EXPERIENCE WITH EXPANSIVE SOILS AND SHALES
IN AND AROUND CHENNAI

S.V. Ramaswamy
Professor of Civil Engineering (Retd.), College of Engineering, Guindy, Anna University, Chennai–600 025, India. 
E-mail: prof.svramaswamy@gmail.com

I.V. Anirudhan
Geotechnical Solutions, Chennai, India. E-mail: anirudhen@eth.net

ABSTRACT: Extensive construction activities are taking place in and around Chennai City in areas where the subsoil consists of residual expansive soil, transported expansive soil or shale. While residual soils have a well defined soil profile, transported soils occur in layers, one of them being the expansive type. In Chennai city soft clay or loose sand layers lie underneath expansive soils in some areas while sand layer overlies expansive soil in other areas. The thickness of each layer is a significant factor in determining the failure mode. The strength properties and consolidation characteristics of soft clay and permeability of sand have a major influence on the response of expansive clay. Expansive shale which occurs in areas south west of Chennai disintegrates on exposure to weather. It loses strength on continuous exposure to water. The distress in structures built on these soils become evident only after a considerable time has elapsed after construction. The thickness of each soil layer, their engineering properties and the environmental conditions should be carefully considered in the design and construction of foundations for lightly loaded structures such as roads, pavements, swimming pools, sumps, garages, warehouses and parking lots.

1. INTRODUCTION

Expansive soil is found in all parts of the world. The countries which reported distress of structures resting on expansive soil till 1969 were as follows: Argentina, Australia, Canada, Cuba, Ethiopia, Ghana, India, Israel, Iran, Mexico, Morocco, Myanmar, South Africa, Spain, Turkey, U.S.A., Venezuela and Zimbabwe (Chen 1970). Subsequently many nations such as China, Cyprus, Jordan, Peru and Saudi Arabia have reported the existence of swelling soils.

1.1 Residual Expansive Soil

Residual expansive soils have a well defined soil profile. There form a major proportion of expansive soils around the world. To cite an example, in Sudan they form one third of the land area of 2.6 million square meters in Sudan and these form the major soil deposit in Ethiopia (Chen 1970). However the transported expansive soils and expansive shale and clay stones also form a significant proportion of expansive soils in different countries of the world. In the north central and Rocky Mountain area of North America soil problems are primarily related to highly over consolidated clays and weathered shale. Meehan et al. (1975) have studied the distress of a number of buildings and other structures resting on clay-stone in Menlo Park, California, USA. The expansive soils which are primarily desiccated colluvial and alluvial soils of volcanic origin have been reported in California (Nelson & Miller 1995). According to Henderson (1978) swelling or expansive clay soils are usually found in lacustrine deposits of Central and Western Canada. The highly expansive soils in China are also lacustrine soils. In Israel, the highly desiccated expansive soils are lacustrine and transported soils which have undergone weathering in the new location. Salem & Kathkuda (1984) describe the process of formation of colluvial expansive soil formation in Jordan. The deposits are derived mainly from weathering of lime, marl or chert. But the underlying rock was found to be basalt. Hence they have concluded that most of the clays originated from the weathering of sedimentary rocks exposed at a higher elevation a kilometer or so to the south of the site. The weathered debris has been transported downwards in the process of hill creep and rain-wash.

1.2 Formation of Residual Expansive Soil

Deep, strongly leached red, brown and yellow soil profiles are found in tropical and sub tropical regions of the world. These are the result of long term chemical weathering in the regions of low relief, high temperatures, abundant rain fall and very good drainage. The clay minerals break down if the intense weathering continues for a sufficiently long time. The silica is released possibly due to leaching action. The remaining soils then consist largely of aluminum oxide or of hydrous iron oxides. The process is then known as laterization.

Frequently associated with the reddish soils of the tropics are very dark colored soils often called black cotton soil. The dark color of these soils is due to the presence of iron, manganese and titanium in the reduced state. These soils are formed under
conditions of poor drainage from basic rocks, or sometimes limestone under alternate wet and drying conditions (Peck et al. 1972).

Residual expansive soil deposits occupying a large portion of south and central India are weathered products developed from underlying parent rocks such as basalt, quartzite, schist or limestone. There have been extensive studies on the behavior of expansive soils in Andhra Pradesh, Karnataka and Madhya Pradesh. The thickness of the soil stratum may vary from 30 cm to 10 m. The formation of such soils is associated with poor drainage. Hence water table may be very deep. Due to the presence of clay minerals, montmorillonite or illite, the clays exhibit strong swelling and shrinkage characteristics under changing moisture conditions. The clays are plastic and sticky when wet and are very hard when dry. During summer deep cracks are developed due to heavy fissuring caused by drying. The summer soil profile of expansive soil is shown in Figure 1.

