of the soil which is a very important factor helps to know the degree of swelling and the depth of the expansive soil in order to make a more economical choice while maintaining the structural integrity of the foundation.

A second factor is the environmental conditions of the area where the expansive soil is found which includes the rain intensity, depth of water table, moisture content of the soil, temperature and vegetation cover.

Third factor is the type of structure in relation to its tolerance of differential movement. The expertise required for the construction of sophisticated foundation such as pile foundation in extreme cases of soil expansion and very large structures is a very important factor.

CONCLUSION

Problematic soils especially expansive soils in the Haspolat region affect the design of foundations because of the clayey nature of the soil, its depth and the degree of its swelling. This is further affected by environmental factors such as precipitation, temperature, depth of the water table, and the natural vegetation which is most likely cleared when construction is about to begin to make way for excavation of the foundation. As a result of the depth of the clay soil in the Haspolat region which is up to 7.75m, the most suitable foundation type for such an expansive soil with high plasticity is the pile foundation which can be driven beyond the problematic soil to a more stable soil. There are a number of types of foundations suitable for each degree and depth of the expansive clay such as shallow, pad, raft and pile foundation. For mild cases in which the depth of the expansive clay is small, a shallow foundation can be used but with small differential movement to be expected. This can be prevented by the use of pad foundations. In extreme cases in which the expansive clay has a large depth and the environmental factors provides a continuous swelling and drying of the clay, such as in the Haspolat region with an expansive clay depth of up to 7.75m, the most suitable foundation type for such an expansive soil with high plasticity is the pile foundation which can be driven beyond the problematic soil to a more stable strata.

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