

FOUNDATIONS ON COLLAPSIBLE AND EXPANSIVE SOILS: AN OVERVIEW

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Abstract: *This study discusses various types of problems associated for constructing engineering projects when the soil consists of collapsible and expansive soils. Collapsible soils and expansive soils causes heavy damages to civil engineering structures like buildings, roads, runways, pipe lines etc., These soils are subject to changes in volume and settlement in response to wetting and drying and resulting in severe damage to structures. Expansive soils in India are popularly known as Black cotton soils. Black cotton soils accounts about 20% of land area in India and are predominantly located in the Deccan trap covering the states. Most Indian Black cotton soils are rich in Montmorillonite, this mineral is responsible for swell-shrink behaviour of the soil. Collapsible soils make the construction of foundations extremely difficult in its natural state. It may cause high differential movements in structures through collapse settlement. Therefore, to study soil replacement technique taking into consideration geotechnical requirements and cost to achieve the optimum replacement layer thickness corresponding to minimum cost of foundation works and reduce the collapse settlement under foundation as well.*

Keywords: *Expansive soils, collapsible soils, problems, soil improvement methods, re-compaction, soil replacement techniques.*

I.INTRODUCTION

Soils are unconsolidated materials, composed of solid particles, produced by the disintegration of rocks. Soils are formed by weathering of rocks due to mechanical disintegration or chemical decomposition. Physical disintegration or mechanical weathering of rocks occurs due to the physical processes like temperature changes, wedging of ice, spreading of roots of plants, abrasion. In all the processes of physical disintegration, there is no change in the chemical composition. The soil formed has the properties of the parent rock. Coarse grained soils, such as gravel and sand, are formed by the process of physical disintegration. When chemical decomposition or chemical weathering of rocks takes place, original rock minerals are transformed into new minerals by chemical reactions. The soils formed do not have the properties of the parent rock. The chemical processes generally occur in nature are hydration, carbonation, oxidation, solution, hydrolysis. Chemical composition of rocks results in formation of clay minerals. These clay minerals impart plastic properties to soils. Clayey soils are formed by chemical decomposition.

Major soil deposits in India are (1) Alluvial deposits: A large part of north India is covered with alluvial deposits. The thickness of alluvium in the Indo-Genetic and Brahmaputra flood plains varies from a few metres to more than one hundred metres. Even in the peninsular India, alluvial deposits occur at some places. (2) Black cotton soils: A large part of central India and a portion of South India is covered with black cotton soils. These soils are residual deposits formed from basalt or trap rocks. The soils are quite suitable for growing cotton. (3) Lateritic soils: Lateritic soils are formed by decomposition of rock, removal of bases and silica, and accumulation of iron oxide and aluminium oxide. The presence of iron oxide gives these soils the characteristic red or pink colour. These are residual soils, formed from basalt. Lateritic soils exist in the central, southern and eastern India. (4) Desert soils: A large part of Rajasthan and adjoining states is covered with sand dunes. In this area, arid conditions exist, with practically little rainfall. (5) Marine Deposits: Marine deposits are mainly confined along a narrow belt near the coast. In the south-west coast of India, there are thick layers of sand above deep deposits of soft marine clays.

