A Guide to Swelling Soils for Colorado Homebuyers and Homeowners

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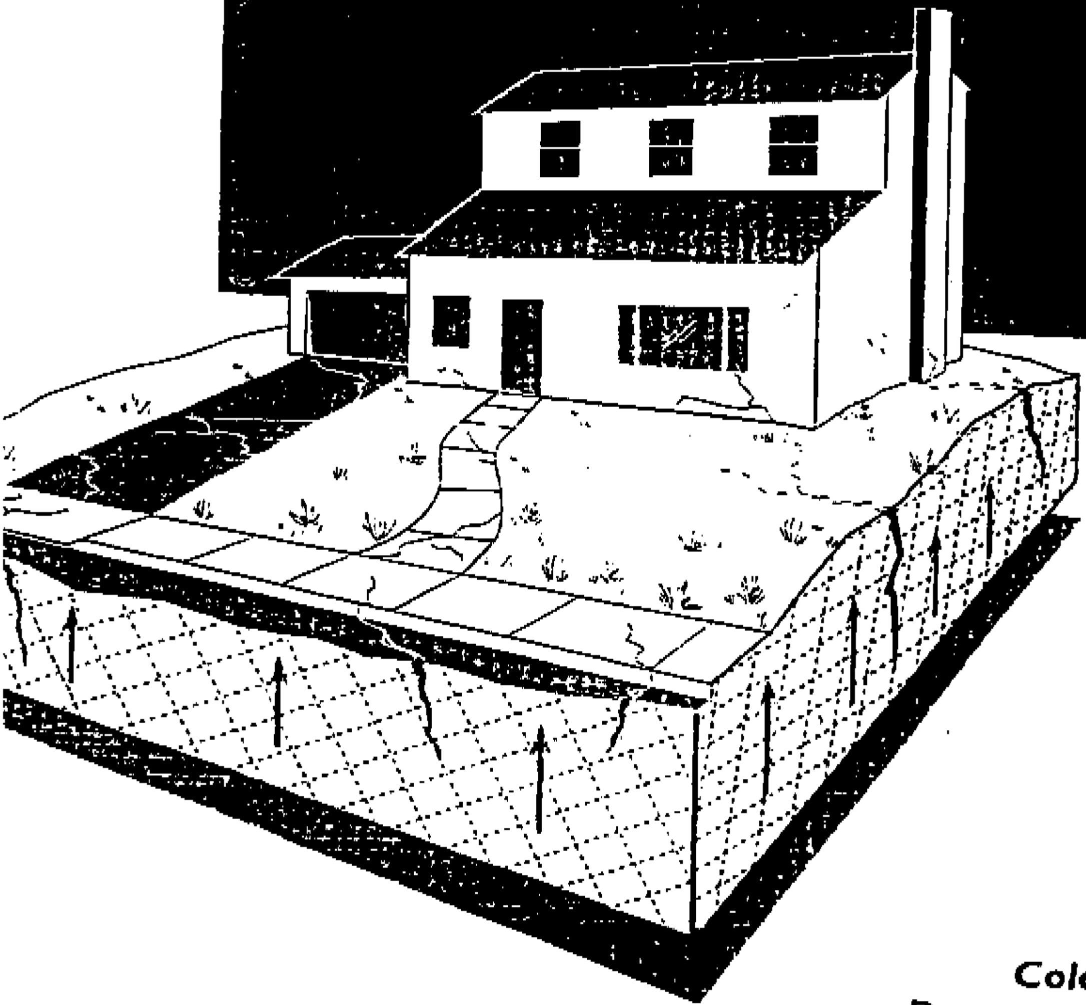

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INTRODUCTION

Swelling soils are a common problem in Colorado. They can cause damage that includes cracked and heaved driveways, sidewalks, basement walls, and floors; broken pipes and water lines; and, in some cases, severe damage to house foundations. Although many areas in the United States have swelling soils, Colorado's semiarid climate and geology combine to make it one of the most severely affected. Nationwide, the cost of repairing damage caused by swelling soils amounts to several billion dollars yearly, more than the cost for all other natural hazards combined.

Swelling soils are capable of causing severe damage to houses, roads, and other engineered structures. The damage may occur slowly over time, and individual houses in a neighborhood may be affected at different times. Special insurance or federal emergency funds typically do not exist for swelling soils damage. Builder's and homeowner's warranties may be available but the coverage they offer is usually limited in scope, amount, and duration. In general, owners of older homes will be solely responsible for the cost of repairing damages.

If you are thinking of buying or building a home on swelling soils, or if you already own a home that may be affected by swelling soils, you need to have a basic knowledge of:

1) What swelling soils are, and how they behave in general;
2) How the build-up of moisture in the soil contributes to swelling soils damage;
3) How homes can be designed and built to resist damage from swelling soils;
4) How to properly landscape and maintain a homesite to reduce damage; and
5) What risks a homebuyer must accept when purchasing a home on swelling soils.

The purpose of this book is to assist Colorado homebuyers and homeowners in reducing damage caused by swelling soils. Although risks from swelling soils cannot be completely eliminated, they can be significantly reduced through proper site-investigation, design, construction, landscaping, and maintenance practices. An awareness of these topics may be critical for the Colorado homeowner whose house is built on swelling soils.

How to Use This Book

This book is divided into two parts. Part I contains a short summary of swelling soils information. It outlines six categories of important facts that homebuyers should know about swelling soils in accordance with the disclosure requirements of Colorado Senate Bill 13 (1984), C.R.S. 6-6.5-101. Prospective homebuyers should read the Part I summary carefully and then utilize the text and figures from Part II to learn more about these topics.

Part II is a more extensive guide to swelling soils for homebuyers and homeowners. It contains seven chapters, arranged in the same order as the six categories outlined in the summary. Important aspects of swelling soils, subsurface moisture, and specialized construction, landscape, and maintenance procedures for swelling soils are explained. Chapter 7 is a step-by-step guide to inspecting a house for swelling soils damage. Several federal, state, and local agencies that may be sources of helpful information about swelling soils and related topics are listed at the end of the book.

