CHAPTER 1

INTRODUCTION

1-1. Purpose

This manual presents guidance and information for the geotechnical investigation necessary for the selection and design of foundations for heavy and light military-type buildings constructed in expansive clay soil areas. The information in this manual is generally applicable to many types of structures such as residences, warehouses, and multistory buildings. Emphasis is given to the maintenance of an environment that encourages constant moisture conditions in the foundation soils during and following construction. Special attention must always be given to specific requirements of the structure such as limitations on allowable differential movement.

a. The guidance and information provided in this manual can significantly reduce the risk of undesirable and severe damages to many structures for numerous expansive soil conditions. However, complete solutions for some expansive soil problems are not yet available; e.g., the depth and amount of future soil moisture changes may be difficult to predict.

b. This manual presents guidance for selecting economical foundations on expansive soil to minimize structural distress to within tolerable levels and guidance for minimizing problems that may occur in structures on expansive soils.

1-2. Scope

a. Guidelines of the geotechnical investigation and analysis necessary for selection and design of military-type buildings constructed in expansive clay soil areas, as outlined in chapters 2 to 5, consist of methods for the recognition of the relative magnitude of the swelling soil problem at the construction site, field exploration, laboratory investigations, and application of methodology for prediction of volume changes in swelling foundation soils. Chapter 6 presents guidance for selection of the type of foundation with structural details of design procedures provided for reference. Chapters 7 to 9 discuss methods of minimizing foundation movement, construction techniques and inspection, and considerations for remedial repair of damaged structures.

b. Guidance is not specifically provided for design of highways, canal or reservoir linings, retaining walls, and hydraulic structures. However, much of the basic information presented is broadly applicable to the investigation and analysis of volume changes in soils supporting these structures and methods for minimizing potential soil volume changes. Guidance is also not specifically provided for the design of structures in areas susceptible to soil volume changes from frost heave and chemical reactions in the soil (e.g., oxidation of iron pyrite), although much of the information presented can be useful toward these designs.

1-3. Background

This manual is concerned with heave or settlement caused by change in soil moisture in nonfrozen soils. Foundation materials that exhibit volume change from change in soil moisture are referred to as expansive or swelling clay soils. Characteristic expansive or swelling materials are highly plastic clays and clay shales that often contain colloidal clay minerals such as the montmorillonites. Expansive soils as used in this manual also include marls, clayey siltstones, sandstones, and saprolites.

a. Damages from differential movement. The differential movement caused by swell or shrinkage of expansive soils can increase the probability of damage to the foundation and superstructure. Differential rather than total movements of the foundation soils are generally responsible for the major structural damage. Differential movements redistribute the structural loads causing concentration of loads on portions of the foundation and large changes in moments and shear forces in the structure not previously accounted for in standard design practice.

b. Occurrence of damages. Damages can occur within a few months following construction, may develop slowly over a period of about 5 years, or may not appear for many years until some activity occurs to disturb the soil moisture. The probability of damages increases for structures on swelling foundation soils if the climate and other field environment, effects of construction, and effects of occupancy tend to promote moisture changes in the soil.

c. Structures susceptible to damages. Types of structures most often damaged from swelling soil include foundations and walls of residential and light (one- or two-story) buildings, highways, canal and reservoir linings, and retaining walls. Lightly loaded one- or two-story buildings, warehouses, residences, and pavements are especially vulnerable to damage because these structures are less able to suppress the differential heave of the swelling foundation soil than heavy, multistory structures.

(1) *Type of damages.* Damages sustained by these structures include: distortion and cracking of pavements and on-grade floor slabs; cracks in grade beams, walls, and drilled shafts; jammed or misaligned doors and windows; and failure of steel or concrete plinths (or blocks) supporting grade beams. Lateral forces may lead to buckling of basement and retaining walls, particularly in overconsolidated and nonfissured soils. The magnitude of damages to structures can be extensive, impair the usefulness of the structure, and detract aesthetically from the environment. Maintenance and repair requirements can be extensive, and the expenses can grossly exceed the original cost of the foundation.