Expansive soil in India is commonly known as 'Black cotton soil”. It is one of the major regional deposits in India covering an area of about 300000 sq. km, occupying nearly 2% of the land area. Pervious gravelly layer is found over residual expansive clays and this topping depending on its thickness has significant influence on the behavior of the underlying expansive soil. Expansive clay-stone or shale can be found at the surface or at some depth below the ground level under an expansive clay layer.

1.3 Transported Expansive Soil

The profile of transported soils is complex. It can extend to a great depth below active zone. Desiccated expansive layer can overlie weak sand layers and soft clay layers. Pervious sandy layers may form the top layer over the bottom expansive clay layer.

The geologic origins of transported expansive soils are not given adequate importance in studying their behavior. Marine, alluvial and colluvial transported swelling soils have their distinctive characteristics. The behavior of transported expansive soils is greatly influenced by the permeability characteristics and strength and deformation properties of the soil layers above or below the swelling soils.

Chennai is a port city in Bay of Bengal and two minor rivers flow through the city. Transported expansive soils, alluvial and marine in origin form the major soil deposit of the city. These occur either as a surface layer over soft clay or loose sand or the bottom layer below a pervious layer.

In the surroundings of Chennai city, expansive shale and clay stone also occur extensively in addition to the soil profiles stated previously. In this paper it is proposed to discuss the foundation problems encountered in the above soil conditions in Chennai city and its surrounding areas.

2. CHENNAI AND ITS SURROUNDINGS

2.1 Adyar and Cooum Rivers

The latitude of Chennai is 13 deg N and its longitude is 80 deg W. Chennai city is traversed by two small rivers Adyar and Cooum. Adyar is a short river about 40 km long from its origin to the sea (Raj 2003). Two streams one starting near Guduvanchery and the other starting east of Sriperumbudur join near Tambaram and take the name Adyar. Surplus water from Chembarambakkam lake joins the river near Thiruneermalai. The river then takes a good shape with well defined banks. Catchment area of the river is about 800 sq km. The water flow depends on the monsoon rains. The stretch of the river within the city is about 15 km. The width of the river ranges from 60 m to 500 m near the sea coast. Regular flooding takes place during rainy season. The base flow of the river is about 1800 cu. m/sec.

Cooum river was first known as River Poonamalle and is closely associated with development of Chennai. The river is about 75 km long from its origin to the sea. It traverses for a length of 18 km within the city. The width of the river varies from 25 m to 60 m. Its flow is dependent on monsoon rains. Regular flooding takes place during monsoon seasons. The base flow of the river is about 550 cum/sec.

The two rivers flowing through Chennai, Cooum and Adyar (Figure 2) and the Bay of Bengal are responsible for the alluvial and marine deposits found in the layered soil profile that exists almost throughout the city.

Floods inundate the city and the surrounding areas every four or five years and the last flood in 2005 paralysed the life in the city for nearly fifteen days. Tsunami devastated Chennai and its surroundings in 2004, the sea encroaching into land for nearly a kilometre. Some portions of the city were under sea in the past before the sea receded. Hence alternate layers
of sand, silt and clay brought by the rivers and the sea have been deposited randomly all over the area.

The soil profile in southern parts of the city generally consists of a top layer of desiccated stiff clay underlain by either very soft clay or loose sand of very low strength. In western portions the thickness of the stiff expansive clay is large and the clay layer extends far below the active zone. In some areas of the city, such as Thiruvanmiyur, pervious layers lie above clay layer. In the surrounding areas of the city shale and clay stone layers occurring below expansive clay layer are also of concern in addition to the above soil profiles.

Transported expansive soils have similar swelling and shrinking characteristics as residual soils with respect to moisture content changes. However marine and alluvial soils have a more uniform and finer grain size distribution. These soils sometimes have a small percentage of sand or sand seams may be present in between layers of expansive soils. Sargunan et al. (1987) have concluded that the sand seams in expansive clay layers in Chennai were responsible for the greater percolation of lime slurry through the expansive soil during the lime slurry pressure injection.

