1.1 GENERAL

Expansive soils, popularly known as black cotton soils in India, occupy about one-fifth of its land area. Mineral “Montmorillonite”, which present in these soils, has affinity for water. Uptake of water by black cotton soils causes swelling in them, when ample water becomes available to it. Thus, during monsoon the soil undergoes heave, which is swell in the vertical direction. Moisture migration form the open area at the edges of the building to the low temperature zone below its centre causes the central portion of the building to heave more than the edges.

Fig.1.1 Mound-shaped heave

This ‘mound-shaped’ heave (Fig 1.1), induces hogging moments in the structure which causes severe damage to it. During summer, evaporation of water from the soil causes it to shrink, which is more pronounced at the edges of the building. Alternate swelling and shrinkage causes strains in the building and its consequent
cracking. Similar damages occur in other structures like retaining walls, canal linings and canal beds and road pavements. Special foundation techniques become necessary to prevent damages to structures founded in these soils. Normally, heavier structures causes foundation problems. But in expansive soils, the problem is more severe in light structures as they cannot counter heave.

Different foundation practices like sand cushion, CNS cushion, stiffened mat, belled piers, under-reamed piles etc., have been tried in these soils with varying degrees of success. However, piles in general and, under-reamed piles in particular, continue to be the most favoured foundations in this country. These piles are generally anchored at a depth unaffected by seasonal moisture variations. Analysis of these foundations requires a special approach which is different from the usual pile-soil slip approach (Terzaghi & Peck, 1967).

1.2 PILE FOUNDATIONS

Normally, pile foundations are adopted where the soil at shallow depths is not strong enough to take the loads. Therefore, foundations are taken deeper. Piles are designed to derive their load-carrying capacity either by virtue of their end-bearing resistance or by the frictional resistance developed between the pile and the surrounding soil at their interface or due to a combination of both. While both frictional and end-bearing resistances are the contributing components in mobilizing load-carrying capacity in compression, frictional resistance alone contributes to the resistance of the pile in uplift which is mostly caused by the heaving of the expansive soil.
1.2.1 STRAIGHT SHAFTED PILE

Piles which have uniform cross-section along their length are called straight shafted piles (Fig. 1.2). These piles may be either precast piles or cast-in-situ piles. They can be used in expansive clays also but should be taken quite deep to provide the necessary resistance.

Fig. 1.2. Straight-shafted Pile

Fig. 1.3 Under-reamed Pile

1.2.2 UNDER-REAMED PILES

In order to increase the load-carrying capacity in compression and in uplift, a portion of the pile is enlarged as it provides a larger bearing area. (Fig. 1.3). These piles are essentially bored cast-in-situ piles because enlargement of the pile diameter is possible only in such piles. Since uplift forces are quite large in respect of foundations installed in expansive clays, under-reamed piles are often preferred to other types of foundations in these soils.

1.3 LOAD CARRYING CAPACITY OF PILE FOUNDATIONS

1.3.1 PLASTIC APPROACH

One of the earliest approaches (Terzaghi and Peck, 1967), assumes that full shear strength is mobilized along the pile-soil interface as the soil heaves and moves
upward relative to the pile. This results in slip and Mohr-Coulomb shear strength theory is aptly adopted for the determination of the forces, along the surface area of the pile.

1.3.2 ANALYSIS BASED ON ELASTIC THEORY

In most of these approaches, the pile is divided into a number of uniformly-loaded cylindrical elements and a solution is obtained by establishing the compatibility between the displacements of the pile and the surrounding soil for each element of the pile. While the displacements of the pile are obtained by considering the compressibility of the pile under axial loading, the displacement of the soil, caused by loading within the soil are obtained by Mindlin’s equation (D’Appolonia and Romualdi, 1963; Salas and Belzunce, 1965; Poulos and Davis, 1968; Mattes and Poulos, 1969; Poulos and Mattes, 1969a; Butterfield and Banerjee, 1971a, 1971b). Of these, Poulos and Davis, and Mattes and Poulos and Poulos and Mattes consider shear stresses to be distributed uniformly around the pile circumference. This approach is the most satisfactory one, especially for shorter piles. Since piles in expansive soils are normally anchored in inactive zone to resist uplift forces and are not normally very long, the above approach is adopted in the analysis carried out in this thesis.

Similar approach was adopted for the estimation of down-drag forces in end-bearing piles (Balakrishna, 1994), where the soil surrounding the pile undergoes consolidation settlement as against heave in the present case. The approach similar to that carried out by Balakrishna is adopted in this thesis, with the exception that direction of forces on the pile is different in the active zone.
1.4 OBJECTIVE AND SCOPE OF THE WORK

1.4.1 OBJECTIVE OF THE WORK

Most of the earliest work adopting the elastic approach was done for the estimation of down-drag forces in piles. However, Poulos and Davis (1973, 1980), have suggested the use of elastic approach for the design of incompressible piles, both straight-shafted and under-reamed, embedded in expansive soils. The absence of design methodology and design curves for compressible piles in swelling soils is the motivating factor for the present study. It involves the analysis of piles in cohesive soils which involves the swelling characteristics and frictional interaction at the pile-soil interfaces.

1.4.2 SCOPE OF THE WORK

The work is conducted in two parts. Part-I consists of straight-shafted piles under vertical load. A detailed parametric study of single pile and pile groups for arriving at the maximum force in the pile is carried out. The parameters considered are, the stiffness of the pile, the Poisson’s ratio of the soil, the pile spacing and the ratio of the pile length to it diameter. Besides, the influence of the depth of the active zone is also studied. For the pile groups, a flexible pile cap only is considered.

Part-II of the work involves the parametric study in respect of under-reamed piles. The influence of the ratios of the diameter of the under-ream(bulb) and the pile stem is also considered, in addition to the parameters mentioned above for the straight shafted (uniform diameter) piles.

The analysis also involves the effect of the inhomogeneity For the purpose, the Young’s modulus of the soil has been assumed to be increasing linearly with depth.
1.5 ORGANISATION OF THE THESIS

An introduction of the topic explaining the motivation, objective and scope of the work is presented in Chapter 1. A review of literature relevant to the topic of this study is presented in Chapter 2.

Chapter 3. describes the methodology adopted for the analysis, giving an insight into the elastic approach, the assumptions involved and the use of Mindlin’s equation in the determination of stresses due to subsurface loading and the Mirror image technique in detail.

In Chapter 4 of the thesis, the results of the analysis pertaining to the straight-shafted single pile and pile groups embedded in homogeneous expansive soils are presented and discussed with respect to the effect of different parameters, like the length-to-diameter ratio, the pile stiffness factor, the spacing-to-diameter in a group, the number of piles etc.,

Chapter 5 contains the results and discussions on lines similar to the above in respect of under-reamed piles.

In Chapter 6, the results of the analysis of straight-shafted single piles and pile groups embedded in non-homogeneous expansive clays, for which the Young’s modulus increases linearly with depth, are presented and discussed.

The summary of the research work and conclusions drawn from the study are presented in Chapter 7, the last and the concluding chapter.