(2) *Example of damages. Figure* 1-1 illustrates damages to a building constructed on expansive soil with a deep water table in the wet, humid climate of Clinton, Mississippi. These damages are typical of buildings on expansive soils. The foundation consists of grade beams on deep drilled shafts. Voids were not provided beneath the grade beams above the expansive foundation soil, and joints were not made in the walls and grade beams. The floor slab was poured on-grade with no provision to accommodate differential movement between the slab and grade beams. The heave of the floor slab exceeded 6 inches. The differential soil movement and lack of construction joints in the structure aggravated cracking.

14. Causes and patterns of heave

a. Causes. The leading cause of foundation heave or settlement in susceptible soils is change in soil moisture, which is attributed to changes in the field environment from natural conditions, changes related to construction, and usage effects on the moisture under the structure (table 1-1). Differential heave may be caused by nonuniform changes in soil moisture, variations in thickness and composition of the expansive foundation soil, nonuniform structural loads, and the geometry of the structure. Nonuniform moisture changes occur from most of the items given in table 1-1.

b. Patterns of heave.

(1) *Doming heave.* Heave of foundations, although often erratic, can occur with an upward, long-term, dome-shaped movement that develops over many years. Movement that follows a reduction of natural evapotranspiration is commonly associated with a doming pattern of greatest heave toward the center of the structure. Evapotranspiration refers to the evaporation of moisture from the ground surface and transpiration of moisture from heavy vegetation into the atmosphere. Figure 1-2 schematically illustrates some commonly observed exterior cracks in brick walls from doming or edgedown patterns of heave. The pattern of heave generally causes the external walls in the superstructure to lean outward, resulting in horizontal, vertical, and diagonal fractures with larger cracks near the top. The roof tends to restrain the rotation from vertical differential movements leading to additional horizontal fractures near the roofline at the top of the wall. Semiarid, hot, and dry climates and deep water tables can be more conducive to severe and progressive foundation soil heaves if water become available.

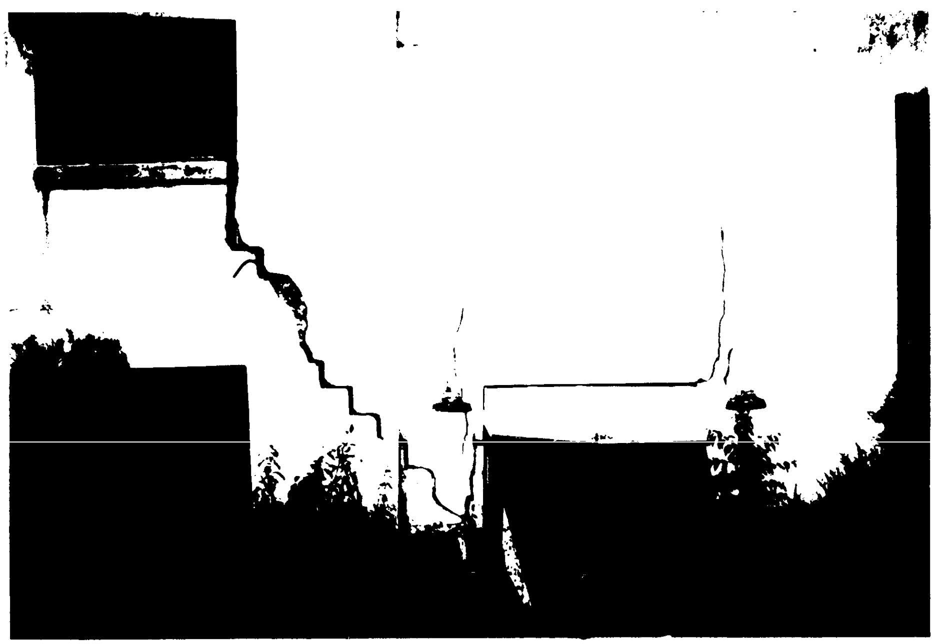
(2) *Cyclic heave.* A cyclic expansion-contraction related to drainage and the frequency and amount of rainfall and evapotranspiration may be superimposed on long-term heave near the perimeter of the structure. Localized heaving may occur near water leaks or ponded areas. Downwarping from soil shrinkage (fig. 1-2) may develop beneath the perimeter during hot, dry periods or from the desiccating influence of trees and vegetation located adjacent to the structure. These edge effects may extend inward as much as 8 to 10 feet. They become less significant on well-drained land. Heavy rain periods may cause pending adjacent to the structure with edge lift (fig. 1-3) and reversal of the downwarping.