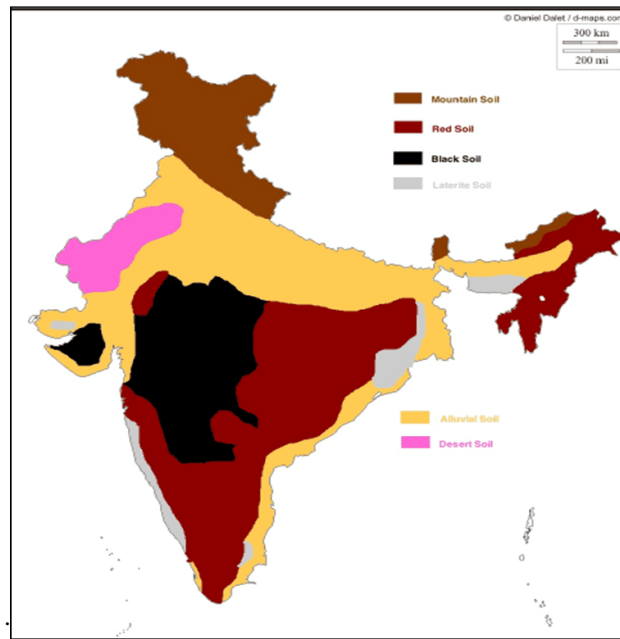


Fig 1: Major soil deposits in INDIA

Geology and climate play significant roles in the distribution of these problematic soils. Soils capable of expansion can occur in both tropical and arid climates; however, those located in arid and semi-arid regions are subject to more extreme cycles of expansion and contraction than those located in more consistently moist areas. Collapsible soils are most often encountered in arid climates, where wind and intermittent streams deposit loose sediment (Mulvey, 1992, Rollins et al., 1992).

Expansive and collapsible soils are some of the most widely distributed and costly of geologic hazards. These soils are subject to changes in volume and settlement in response to wetting and drying, often resulting in severe damage to structures.

EXPANSIVE SOILS

Some soils undergo slow volume changes when change water content that occur independently of loading and are attributable to swelling or shrinkage. These volume changes can give rise to ground movement which can cause damage to low-rise buildings that they don't have sufficient weight to resist. These soils also represent a problem when they are encountered in road construction, and shrinkage settlement of embankments composed of such clays can lead to cracking and breakup of the roads they support. Construction damage is notable, especially where expansive clay forms the surface cover in regions which experience alternating wet and dry seasons leading to swelling and shrinkage of these soils. The principle cause of expansive soils is the presence of swelling clay minerals such as Montmorillonite. The potential for volume change in soil is governed by its initial moisture content; void ratio and vertical stress as well as the amount and type of clay minerals. Cemented or undisturbed expansive soils have a high resistance to deformation. Therefore, remoulded expansive soils tend to swell more than undisturbed ones. Expansive or swelling soils usually are those types of soil that swell when they are subjected to moistures or partially saturated. Also, these types of soils shrink due to losing moisture contents. Generally, their plasticity indices range high and their bearing capacities differ from when wetted with when dried. These soils are mostly found in arid and semiarid areas and contain large amount of clay minerals. Expansive soils are found in large areas of southwest and western United States including Oklahoma, Texas, Colorado, Nevada, California, Utah, and others. These soils are also found in large areas of India, and Australia (sometimes called black cotton soils), South America, Africa, and the Middle East (Bowels, 1988; Kalantari, 1991; Murphy, 2010).

III. COLLAPSIBLE SOILS

A collapsible soil is also known as loess. It is basically a clayey silt with a metastable structure. Collapsible soil shows high strength and stiffness at normal water content conditions. On the other hand, upon wetting it suffers a sudden plastic deformation, i.e., collapse, which could be severe in some cases (wesi-geotechnica).

Collapsible soils consist of loose, dry, low-density materials that collapse and compact under the addition of water or excessive loading. These soils are distributed throughout the southwestern United States, specifically in areas of young alluvial fans, debris flow sediments, and loess (wind-blown sediment) deposits. Soil collapse occurs when the land surface is saturated at depths greater than those reached by typical rain events. This saturation eliminates the clay bonds holding the soil grains together (Mulvey, 1992). Like expansive soils, collapsible soils result in structural damage such as cracking of the foundation, floors, and walls in response to settlement. In one case of soil collapse, 14 houses in a Cedar City, Utah neighbourhood had to be jacked off their foundations and relocated due to severe settlement (Rollins et al., 1992). Human activities that facilitate soil collapse include: Irrigation; Water impoundment; Watering the lawn; Changing the natural drainage; and Disposal of wastewater.