Prospective homebuyers should use Part II to get a better understanding of the topics introduced in Part I. Homeowners can use all parts of the book to help maintain the long-term integrity of their home and their investment.

In all of the chapters and appendices, important terms will be highlighted in **boldface type** and explained where they first appear. These terms are used by professional geologists, engineers, and homebuilders, and many of them may be unfamiliar to the first-time reader. However, you may find an understanding of them to be extremely useful when you are dealing with swelling soils, or with housing and construction in general.

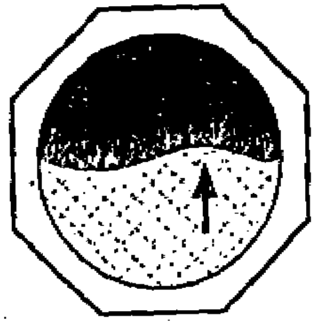
Replacement of Older CGS Publications

This book replaces two older publications from the Colorado Geological Survey: *Home Landscaping and Maintenance on Swelling Soil*, by Candace L. Jochim, revised, fifth printing, 1987 (Special Publication 14); and *Home Construction on Shrinking and Swelling Soils*, by Wesley G. Holtz and Stephen S. Hart, 1978 (Special Publication 11).

PART I

SUMMARY OF CHAPTERS 1–6

The Geology of Swelling Soils
(Summary of Chapter 1)

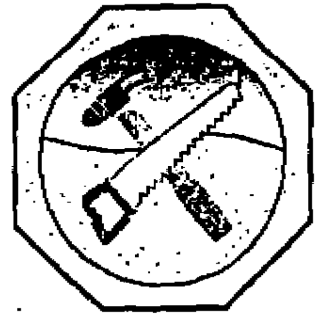


- Swelling soils and bedrock contain clay minerals that attract and absorb water. As a result, they swell in volume when they get wet and shrink when they dry (refer to Figs. 1–3, p. 16 and 17). Many geologists, engineers, and builders use the term "swelling soil" to include both soil and bedrock.
- "Bentonite" is a term that is often used synonymously with "swelling soil." Some bentonite layers are comprised of pure volcanic ash that has been weathered to clay. This type of bentonite may have extremely high swell characteristics.
- There are many factors that control how much a soil can swell, including the type and concentration of minerals, soil density, the amount of moisture change that can occur, and the restraining pressure of the surrounding soil.
- Swelling soils and bedrock may be found throughout Colorado, with the general exception of the highest mountain areas (refer to Fig. 4, p. 18).
- The swell potential of soils beneath any particular property depends on the local geology. Exploratory drilling or trenching, accompanied by sampling and laboratory testing, are necessary to evaluate the swell potential of subsurface layers at different depths (refer to Fig. 7, p. 21).
- Layers of swelling claystone bedrock that dip (tilt) into the ground at steep angles near mountain uplifts constitute a distinct geological hazard called "heaving bedrock" (refer to Figs. 8 and 9, p. 22 and 23). Jefferson and Douglas counties have adopted land development regulations to address this special geologic hazard.
- *See Chapter 1 and Figures 1–9, starting on p. 15, to learn more about the geology of swelling soils.*

Subsurface Moisture (Summary of Chapter 2)

- The relative increase or decrease in subsurface moisture has a major effect on swelling soil behavior. An increase in moisture will result in swelling, while a decrease will result in shrinking.
- Under natural conditions, shallow soils beneath the surface of the ground will alternately become wetter and drier as a result of seasonal moisture and temperature changes.
- Urbanization and land development significantly increase the amount of moisture in the ground, and can result in a deeper zone of subsurface wetting.
- The increase in soil moisture following land development often triggers soil swelling, and may cause significant swelling soils damage.
- One of the most important means of mitigating swelling soils damage is reducing the accumulation of subsurface moisture.
- ***See Chapter 2 and Figures 10 and 11, starting on p. 25, to learn more about subsurface moisture and its effect on swelling soils.***

Construction on Swelling Soils (Summary of Chapter 3)



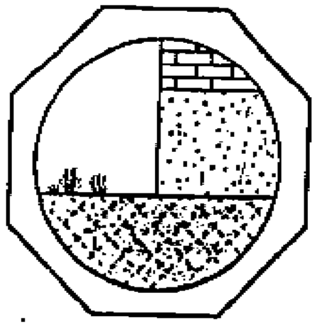
- Special designs and construction methods have been developed for grading and ground preparation, foundations, floors, building interiors, exterior flatwork, and surface and subsurface drainage systems for sites where swelling soils are present.
- Basic swelling soil designs work in a number of different ways. They may be geared toward reducing the swell potential of the soil, concentrating the load of the house onto pads or piers, letting certain parts of the structure heave and move relative to other parts with minimal damage, and/or reducing the amount of water that infiltrates into the ground next to the foundation.
- The exact type of design and construction used for a house depends, in part, on the potential severity (swell potential) of swelling soils. However, swelling soils may or may not be the primary consideration in many of the decisions made by the builder.
- Quality control during construction is the key to the success of any special design for swelling soils. Poor construction quality can add significantly to swelling soils damage to a house.
- *See Chapter 3 and Figures 12–29, starting on p. 29, to learn more about construction on swelling soils.*

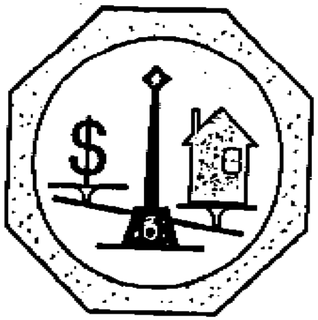
Landscaping on Swelling Soils
(Summary of Chapter 4)