(3) *Edge heave.* Damaging edge or dish-shaped heaving (fig. 1-3) of portions of the perimeter maybe observed relatively soon after construction, particularly in semiarid climates on construction sites with preconstruction vegetation and lack of topographic relief. The removal of vegetation leads to an increase in soil moisture, while the absence of topographic relief leads to ponding (table 1-1). A dish-shaped pattern can also occur beneath foundations because of consolidation, drying out of surface soil from heat sources, or sometimes lowering of the water table. Changes in the water table level in uniform soils beneath uniformly loaded structures may not contribute to differential heave. However, structures on a deep foundation, such as drilled shafts with a slab-on-grade, can be adversely affected by a changing water table or changes in soil moisture if the slab is not isolated from the perimeter grade beams and if internal walls and equipment are not designed to accommodate the slab movement.

(4) *Lateral movement.* Lateral movement may affect the integrity of the structure.

(a) Lateral thrust of expansive soil with a horizontal force up to the passive earth pressure can cause bulging and fracture of basement walls. Basement walls and walls supporting buildings usually cannot tolerate the same amount of movement as free-standing retaining walls. Consequently, such walls must be designed to a higher degree of stability.

a. Vertical cracks



b. Diagonal and vertical cracks

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Figure 1-1. Examples of cracks in an exterior wall.

(*b*) The walls and foundations of structures constructed on slopes greater than 5 degrees (9 percent) may experience damage from downhill soil creep of cohesive expansive soils. Downhill creep can also shear shaft foundations. The mechanism of creep may be such that the soil alternately expands and contracts aided by gravity. The depth of creeping soil varies from a few inches to several feet.

Table 1-1. Examples of Causes of Foundation Heave from Changes in Soil Moisture

Changes in field environment from natural conditions	1.	Significant variations in climate, such as long droughts and heavy rains, cause cyclic moisture changes resulting in edge movement of structures.
	2.	Changes in depth to the water table lead to changes in soil moisture.
	3.	Frost heave and chemical reactions in the soil, such as oxidation of iron pyrite, noted.
Changes related to construction	1.	Covered areas reduce natural evaporation of moisture from the ground increasing soil moisture.
	2.	Covered areas reduce transpiration of moisture from vegetation increasing soil moisture.
	3.	Construction on a site where large trees were removed may lead to an increase of moisture because of prior depletion of soil moisture by the extensive root system.
	4.	Inadequate drainage of surface water from the structure leads to ponding and localized increases in soil moisture. Defective rain gutters and downspouts contribute to localized increases in soil moisture.
	5.	Seepage into foundation subsoils at soil/foundation interfaces and through excavations made for basements or shaft foundations leads to increased soil moisture beneath the foundation.
	6.	Drying of exposed foundation soils in excavations and reduction in soil surcharge weight increase the potential for heave.
	7.	Aquifers tapped.
Usage effects	1.	Watering of lawns leads to increased soil moisture.
	2.	Planting and growth of heavy vegetation, such as trees, at distances from the structure less than 1 to 1.5 times the height of mature trees aggravate cyclic edge heave.
	3.	Drying of soil beneath heated areas of the foundation, such as furnace rooms, leads to soil shrinkage.
	4.	Leaking underground water and sewer lines can cause foundation heave and differential movement.

1-5. Elements of design

The foundation should be constructed or taken to a depth to protect the structure against damage by swelling or shrinking soil. Furthermore, the foundation should transmit the combined dead and imposed loads to the ground without causing settlements or other movements that are large enough to impair or damage the structure or reduce its overall usefulness. Finally, the foundation should provide protection from the freeze-thaw cycle of soil in cold climates and adequately resist any chemical or deleterious attack such as by sulfates and other harmful material in the soil.

a. Decision process of design.

(1) Figure 1-4 shows steps in the decision process, during the predesign and design phases, to properly select the foundation and superstructure. These steps include: site and soil investigations; a study of topography, drainage, and soil stabilization; and the selection of the foundation and superstructure.

(2) A foundation report for future reference should be made after construction.

b. Economics of the foundation. A thorough geotechnical study and an investigation of the foundation system during the predesign and preliminary design phases are normally essential.