2.2 Rainfall and Temperature

The rainfall particulars of Chennai are given in Figure 3. There is greater rainfall during four to five months followed by a relatively dry season of about eight months.

The annual temperature pattern of Chennai is shown and Figure 4. Chennai has a very warm climate and its average annual temperature is 28.4 deg C. The peak summer temperatures in summer may rise above 42 deg C. The difference between rainy and dry season temperatures is large in Chennai, about 8 deg (Ramaswamy & Garoma 1998).

3. RESIDUAL EXPANSIVE SOIL IN THE SURROUNDINGS

3.1 Sripurumbudur

Sripurumbudur, south west of Chennai city has very thick deposits of residual expansive clay mostly derived from complete weathering of shale and mudstone. Some areas are covered with a gravel layer of thickness varying between 0.50 m and 5.00 m. The clay is reported to have liquid limit in the range of 60% to 120% and the plasticity index 40% to 80%. The differential free swell index is 50% to 140%. The soil is very compact with N values 40 to more than 100 right form shallow depths. The soil profile is shown in Figure 5.

The in situ SPT samples when allowed for swelling just by water spray exhibited large volume changes as evident from the photographs shown in Figure 6.

Several construction activities are going on in this region for the last six to eight years. The major difficulty with this
residual swelling soil is the large thickness and very deep ground water allowing very thick dry zone in the top. There are a number of cases of distress reported from various construction sites, of which the major issues are related to the uplift of ground floor slabs and failure of underground sumps due to swelling of soil below the sump. Most of the industrial buildings have undergone progressive distress in the flooring and repeated replacements over the last few years.

The west part of Oragadam has partly weathered shale and slate formation overlain by highly weathered mudstone. Typically, the excavated hard shale slakes by one or two cycles of drying and wetting. The compacted shale cuts from excavations have shown significant heaving within few days after the laying reducing the density to much less than 60% Proctor density. The water added for compaction makes the shale pieces swell in a few days. Typical response of cores obtained from shale and mudstone at very shallow depth to just one cycle of drying and wetting is shown in Figure 8.

The exposure of large excavations to sun have resulted degeneration of the formation at a very fast rate requiring more excavations to remove the disintegrated excavation surface. Cases are reported where the excavations had to continue for few meters for ensuring a stable founding stratum.

3.2 Expansive Shale at Oragadam

Further south of Sriperumbudur, Oragadam is presently an industrial hub where thick deposits of completely weathered mudstone having high swelling potential are present. Several constructions in this area reported distress in floors such as lifting of floors and failure of ground beams resting over natural soil. The gravel cover in most of the area is very thin. The deep ground water table is also a factor in creating favorable conditions for volume change. A typical soil profile from Oragadam is shown in Figure 7.

Meehan et al. (1975) have studied the distress of a number of buildings and other structures resting on clay stone in Menlo Park, California, USA. The damage to the residential facilities had been caused by the expansive nature of underlying rock and soil. It took several years of progressive deterioration of performance of foundations, pavements, slabs and swimming pools before the problem was recognized and the remedial measures undertaken.
The problems in shale and clay stone require fairly long time before they are identified. The ingress of water into the foundation is to be prevented since the clay stone reaches a consistency of tooth paste when kept continuously in contact with water. This reduces the carrying capacity of even piles considerably. The increase in water content can also result in creation of uplift forces.

4. TRANSPORTED EXPANSIVE SOIL

4.1 Expansive Soil Extending to Great Depth

Chennai has transported expansive soil deposits extending to great depth in western portions of the city in Anna Nagar and surrounding areas. The soil profile at Anna Nagar consisted of highly plastic clay up to a depth of 4.5 m where water table was encountered. The water table fluctuated between 1.5 m to 7.0 m. Average index values are Liquid Limit = 55, Plastic Limit = 20, Plasticity Index = 35 and Shrinkage Limit = 9.5. The clay was moderately to highly expansive and the clay mineral was montmorillonite (Ramaswamy & Narasimhan 1979).

Nagaraju (1994) investigated a three storey building of area 16 x 10 m founded on reinforced strip footings. The loading was 100 kN/m. The building had undergone distress in the form of vertical and diagonal cracks (Figure 9). The distress was attributed to the heave at the centre caused by migration of moisture and shrinkage at the edges due to loss of moisture.