- Many conventional landscaping practices (such as planting bluegrass lawns, trees, and gardens near foundations) are not recommended for areas of swelling soils because they contribute excess water to the soils (refer to Figs. 30 and 31, p. 48 and 50).
- There are some simple landscaping guidelines that should be followed in order to reduce swelling soil problems. The sloped area immediately adjacent to the house is an especially critical area for landscaping (refer to Fig. 34, p. 53).
- Irrigation should be limited to the amount necessary to maintain vegetation. This applies to all portions of your yard. Excessive watering, even with good drainage, drives water into the soil and increases the likelihood of swelling soil problems.
- Xeriscape™ landscaping is an attractive and cost-effective way to reduce swelling soils activity and conserve water. Other advantages include lower maintenance and less mowing.
- Xeriscaping makes use of many types of water-wise plants, and can include use of rock and organic mulches (refer to Figs. 32 and 33, p. 51 and 52 and Table 1, p. 52). The possibilities for creating a pleasing and effective Xeriscape are endless.
- There are numerous sources for information and ideas when it come to Xeriscaping. Some of these are listed in "Information Sources", p. 76.
- ***See Chapter 4 and Figures 30–34, starting on p. 47, to learn more about landscaping on swelling soils.***

HOME MAINTENANCE ON SWELLING SOILS
(SUMMARY OF CHAPTER 5)

- Homeowners should routinely inspect and maintain all of the different systems that were designed to protect the house from swelling soils damage, including slabs, walls, subsurface and surface drainage, slopes, and landscaping.
- Proper maintenance and irrigation practices are absolutely necessary to help prevent a house from being damaged by swelling soils and reduce potentially costly repairs.
- Conversely, the lack of proper maintenance and irrigation practices can contribute significantly to conditions that cause swelling soils damage.
- This is one of the most important chapters if you are a homeowner. *See Chapter 5 and Figures 35 and 36, starting on p. 55, to learn more about home maintenance on swelling soils.*





Swelling Soils and Homeowner Risk
(Summary of Chapter 6)

- Under Colorado law, the presence of swelling soils beneath a new house must be disclosed, and background information must be furnished to a homebuyer by the builder. During resale of an existing house, disclosure of pertinent soil conditions as well as any known damage or repairs must be given by the homeowner and the real estate broker. However, the homebuyer should not rely solely on this information.

- Colorado Senate Bill 13 (1984), C.R.S. 6-6.5-101, describes the responsibility of a builder of a new home to disclose evidence of any significant soil hazards, including swelling/expansive soils, to a potential buyer. This Colorado Geological Survey book is designed to satisfy the disclosure requirements in Part 1 of the statute:

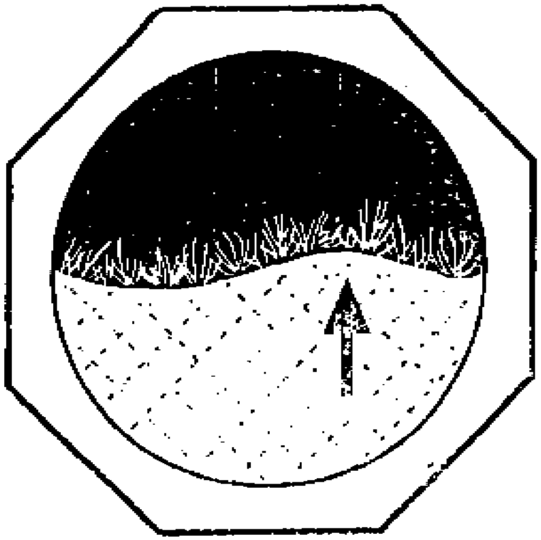
> **At least fourteen days prior to closing the sale of any new residence for human habitation, every developer or builder or their representatives shall provide the purchaser with a copy of a summary report of the analysis and the site recommendations. For sites in which significant potential for expansive soils is recognized, the builder or his representative shall supply each buyer with a copy of a publication detailing the problems associated with such soils, the building methods to address these problems during construction, and suggestions for care and maintenance to address such problems.**

There are no criteria in the statute for determining "significant" potential for expansive soils. In practice, the potential may be seen as "significant" when the project geotechnical engineer recommends using certain construction methods and designs specifically to reduce the effects of swelling soils. This information should be included in a summary soils report for each lot or for a larger project. (Ideally, a summary soils report should include the swell potential, observations, and recommendations given for the subject homesite. The information provided should be the most specific information available for the site.) It should include the engineering information used by the builder or developer in determining the site's building recommendations.

- Designs for houses are based on the potential severity of swelling soils. The design of the house should be specifically tailored to the amount of uplift or heave that is expected due to soil swelling for a particular homesite.
- Swelling soils should be considered seriously along with other common factors such as location and cost when you are thinking of buying a house.
- Find out everything you can about a particular new or resale house, especially how (and if) it was actually constructed with regard to the soil conditions. Look for signs of damage and/or repairs, and poor landscaping and maintenance practices, as shown in Chapter 7, and hire a structural engineer to assess the house if you have concerns or want more information.
- The final decision to purchase a house on swelling soils is yours. It should reflect a knowledge and acceptance of the risks involved. It may be extremely useful to hire a professional house inspector or engineer to help you with your decision.
- ***See Chapter 6 and Figure 37, starting on p. 61, to learn more about swelling soils and homeowner risk.***

PART II

GUIDE TO SWELLING SOILS



The Geology of Swelling Soils

Chapter 1

Swelling Soils and Swelling Bedrock

Swelling soils and **swelling bedrock** contain clay minerals that can attract and absorb water. As a result, these materials swell in volume when they get wet and shrink when they dry (Fig. 1). They are also called expansive, shrinking and swelling, bentonitic, heaving, or unstable soils and bedrock. When engineers or geologists talk about swelling soils, they are using a general term that may include swelling bedrock. The difference is that