(1) The features of the design should be kept simple to minimize costs and future maintenance expenses. Irregular geometries should be avoided. Construction of independently supported rectangular sections of the structure separated by joints, for example, may be appropriate if differential movement and separation between the independent sections does not significantly detract from the aesthetics or present a safety hazard. External parts of the structure, such as porches, terraces, breezeways, and garages, should be supported by part of the engineered foundation or isolated from the main structure. If the external parts of

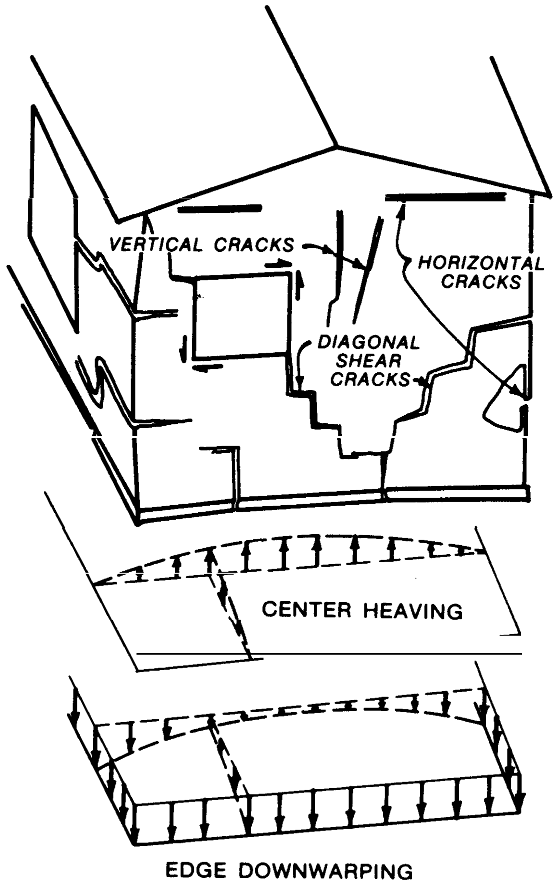

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Figure 1-2. Examples of wall fractures from doming heave of swelling and shrinking foundation soils.

the structure are simply supported on-grade or attached to the structure, they can contribute to future maintenance problems.

(2) Potential problems that could eventually affect the performance of the structure are best determined during the predesign and preliminary design phases when compromises can be made between the structural, architectural, mechanical, and other aspects of the design without disrupting the design process. Changes during the detailed design phase or during construction will probably delay construction and pose economic disadvantages.

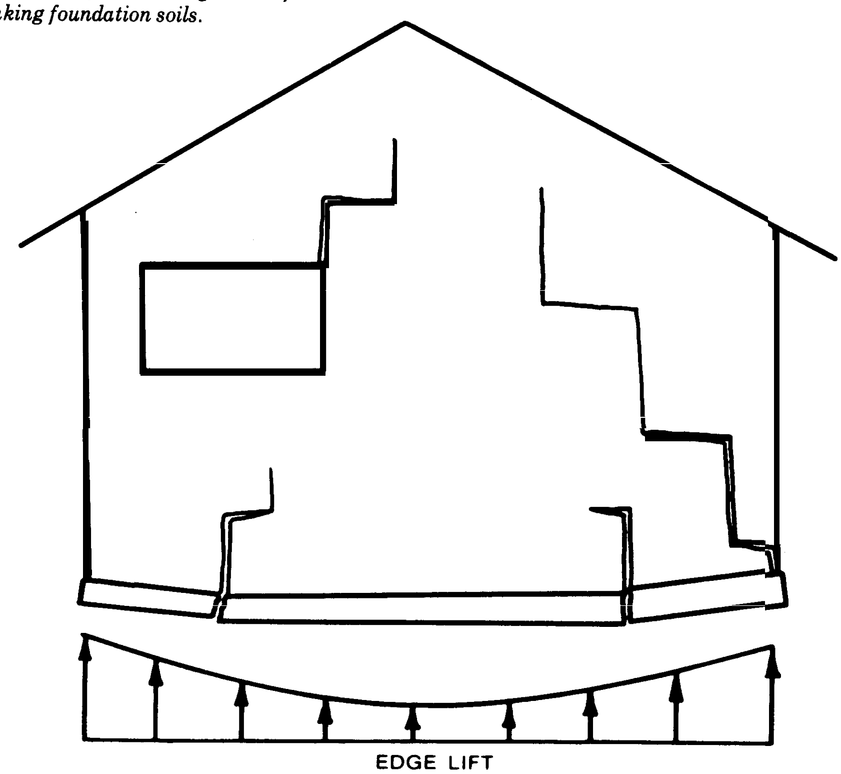

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Figure 1-3. Examples of fractures from dish-shaped lift on swelling foundation soils.

