
INTRODUCTION

Expansive soil is a term generally applied to any soil or rock material that has a potential for shrinking or swelling under changing moisture conditions. When a soil is referred to in this book as *expansive* or when reference is made to *swell potential* it should be recognized that there also exists a potential for shrinking or settlement to occur due to changes in moisture content. Thus, the terms *expansive soil* and *swell potential* will generally be used in a universal sense to refer to soils that both shrink and swell. This does not include, however, the class of soils generally referred to as *collapsible* soils.

The primary problem that arises with regard to expansive soils is that deformations are significantly greater than elastic deformations and they cannot be predicted by classical elastic or plastic theory. Movement is usually in an uneven pattern and of such a magnitude as to cause extensive damage to the structures and pavements resting on them.

Expansive soils cause more damage to structures, particularly light buildings and pavements, than any other natural hazard, including earthquakes and floods (Jones and Holtz, 1973). In a special report published by the Federal Emergency Management Agency, the following figures were cited (FEMA, 1982).

Selected annual U.S. losses from expansive soils were \$798.1 million in 1970 and are expected to rise to \$997.1 million by the year 2000 (Wiggins et al., 1978; Petak et al., 1978). These values are for *residence losses only*. Loss figures were developed on a consistent base using constant 1970 replacement dollars.

The cost of damage to other structures such as commercial/industrial buildings and transportation facilities raises these total estimated values by a factor of 2 to 3.

The Department of Housing and Urban Development (Jones, 1981) estimated average annual losses due to shrink-swell phenomena as \$9 billion in 1981. A rank-ordered

list of hazards showed shrink–swell phenomena to be second, below insect damage, as the most likely natural hazard to cause economic loss. Jones' estimates were based partially on subjective judgements and, in part, on documentation. Documented evidence is limited, especially since this problem is not generally considered for official disaster declaration by federal or state agencies and losses are not generally covered by insurance. (An exception to this was the 1980 disaster declaration in Tulsa, Oklahoma, where extended drought caused shrinkage damage to residences in that area to such an extent that relief funding was made available through the Small Business Administration.)

Although the estimation of damage is inexact and somewhat subjective, even the most conservative estimates show that expansive soils are a major contributor to the burden that natural hazards place on the economy. Despite the fact that billions of dollars in yearly damage losses have been attributed to these problem soils, the state of the practice in design and construction is severely limited by continued lack of understanding of expansive soil behavior and soil–structure interaction. Also, a greater appreciation of risks associated with building on expansive soils must be developed on the part of owners, lending institutions, regulatory officials, builders, architects, and engineers. Loss mitigation, through responsible engineering and construction, is essential in helping to alleviate the risk from this natural hazard. The first steps in mitigation are to recognize the problem and understand the preventive options that are available. The next step, which is essential, is to provide careful, responsible engineering and construction. Research is also important, as it provides knowledge and data for input into understanding of phenomena and design.

1.1 PURPOSE

The purpose of this book is to provide a source of information for concerned individuals involved in all phases of investigation, design, construction, marketing, ownership, and repair of structures built on expansive soils. Techniques available for dealing with the problems associated with design and construction are presented, and reliable methods are pointed out. However, in each situation there will continue to be a degree of uncertainty. The current technology is not at a stage where a guarantee of “absolutely no damage” can be assured by design and construction practices. Through good understanding of the problems and phenomena, engineers should be capable of addressing the differences in risk associated with alternative solutions and communicating level of risk to their clients.

1.2 ORGANIZATION

The book is organized to follow, to the extent possible, the chronology of events and potential stages of investigation and design in the life of a structure founded on expansive soils.

Chapter 2 reviews the factors that affect swelling and shrinking of soils, and describes the site characterization process for assessing those factors. The factors affecting soil volume change are discussed in relation to soil properties, environmental effects, and state of stress. Methods of sampling expansive soils are discussed, and field techniques for evaluating expansive soil sites are summarized.

Laboratory identification tests and classification schemes are presented in Chapter 3. Many methods are available for reliably and inexpensively identifying soils that have expansion potential. Identification test procedures and classification schemes are summarized.

Chapter 4 presents methods for quantitatively predicting the amount of potential soil heave that can occur. Availability of water is a primary factor governing the potential magnitude and rate of soil movement. Therefore, environment must be considered in prediction of heave. Chapter 4 presents theoretical considerations, testing methods, and environmental factors that are important in heave prediction.

Design alternatives are presented in Chapter 5. Alternatives must be assessed according to many factors, such as site conditions, groundwater and soil characteristics, and costs. Advantages and disadvantages must be considered and an acceptable level of risk must be determined. In Chapter 5, alternatives related to both structural features and treatment are listed. Constraints associated with the alternatives are presented so that risks can be assessed for the conditions that exist. Foundation alternatives for buildings and treatment alternatives for highway subgrades are treated separately.