IV. PROBLEMS ASSOCIATED WITH EXPANSIVE SOILS

A large part of the central India a part of the south India is covered with expansive soils. Although these soils are good for growing cotton, they are treacherous for foundations of structures. Heavy damages may occur to buildings, roads, runways, pipe lines and other structures built on such soils if proper preventive measures are not adopted. The damages can be prevented to a large extent if the characteristics of the expansive soil are properly assessed and suitable measures are taken in the design, construction and maintenance of structures built on expansive soils.

Problems often associated with expansive soils include: Foundation cracks; Heaving and cracking of floor slabs and walls; Jammed doors and windows; Ruptured pipelines; and Heaving and cracking of sidewalks and roads.

Geologists work with geotechnical engineers to evaluate soil and rock prone to shrinking and swelling. These areas are mapped and denoted for their expansion potential. Expansive soil and rock are removed and replaced with non-expansive materials to provide a suitable foundation for new structures. Expansive materials can also be chemically treated, preloaded, or prewetted to decrease swell potential (Engineering and Environmental Geology of Southwestern Utah, Utah Geological Association Publication 21, K.M. Harty, Editor, 1992.)

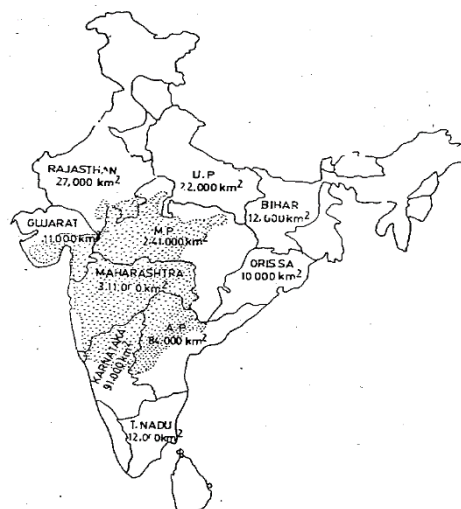


Fig 2: Area covered by expansive soils in different states of India



Fig 3: Photograph of expansive soils under very dry conditions. Severe soil shrinkage has resulted in desiccation cracks

V. PROBLEMS ASSOCIATED WITH COLLAPSIBLE SOILS

A collapsible soil suddenly decreases in volume when it becomes saturated. Collapsible soils are generally aeolian (wind-deposited) soils which have low water content and high void ratio in natural state. Such soils usually have a honey-comb structure in which porous structure is maintained by a water-soluble interparticle bond. When the water content of the soil is increased, the interparticle bond is broken and the soil mass suddenly decreases in volume causing its collapse. Buildings and other structures constructed on a collapsible soil have large settlements causing damage. Roads, highways, pipelines and other utilities constructed on such soils have maintenance problems (Dr K R Arora).

Human activities that facilitate soil collapse include: Irrigation; Water impoundment; Watering the lawn; Changing the natural drainage; and Disposal of wastewater.

Geologists work with geotechnical engineers to identify soils prone to collapse and evaluate their potential to fail under loading and/or saturation. Collapsible soil be removed and replaced with approved and properly compacted materials. Collapsible materials can also be saturated (hydro compaction) to force the soils to collapse prior to construction.