Ramaswamy & Narasimhan (1979) had investigated a single storey building at Anna Nagar which has undergone severe cracking

The foundation was 0.9 m wide brick masonry strip footing founded at a depth of 1.65 m. The walls were 34 cm thick and the roofing was of Madras Terrace except one room. The basement was filled with beach sand. At the time of inspection five years after construction extensive cracks have developed in all the walls and the Madras terrace roofing. In spite of the fact that the cracks had been plastered on five occasions they had reappeared. The cracks generally emanated from the windows and the Madras terrace roof was damaged so extensively as to let in sunlight. The floors have heaved noticeably in all the rooms. The site was subject to water stagnation during rainy season.

The differential heave pattern of the building is shown in Figure 10 as indicated by the plinth line at the time of inspection. The maximum level was found to be in the middle portion of the sides AB, BE, EF and FA indicating that the building had heaved in an inverted dish pattern. Severe cracking had occurred near the eastern window of the hall along the face DE. Generally maximum heaving had occurred in the portion adjacent to the kitchen. Cracks were observed both in the interior and exterior portion indicating that the differential heave had been large enough to cause damage to the structure. The maximum differential heave was found to be 7.2 cm.

Seasonal variations in moisture content in the subsoil had provided scope for heave and shrinkage causing damage to the building. The relatively heavily loaded portion containing the stair case had not suffered much damage. Similarly reinforced concrete roof was free from damage while Madras Terrace roof was heavily damaged. The flooring in spite of sand filling had cracked due to the heave of the subsoil. However the sand filling prevented the lateral thrust on the side walls in the plinth.

There was an accumulation of moisture in the interior of the building due to the construction of the relatively impervious building. The increase in water content causes a difference in water content between the centre of the building at the edges. This moisture differential is further aggravated by the loss of moisture and the edges which caused shrinkage. Mohan

Fig. 9: Diagonal Cracks in the Building at Anna Nagar (Nagaraju 1994)

Fig. 10: Differential Heave Pattern of the Building at Anna Nagar (Ramaswamy & Narasimhan 1979)
(1980) considered shrinkage as the major cause of damage to buildings in India. There is an accumulated differential movement between different parts of the building due to heave at the centre and shrinkage at the edges. It is to be noted that the moisture content can also be created by manmade factors such as leaking water taps, accumulation of drainage water on one side and breakage of water mains. Since the stiff clay extends to great depth, underreamed bored piles could have been effectively used to control heave and shrinkage.

4.2 Expansive Clay Deposit Underlain by Sand Layer

The soil profile consisting of expansive clay layer overlying sand layer occurs in some areas of the city such as Thiruvanmiyur and Ashok Nagar. Koteeswaraiyah (1984) had investigated the distress of HIG Blocks built by Tamil Nadu Housing Board at Thiruvanmiyur. The soil profile at Thiruvanmiyur consists of 0.0–0.30 m Filled up Soil, 0.30–1.5 m Brown Clay, 1.5–1.95 m Clayey Sand, 1.95–2.25 m Black Sandy Clay and below 2.25 m Black Clay. The thickness of the sand layer is relatively small. The volume change in clays was considered as the main factor for the distress. One of the factors causing the reduction in water content was the fluctuations in ground water table. There were a large number of Enterolobium Saman trees which have a huge water demand in close proximity to the blocks of buildings. It was observed that the water content in the sand clay layer is reduced to 15 percent in summer from 32 percent in winter. The root activity is confined to permeable layers.

Subash (1994) reported a case of distress of a two storey building at Ashok Nagar. The soil profile at Ashok Nagar is 0.0–1.25 m Yellow Silty Loam, 1.25–2.5 m Sand, 2.5–5.00 m Highly Plastic Clay. Severe cracks were observed at the roof level. Horizontal and diagonal cracks have been formed in the interior walls (Figure 11). There were a large number of trees surrounding the building. The cracks were attributed to the shrinkage settlements caused by withdrawal of moisture from the soil by the evapo-transpiration action of the trees.

The sand layers in the expansive clay deposits act as drainage layers. When trees are grown in such soil profile the root activity in permeable layers enable a faster and greater withdrawal of moisture from the clay layers. This results in shrinkage of sub-soil causing differential settlement of the building. The increased permeability caused by sand layers is helpful in greater diffusion of liquid additives added to improve the performance of expansive soils.

4.3 Stiff Expansive Clay Underlain by Soft Clay

4.3.1 The Site

In a number of areas in south Chennai soil profile consists of stiff expansive clay underlain by soft clay. The thicknesses of the layers vary widely between different sites. The area is approximately bounded by IIT in the west, Buckingham canal in the east, Sardar Patel Road in the north and MRTS in the south. The area extended to about 3.0 km in the north-south direction and about 1.0 km in the east-west direction (Figure 12).