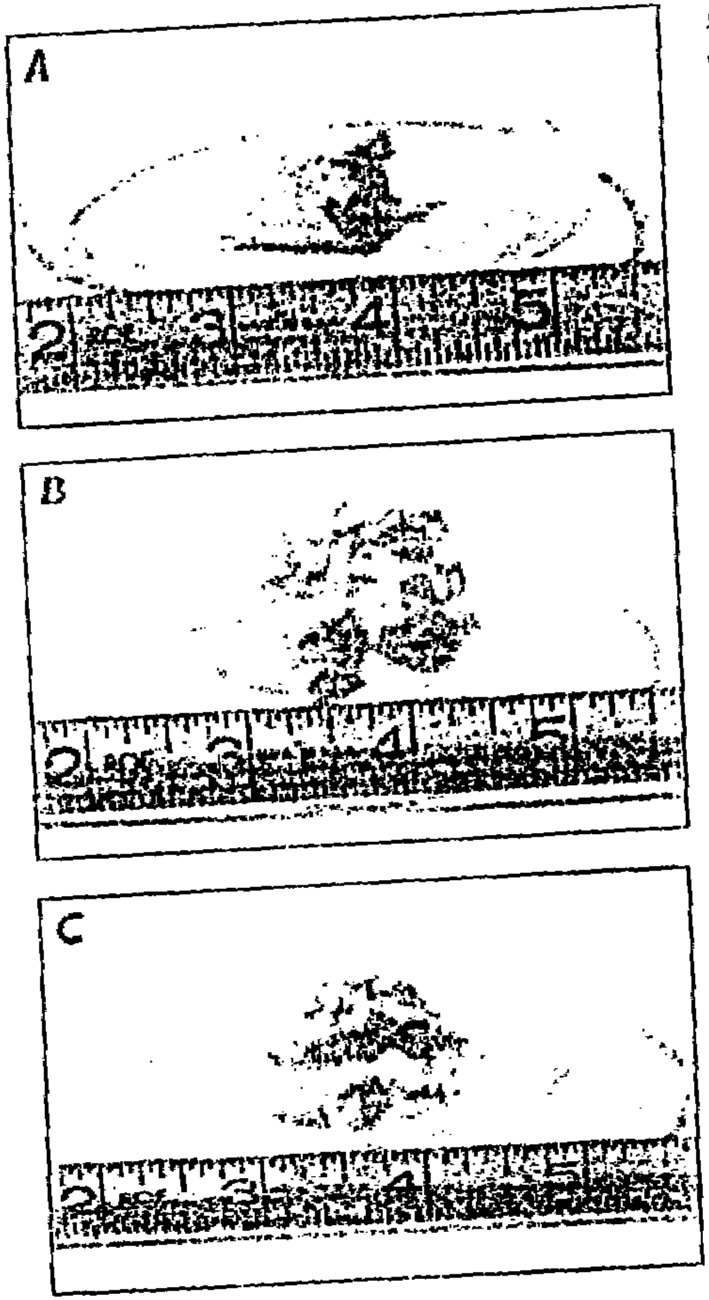


Figure 1. An example of swelling and shrinking behavior. A) A piece of highly expansive claystone before addition of water. B) One hour after adding water, the volume of the piece has almost tripled. C) Forty-eight hours later, the it is drying out and has begun shrinking and cracking.

swelling soils contain clay, while swelling bedrock contains claystone. In this book, we will use the general term "swelling soils" to include soils and bedrock that exhibit swelling behavior. Figure 2 shows some common occurrences of soil and bedrock in Colorado.

Smectite (montmorillonite) is the clay mineral responsible for most swelling soil and bedrock damage in Colorado. Bentonite is a special type of smectite that was originally deposited as ash from ancient volcanoes. **Bentonite** may have especially high swelling characteristics. **Illite** and **mixed illite-smectite** are common clay minerals that may swell, but to a lesser degree than smectite.

Swelling and Shrinking Behavior

Damage from swelling soils occurs when the soil changes volume as a result of a moisture change. **Swelling** occurs when moisture is added. Certain clay minerals may exert a chemical and physical attraction on the moisture, pulling layers of water molecules into microscopic areas between the flat clay plates. The clay plates are pushed farther apart as more water layers are pulled in (Fig. 3). This pushing apart (swelling) can cause high swell pressures and/or an increase of volume within the mass of soil that is being wetted. **Shrinkage**, the opposite effect of swelling, occurs when the soils dry out. As drying occurs, layers of water molecules are pulled out from between the clay plates by evaporation or by capillary forces from plant roots. This causes the area between clay plates to collapse on a microscopic level, and may cause a decrease in volume within the mass of soil that is being dried.

Swelling accounts for most of the damage to structures and roads in Colorado. Colorado soils are usually dry in their natural condition, but tend to become wetter after subdivisions are constructed and occupied because additional sources of water become available. The relationship between swelling soils, subsurface moisture, and subdivision development activities is discussed in Chapter 2.

Swell potential and swelling pressure are two measurements of a soil's ability to expand against different restraining pressures under laboratory conditions. Soils are typically rated as having either very high, high, moderate, low, or no swell potential. Swelling pressure is the pressure exerted by the soil mass against a restraining force when it is wetted. Typical swelling pressures for expansive soils in Colorado can reach 15,000 pounds per square foot. Soils having such high swelling pressure are capable of causing uplift to concrete slabs and footing-type foundations, which exert relatively low loading pressures.

The potential volume expansion of a soil under actual field conditions depends on five main factors:

1) **Type of minerals.** Smectite and (to a lesser degree) illite are the most common types of clay minerals in swelling soils in Colorado. Soils that contain relatively stable clay minerals such as kaolinite, or non-clay minerals such as quartz or feldspar, usually have no swell potential.