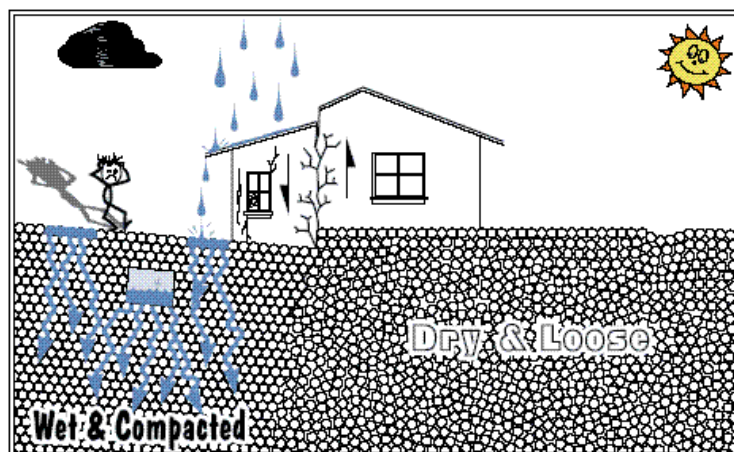


Fig 4: Showing depicting foundation failures as the result of collapsible soils

Conditions in arid and semi-arid climates favour the formation of the most problematic collapsible soils. The mechanisms that account for almost all naturally occurring collapsible soil deposits are debris flows, rapid alluvial depositions, and wind-blown deposits(loess). Collapsible soils are moisture sensitive in that increase in moisture content is the primary triggering mechanism for the volume reduction of these soils. One result of urbanization in arid regions is an increase in soil moisture content. Therefore, the impact of development-induced changes in surface and groundwater regimes on the engineering performance of moisture sensitive arid soils, including collapsible soils, becomes a critical issue for continued sustainable population expansion into arid regions. In practicing collapsible soils engineering, geotechnical engineers are faced with (1) identification and characterization of collapsible soil sites, (2) estimation of the extent and degree of wetting, (3) estimation of collapse strains and collapse settlements, and (4) selection of design/mitigation alternatives (SANDRA L. HOUSTON).

VI. GENERAL METHODS FOR FOUNDATIONS ON EXPANSIVE SOILS

Many researchers such as Peck et al. (1974), Bowels (1988), Kalantari (1991) and Murphy (2010) propose three general methods to prevent structural damages to newly constructed buildings when expansive soils are present (Behzad Kalantari).

1. Elimination or reduction of swelling
2. Use of sufficiently strong structures that will remain undamaged despite the swelling
3. Isolating the structure from the swelling soil

Each of the mentioned methods can also describe one or several techniques that are explained with more details in the following sections.

1. Elimination or reduction of swelling: Elimination or reduction of swelling soil may be described in three ways:
 - I. Replacing the expansive soil
 - II. Changing the nature of soil
 - III. Controlling the water content of subsoil foundation
2. Use of sufficiently strong structures that will remain undamaged despite swelling: Structures capable of remaining undamaged and undisturbed despite being supported directly on expansive soil must possess great strength and rigidity. It is possible to describe this type of technique to combat swelling problem of expansive soils in two ways:
 - I. Controlling the direction of expansion
 - II. Loading the soil to sufficient pressure intensity to balance swell pressure
3. Isolating the structure from the swelling soil: This type of construction technique suggests the use of deep foundations (piles and/or piers) with a suspended floor slab, that the structure will be independent of the soil damaging movement. Use of deep foundations in expansive soils is one of the most widespread techniques.

VII. GENERAL METHODS FOR FOUNDATIONS ON COLLAPSIBLE SOILS

If the compressible soil is susceptible to wetting, it will collapse after construction some time later. To avoid foundation failure, preventive measures are adopted before the construction. Some of the commonly used methods are given below:

1. Re-compaction: If the expected depth of wetting is up to about 1.5m from the ground surface, the collapsible soil moistened before the construction of the foundation. The moist soil is compacted by heavy rollers. Spread footings and rafts may be constructed on the compacted soil. An alternative to re-compaction by rollers is to use heavy tamping (or pounding). About 8 to 30m drop of the ponder is generally effective in the densification of the soil.
2. Chemical solution: In this method, the foundation trenches are filled with a solution of sodium silicate and calcium chloride to stabilise the soil chemically. After stabilisation, the collapsible soil behaves like a soft sand stone and resists collapsible after saturation. However, the method is effective only when the solution can penetrate the collapsible soil at the side walls and base of the foundation trench to the desired depth. The method is quite effective for fine sands.
3. Chemical injection: A sodium silicate is injected into a collapsible soil deposit. However, this method is effective only for soils that are likely to compress under the weight of the structure to be built on these soils. This method has been effectively used in the former Soviet Union.

For the compressible soils susceptible to wetting to a depth of greater than 1.5m, the following methods are quite effective.

1. Ponding: In this method, low dikes are constructed around the construction site and the whole site is flooded with water to cause collapsible of the soil before the construction is started. However, this method is effective only when there is an impervious stratum beneath the collapsible soil deposit to prevent seepage.
2. Vibro-flotation: Vibro-flotation is used to compact the collapsible soil before construction. This method is effective only for free-draining soils.