The thickness of top stiff clay layer is greater at the northern boundary, about 5 to 6 m and it decreases to about one metre near the southern boundary. The clay is marine and the top portion is desiccated. However depth of desiccation varies from place to place. The area was extensively cultivated prior to 1960. Building activities in the area started in the sixties with the construction of a few single and two storey buildings as part of the Central Institutes of Technology (CIT) campus. The site investigation then consisted of trial pits of about a meter depth. The soil up to a depth of 1 to 2 m
was found to be stiff clay. Strip footings without any
reinforcement were adopted as the foundation system.

4.3.2 Reprographic Section, NITTT

The National Institute of Technical Teachers Training
(NITTT) campus is situated at the southern edge of the site.
The construction work started there in the late sixties. The
soil profile at the site essentially consisted of a top layer of
stiff clay of about 1 to 2 m thickness underlain by a soft clay
layer of very low strength of about 5 to 6 m thickness which
rests on soft rock (Figure 13).

A number of single and double storey buildings resting on
plain concrete footing were built initially and they did not
show any distress. However a water tank with its columns
resting on isolated RCC footings started tilting even during
construction possibly due to bearing capacity failure of soft
clay layer and water was not pumped in. The rehabilitation
measures were not successful in stabilizing the structure and
the tank was demolished.

As result of this experience, the building housing reprographic
section built in 1979 was founded on raft foundation. It was a
two storey building, 10.0 × 12.7 m in plan and 8 m high. The
foundation was ribbed mat-ribbed beam placed at 120 cm
depth was 160 cm deep, 40 cm wide and placed at 3.5 m
centre to centre and the mat was 22 cm thick resting 10 cm
thick mud mat and 30 cm sand cushion. The building started
settling immediately. Hence the extension to the reprographic
building, 11.6 × 12.7 m in plan and 8 m high built in 1980
was founded on pile foundations. The piles were driven to a
depth of about 10 m and were resting on rock. The buildings
were connected by an expansion joint. The building on raft
foundation settled uniformly. The differential settlement
between these two portions of about 13 cm is clearly evident
in Figure 12. No distress was observed in the portion built on
raft foundation in spite of large settlement, while panel walls
in the building on pile foundation showed several cracks.

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</thead>
<tbody>
<tr>
<td>Differential Settlement, cm</td>
<td>3.20</td>
<td>4.30</td>
<td>5.30</td>
<td>7.50</td>
<td>9.50</td>
<td>13.5</td>
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The building on raft continued to settle fairly uniformly and
now the differential settlement is of the order of 30 cm or so
as is evident in Figure 14. The building has also developed
a slight tilt. This has resulted in minor damages to the facade.

4.3.3 CPT Guest House

The Central Polytechnic (CPT) Guesthouse was one of the
seriously damaged structures (Figure 15) in the Central
Institutes of Technology (CIT) campus located approximately in
the middle of the area. The building was founded on plain
concrete footings at a depth of 1.2 m to 1.5 m. The soil
profile details (Koteeswaraiah 1984) are shown in Table 2.

Brownish sandy clay / clayey sand/
silty clay, N = 10-25

Grey and dark grey soft to very soft
clay and very soft sandy clay, N =
zero -2, (NMC=39-88%, LL=49-
110%, PI=32-77%, LI = 0.70-0.84)

Disintegrated rock, N >100

Fig. 13: Soil Profile at NITTT

<table>
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<tr>
<th>Depth</th>
<th>Soil Type</th>
<th>Soil Properties</th>
</tr>
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<tbody>
<tr>
<td>0.00 to</td>
<td>Fill</td>
<td>Sand – 2%, Silt – 19%, Clay – 79%,</td>
</tr>
<tr>
<td>0.15 m</td>
<td>Material</td>
<td>LL – 73%, PL – 24%, PI – 49%</td>
</tr>
<tr>
<td>0.15 to</td>
<td>Brown</td>
<td>Sand – 2%, Silt – 19%, Clay – 79%,</td>
</tr>
<tr>
<td>1.95 m</td>
<td>Clay</td>
<td>LL – 73%, PL – 24%, PI – 49%</td>
</tr>
<tr>
<td>1.95 to</td>
<td>Black</td>
<td>Sand – 62%, Silt – 10%, Clay – 28%</td>
</tr>
<tr>
<td>4.00 m</td>
<td>Sandy Clay</td>
<td>LL – 32%, PL – 14%, PI – 18%</td>
</tr>
</tbody>
</table>