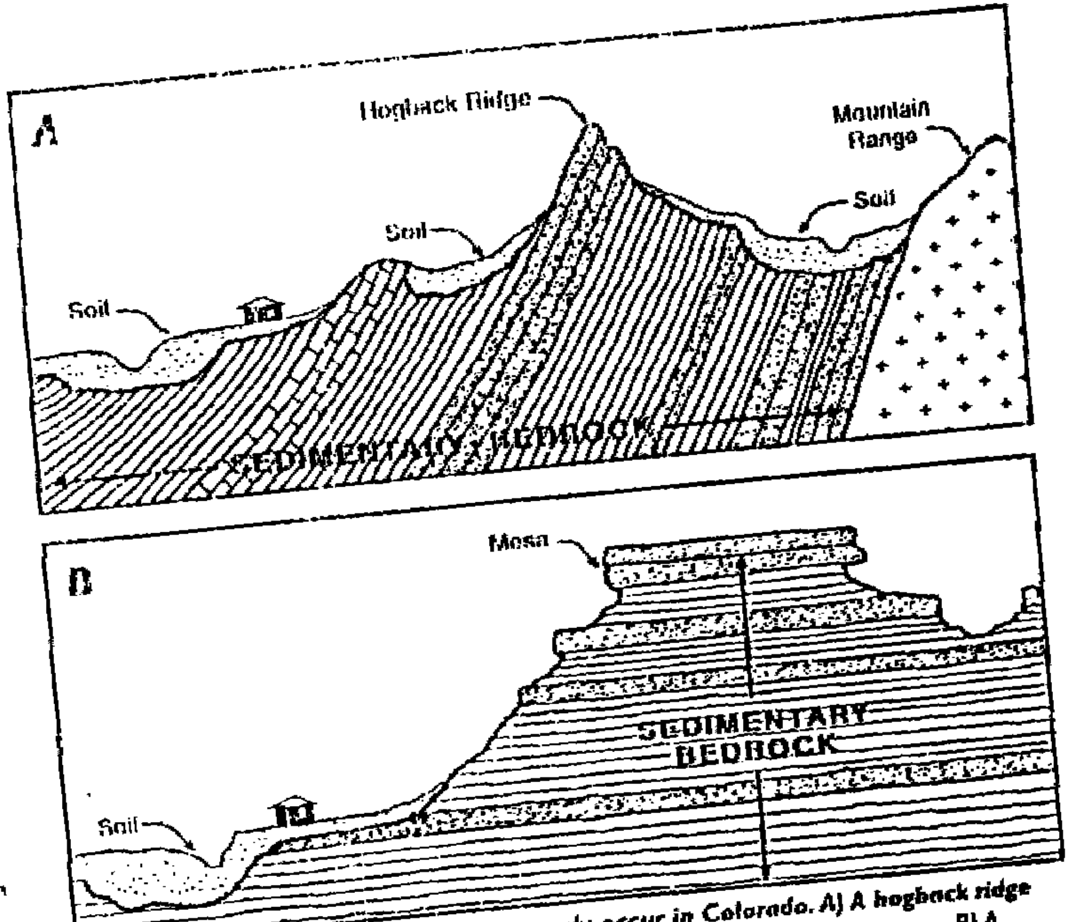


Figure 2. Soil and bedrock as they commonly occur in Colorado. A) A hogback ridge of upturned (steeply dipping) bedrock along the edge of a mountain range. B) A mesa with flat-lying bedrock layers, and thin soil deposits at the bottom of the slope.

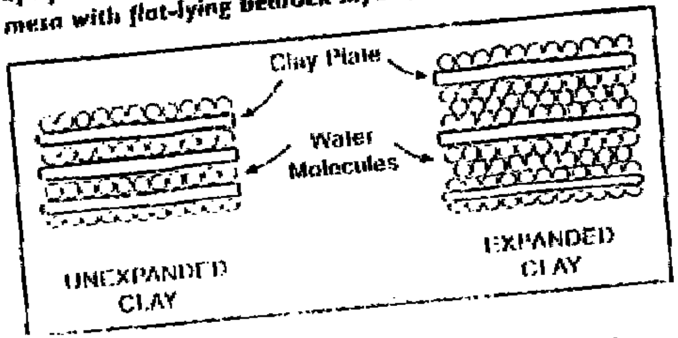


Figure 3. Expanding clay plates, as seen at a microscopic level. (Modified from Hart, 1974.)

2) **Concentration of swelling clay.** The more particles of swelling clay present in a piece of soil or bedrock, the greater its swell potential.

3) **Density.** A dense material containing swelling clays will have more clay particles and fewer air-filled voids than a loosely packed material of similar mineral composition. As a result, the dense material will have a greater swell potential.

4) **Moisture change.** A dry soil has the potential to absorb more moisture than a wet soil, and can subsequently undergo a greater amount of volume expansion. The amount of moisture change that can occur in a soil is a function of the initial amount of moisture in the soil (natural moisture content), the ability of the clays in the soil to pull in additional moisture (swell potential), and the amount of free-draining water and/or water vapor available to the soil.

5) **Restraining pressure.** A layer of swelling soil that occurs near the ground surface may swell significantly and cause uplift and heaving because there is very little restraining pressure to prevent it from swelling. However, the swell potential of a similar layer that occurs several feet below the surface is restrained by the weight of the surrounding and overlying soil (overburden). If the overburden weight is greater than the soil's swelling pressure, then actual swelling and uplift are unlikely.

Occurrence of Swelling Soils in Colorado

Swelling soils are widespread throughout Colorado. They cover broad areas of the eastern plains, and are found mainly in valleys and on mesa slopes in western Colorado (Fig. 4). A majority of the state's major population centers are located in areas of potentially swelling soils and bedrock. On a smaller scale, however, individual sites within these areas may not have swelling soils beneath them because of localized geological variations (as in Fig. 5).