Soil treatment methods are discussed in Chapter 6. The appropriate type of treatment depends on the soil and environmental conditions, and the degree of risk the owner is willing to assume. Much research and some application of these techniques have been performed on federal government projects, in university studies, and in the construction industry. The recommendations made in this report regarding applicability and effectiveness of various methods of treatment under particular conditions are based on reports from these projects and interviews with consultants, builders, and investigators in academia and government.

Chapter 7 deals with remedial measures for structures that have been damaged by expansive soil movements. It is an important fact that remedial measures, such as releveling buildings or repaving highways and roads, typically cost far more than any initial "savings" that may have been realized from inadequate design and construction. Remedial work begins with a diagnosis of the problem. Diagnostic procedures are discussed. Example formats for diagnostic data gathering and reports are suggested and some remedial measures that have been used for different foundation types and for pavement systems are described and assessed for effectiveness and cost. The selection of a repair alternative must be based on an assessment of acceptable future risk. There frequently must be a compromise between the parties involved, particularly if those paying the repair costs are not those benefiting from the repairs. In many situations, there is disagreement about what constitutes failure. Some recommendations and comments about these aspects of acceptable risk are included in this section.

1.3 GENERAL CONSIDERATIONS

The major concern with expansive foundation soils in North America exists generally in the western and midwestern United States and Canada, and the Gulf States. In the course of preparing this book, consulting firms in a number of different locations in North America were visited. These include the Front Range area in Colorado; Tulsa, Stillwater, and Oklahoma City, Oklahoma; Dallas, Fort Worth, and Houston, Texas; Los Angeles and San Diego, California; Orlando and Gainesville, Florida; Minneapolis, Minnesota; Fargo and Minot, North Dakota; and Regina and Saskatoon, Saskatchewan, Canada.

Although expansive soils are encountered in nearly every state and province of the United States and Canada, the potential problems related to expansive soils in the northeastern areas are not as severe or widespread as problems encountered in the western and southern regions. In general, expansive soil problems may be categorized into different geographic areas. In the north-central and Rocky Mountain areas of North America, including North and South Dakota, Montana, Wyoming, Colorado, Alberta, and Saskatchewan, the expansive soil problems are primarily related to highly overconsolidated clays and weathered shales. In these areas, the foundation and pavement problems relate primarily to swelling as a result of increased moisture content after construction. In general, the time required for swelling to take place is relatively long, being on the order of 5 to 8 years. Rebound of these soils by unloading due to excavation may be another factor contributing to swell.

In eastern Oklahoma, eastern Texas, Florida and the Gulf States, and the Great Lakes and Lake Agassiz areas, the problem includes both shrinking and swelling. In those areas, moisture fluctuations over the different seasons cause shrinking during drier periods and swelling when they are wetted again. Volume change can take place over relatively short periods of time ranging from a few hours to many years.

In central and western Texas and western Oklahoma the problems include both swelling of overconsolidated, desiccated soils as well as shrinking. In Minnesota some expansive soil problems exist in the Cretaceous shales found primarily in the southeast and south central portions of the state.

In the southern California area the problem is primarily one of desiccated alluvial and colluvial soils. Many of the soils have a volcanic origin and have been desiccated in the natural state. Development construction is generally accompanied by irrigation around houses and buildings. The additional irrigation water causes swelling problems to occur. In this area, swelling can occur even after relatively short periods of time.

Foundation types range from shallow to deep foundations and the choice of a foundation depends to a large extent on the life styles and irrigation practices in the local area. Also, the amount of grading that is done during development of a site varies from place to place, depending on topography. In general, the warmer areas such as Texas, Florida, and California do not utilize basements under houses. In these areas, shallow foundations and slabs on grade are commonly used foundation systems. In the northern areas, basements have become common because of the

need for furnaces and heating equipment. Deep foundations utilizing pier and grade beam construction are utilized more frequently in those areas.

Pavement systems, and canal and pipeline projects often utilize soil treatment methods. Large-scale applications of moisture barriers, lime and cement stabilization, and other techniques have been used by the state highway departments of Texas, New Mexico, Colorado, Mississippi, California, and Arizona. Large federal projects also have applied soil treatment methods for canals and for commercial and military airfields.

Site investigation and design practices vary from location to location, but within a particular area, local practices appear to be fairly similar to one another. Also, the degree of awareness on the part of the public and the engineering community varies from place to place. The engineering community is becoming more aware of the existence of expansive soils and their locations. As a result, more problems are diagnosed correctly, whereas in earlier years many expansive soils problems were incorrectly attributed to settlement.

Of major importance is the need to make owners aware of the potential problems that may exist and the fact that money spent on proper investigation and design is a worthwhile investment. In that regard the following quote is very appropriate (Krazynski, 1979):

To come even remotely close to a satisfactory situation, trained and experienced professional geotechnical engineers must be retained to evaluate soil conditions. The simple truth is that it costs more to build on expansive soils and part of the cost is for the professional skill and judgement needed. Experience also clearly indicates that the cost of repairs is very much higher than the cost of a proper initial design, and the results are much less satisfactory.