Fig. 14: Increasing Differential Settlement between
the Two Buildings

Table 2: Soil Profile at CPT Guest House
(Koteeswaraiah 1984)
Experience with Expansive Soils and Shales in and Around Chennai

Fig. 15: Horizontal Cracks Observed at CPT Guest House (Koteeswaraiah 1984)

The top layer of brown clay was highly expansive and, 1.80 m. thick. The foundation was located within the active zone. The layer below the expansive clay was more permeable and acted as a source of water. Also the distress was noticed only some years after the construction. Chennai city experiences hot weather for about 9 months and a rainy season of about 3 months resulting in significant water content variations in the soil. Hence the distress to the building can be attributed to the swelling and shrinkage of the expansive clay layer. The Enterolobium Saman trees surrounding the building were also significant factor in causing the distress.

The rehabilitation measures initially adopted were mainly structural such as lintel beams and plinth beams. A few Enterolobium Saman trees were also cut down in an attempt to reduce shrinkage settlement. However the measures were not successful and the building was abandoned and demolished later. The damage to the structure could have been minimized or avoided if the foundation had been located below the active zone (Koteeswaraiah 1984). A new building supported by pile foundations resting on rock is performing satisfactorily.

4.3.4 Discussion

The two case histories reported herein underline the importance of proper selection of the foundation system taking into consideration possible environmental changes in the future as well as the soil profile. The two soil types that formed a major portion of the soil profile, stiff expansive clay and very soft clay, are both problematic. The selection of appropriate foundation in a particular area depended on the proper estimation of the thickness of each layer. The thickness of the top expansive clay layer varied from 0 to 1 m in the southern portion of the area to about 7 to 8 m in the northern portion (Figure 16).

The total thickness of the layers was 9 to 10 m. Hence the distress of the buildings near the southern boundary was due to the bearing capacity failure/settlement of soft clay while the swelling and shrinkage of the top stiff expansive clay layer are the dominant causes of failure near the central and northern portions (Figure 17). Problems have risen since the experience in one area was applied to other areas without adequate soil investigation.

In the case of the building housing reprographic section at NITTT, the performance of raft foundation can not be considered satisfactory. Though it was structurally safe, the settlement was beyond permissible limits. Pile foundation resting on rock performed better and was an appropriate choice. Pile foundation would have been a satisfactory choice in the case of CPT guesthouse. Underpinning of foundation by piles would have been a better retrofitting method than plinth beams and might have saved the building. Hence in the case of stratified soil profiles with layers of problematic soils it is essential that the soil more likely to cause distress is identified and a suitable foundation selected.

5. CONCLUSIONS

Residual expansive soils have generally a well defines soil profile. However the weathering process may result in a pervious layer being formed above the expansive layer.
Expansive shale or clay-stone deposits disintegrate on exposure to sun and become slushy when continuously exposed to water. The distress in structures resting on these soils are evident only after fairly long time have elapsed after construction.

Relatively large areas of transported expansive soils are found in different countries. They occur in layered soil profiles.

The behaviour of transported expansive soils is affected by their method of deposition, marine, alluvial or colluvial. Permeability characteristics and strength properties of the soil under or over the expansive soil significantly affect the field performance.

When the transported expansive soils extend to a depth below the active zone, there will be accumulation of moisture at the centre of the building causing it to heave while there will be depletion of moisture at the edges causing it to shrink. The resulting differential movement causes damage to the building. Under reamed bored piles will perform satisfactorily in such soils if the depth of expansive soil can provide sufficient anchorage.

When the transported expansive layer is underlain by sand, the permeability of sand increases the rate of inflow and outflow of water from the expansive soil. Shrinkage settlements can cause damage to the structures when there is a lowering of ground water table in summer. Vegetation near the building will also cause damage since sand layers facilitate easy withdrawal of water by tree roots.

When the transported soil is underlain by weak sand or soft clay, it is essential to identify the soil layer which will cause damage. The thicknesses of each layer have to be properly estimated. A calculated judgement has to be made whether swelling or shrinkage of expansive soil or bearing capacity or settlement of the weak soils will be the controlling factor before selecting a suitable foundation.

REFERENCES