How to Recognize Swelling Soils

One way to find out if swelling clays are present is by simply looking at the ground surface. Soils

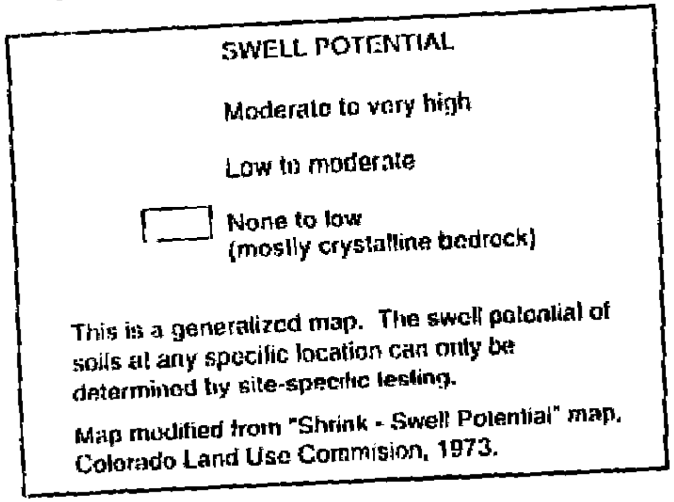


Figure 4. Explanation.

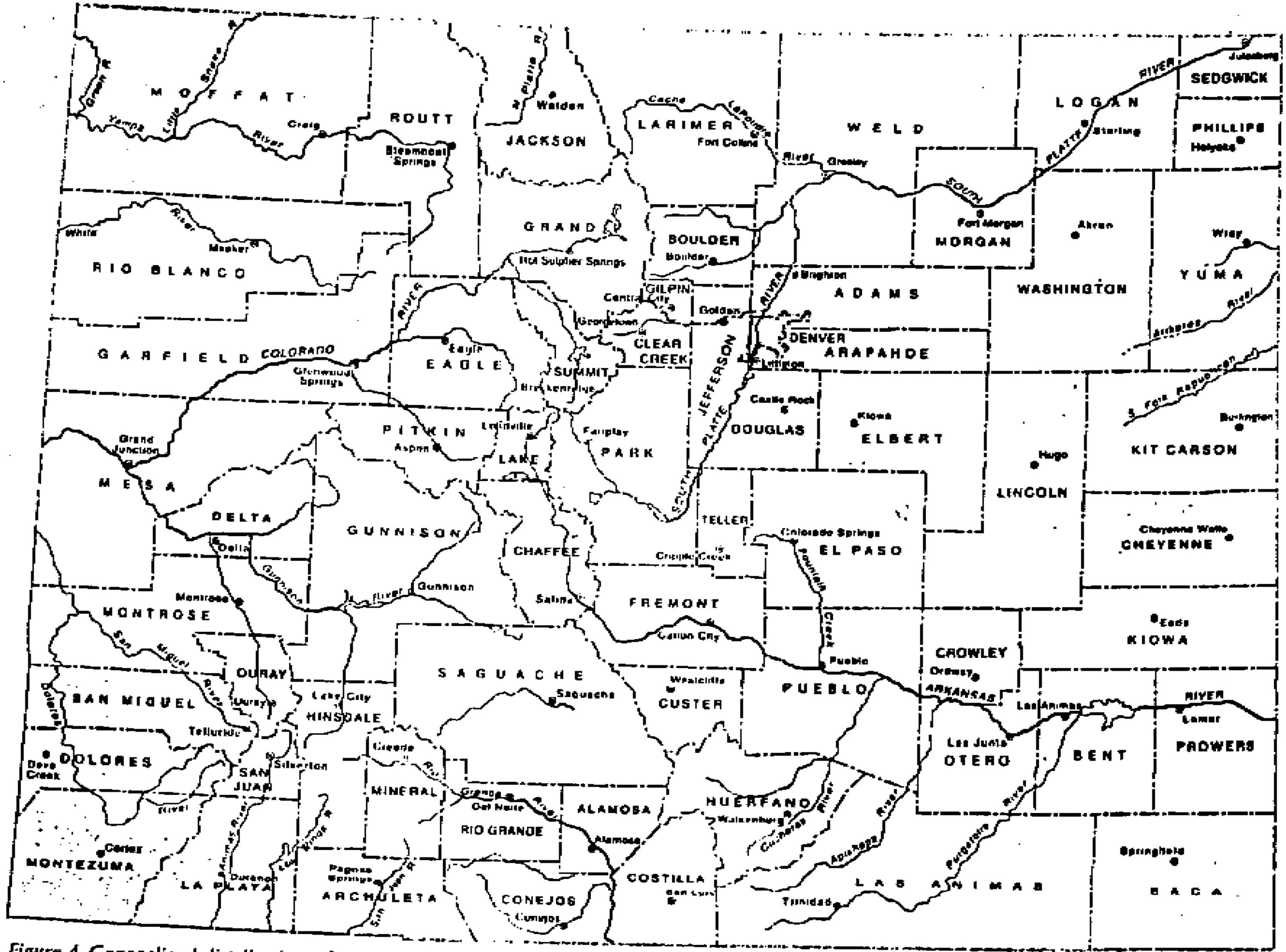


Figure 4. Generalized distribution of swelling soils and shallow swelling bedrock in Colorado. (From Jochim, 1987.)