3. Rock-columns: Rock columns are like stone columns but instead of gravel, large boulders are used in the construction. The large boulders penetrate the collapsible soil deposit and act like piles. They transfer the load of the structure to stable soil layers beneath the collapsible soil.
4. Drilled piers and piles: For the compressible soils susceptible to wetting to large depths, pre-collapsing becomes difficult. In such cases, foundations are extended beyond the zone of possible wetting using drilled piers and piles. The design of drilled piers and piles must consider the negative friction caused due to collapsible soils. The design should also consider the settlements after wetting.
5. Control of drainage: Potential water sources which causes wetting may be controlled by providing suitable drainage. If necessary impervious membranes can be used to stop seepage. Sometimes, infiltration wells are used for drainage. Construction of foundations on a collapsible soil is a challenging task. The geotechnical engineer may use any of the above methods depending upon the experience and the site conditions. Sometimes, combination of two or three method may be required.

VIII.SOIL REPLACEMENT TECHNIQUES

Soil replacement is one of the most familiar techniques in dealing with collapsible soils. It is implemented by removing the weak soil and replacing it with a better compacted soil. Unfortunately, the determination of replacement layer thickness is questionable because it is based on experience (Morsy, Osama, Bassioni, Hesham, Mostafa, Tareq).

Rollins and Rogers reported that this method offers several advantages, the first that it decreases the amount of collapsible material in the zone of significant stress, the second that it increases the depth to which water must percolate before reaching collapsible material, and the third that it decreases the induced stress to which the collapsible soil is subjected. This reduction in the induced stress many keep the stress below the critical value necessary to produce significant collapse settlement. In addition, this technique minimizes the differential settlement under the footing.

Experimental tests had been also conducted on circular footing resting on collapsible soil and water could infiltrate into soil from the bottom. Using compacted sand cushion with thickness equals twice the footing diameter resulted in a significant reduction in collapse settlement.

Naema, Ali proved that the improvement of collapsible soils by sand/crushed stone replacement is possible to control/mitigate their risk potentials against sudden settlement when exposed to water. She also found that the soil replacement with compacted cohesion less soil reduces the foundation settlement by about 50% and increases bearing capacity by about 100%. The subgrade should be improved with compaction and pre-wetting before placing the top compacted sand replacement to obtain good results of higher bearing capacity, and low and uniform settlement. The most effective thickness for the compacted sand layer, within the tested range, was found to be equal to the plate width.

IX.CONCLUSION

There are many available improvement techniques that can be used for the purposes of increasing bearing capacity and decreasing settlement of collapsible soil such as soil replacement, prewetting, stone columns, stabilization with additives and dynamic compaction. Most of researches investigated the effect of using different soil improvement techniques on increasing soil bearing capacity and /or decreasing the expected settlement while, there is a lack of researches which consider the cost of foundation works as one of the governing factors when selecting between different soil improvement techniques. Using compacted sand cushion with thickness equals twice the footing diameter resulted in a significant reduction in collapse settlement. Determining of physical properties such as dry density and liquid limit of soils can be helpful to identify collapse potential of soils. High Expansive Black cotton soil can be effectively utilized as a Geo technical material by addition of 30-40% fly ash and 6-10% cement. At these dosage of admixtures, the Black cotton soil can be behaving non-plastic and non-swelling can reduce the problems of volume change (Jaya Prakash Babu.V). According to Miss Kapilani S. Gaikwad, Lime-stabilization of geo-materials by producing cohesive materials in the soil increases the strength and decreases materials plastic properties. This is why these materials can be used for projects where high strength and high-performance materials are desirable. The increase in strength of lime stabilized materials in compression as well as in tension is attributed to the reactions between clay particles and lime. The clay content of lime-stabilized materials can affect the strength of the materials. The clay-lime compound provides the cemented material in soil.

X.ACKNOWLEDGEMENT

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