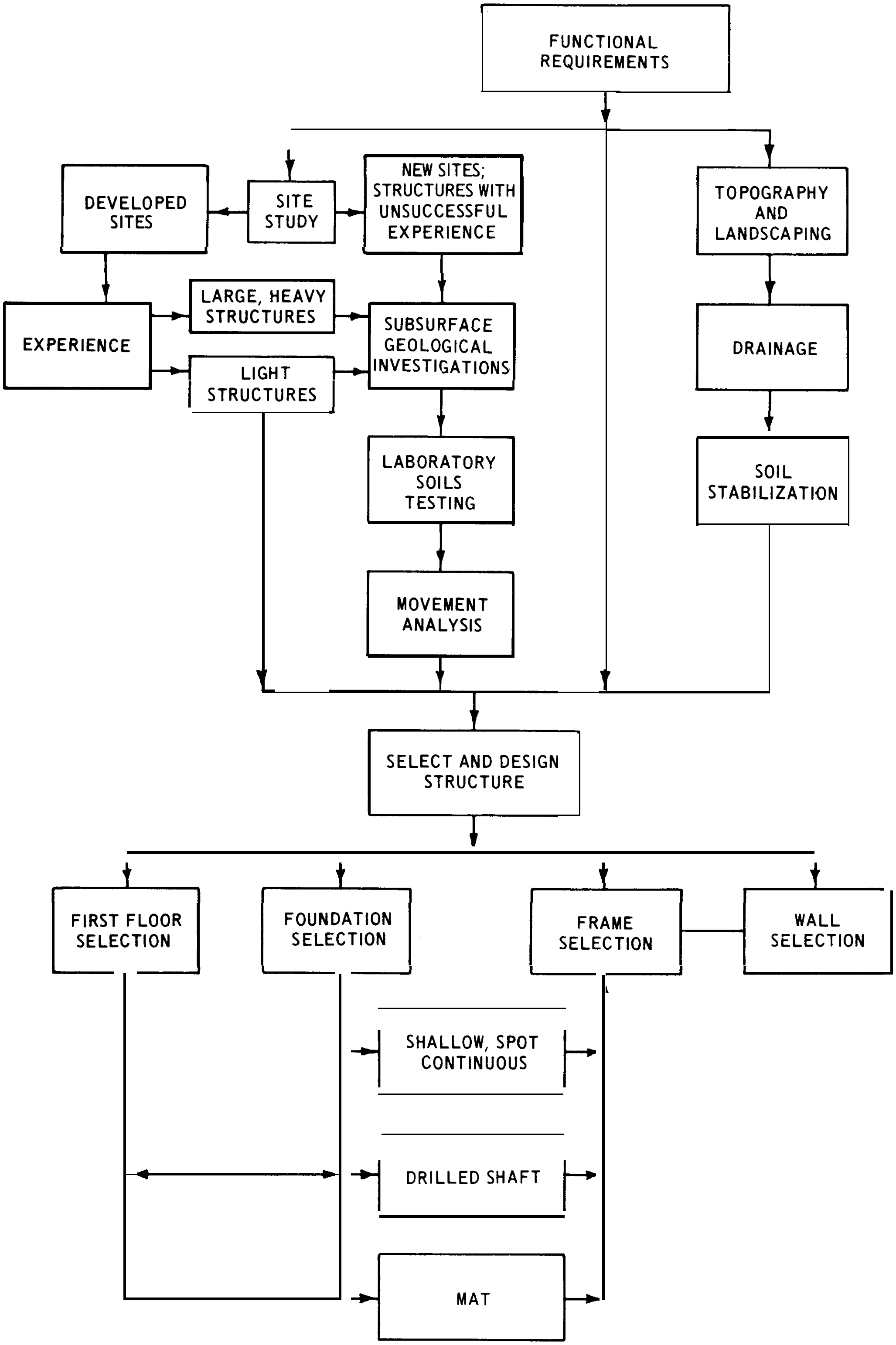

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Figure 1-4. Decision process of design.