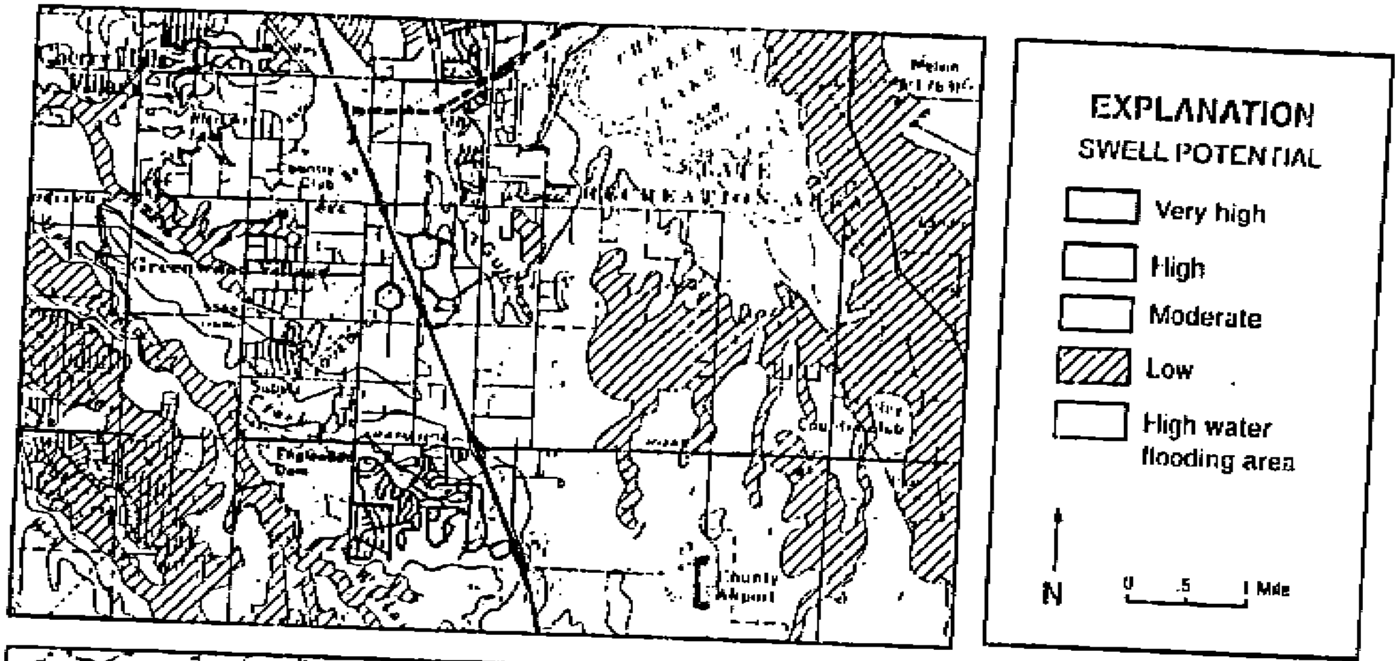


Figure 5. Example of a map showing local distribution of swelling soils. Maps of this type available from the Colorado Geological Survey for the Front Range urban corridor area, from Pueblo to Fort Collins (in publication EG-7 by Hart, 1974).

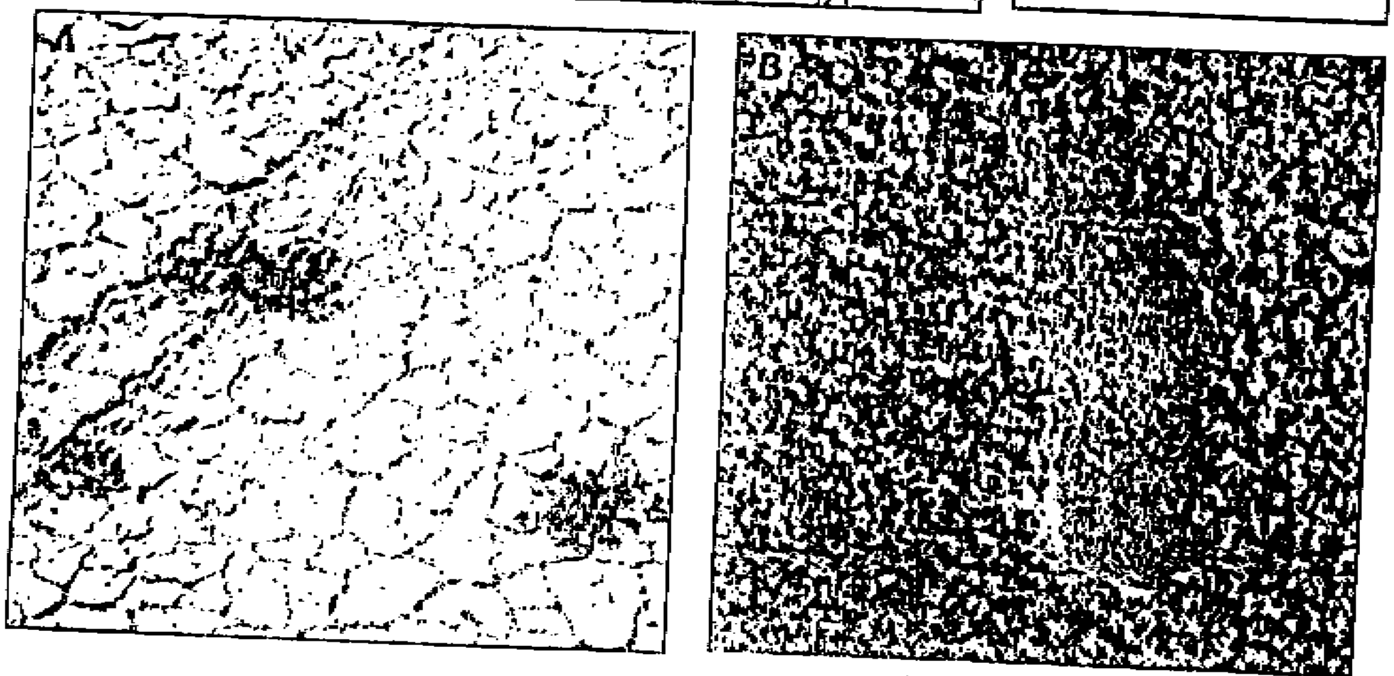


Figure 6. Evidence of swelling soils at the ground surface. A) Small-scale desiccation cracks in soil containing swelling clay. Note tire tracks for scale. B) "Popcorn" texture in soil containing swelling clay having very high swell potential. Note footprint for scale.

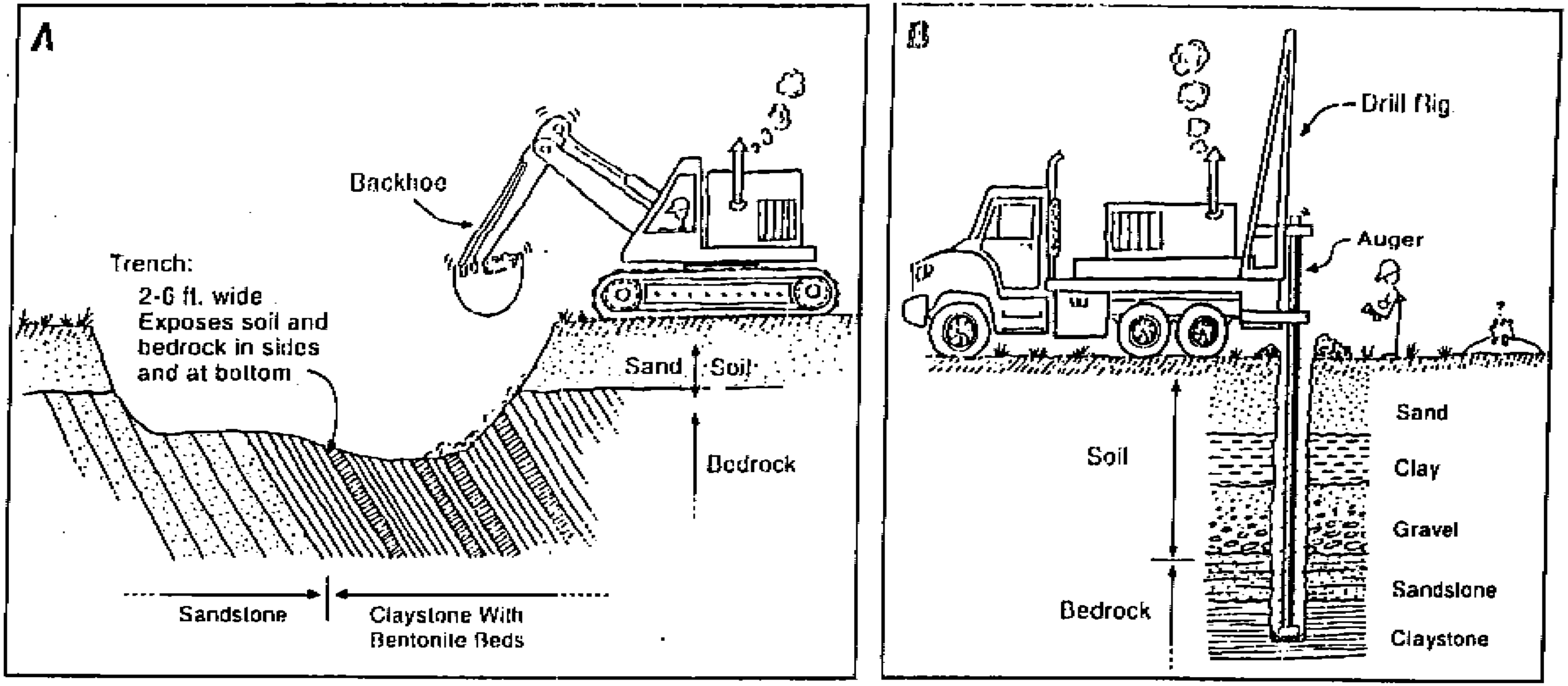


Figure 7. Exploration methods used to identify and test different soil and bedrock layers for swell potential and other engineering properties. A) Trenching, B) Drilling.

containing swelling clays will be very sticky when wet, and may display **desiccation cracks** (Fig. 6A) or a puffy **"popcorn" texture** (Fig. 6B) when dry. Heat and evaporation may cause larger cracks, on the order of several feet deep and up to an inch wide, to open up in the ground. These features may not be evident where topsoil or heavy vegetation covers the native soil.

It is far more important to identify whether deeper layers or lenses of swelling soil are present beneath a property. The evaluation of subsurface layers is most often done by drilling one or several test holes or by digging a trench (Fig. 7).

Drilling is effective for relatively flat-lying soil and bedrock because it allows for inspection and sampling of successively deeper layers, while **trenching** is effective in areas underlain by steeply dipping bedrock because it exposes many near-surface bedrock layers for inspection and sampling. Samples taken from test holes or trenches are tested for swell potential and swelling pressure in a laboratory. This information is used to design foundations for buildings. Such evaluations are a required practice in many areas of Colorado where swelling soils are anticipated.

Steeply Dipping Bedrock Areas

Heaving bedrock is a distinct geological hazard in certain areas of Colorado near the base of mountains where the sedimentary bedrock layers are steeply dipping (upturned and tilted, as shown in Fig. 3A). In such areas, the bedrock layers may swell unevenly to form linear heave features along the ground surface (Fig. 8). Houses built over such heave features may be subjected to extreme amounts of vertical and lateral stress, and the resulting damage can be severe.

The mechanisms responsible for heaving bedrock movements are geologically complex. Heaving may occur due to uneven swelling of individual bedrock layers, each having a different swell potential (Fig. 9A), or due to shear-slip movements along bedding planes or fracture surfaces (Fig. 9B). The processes that cause heaving bedrock are not well known. **Rebound** (expansion of the clay minerals as a result of sudden unloading) may be a factor, in addition to water-induced swelling of clay particles in the bedrock. Moisture can penetrate a greater depth into steeply dipping bedrock than in flat-lying bedrock, resulting in a deeper zone of potential swelling.

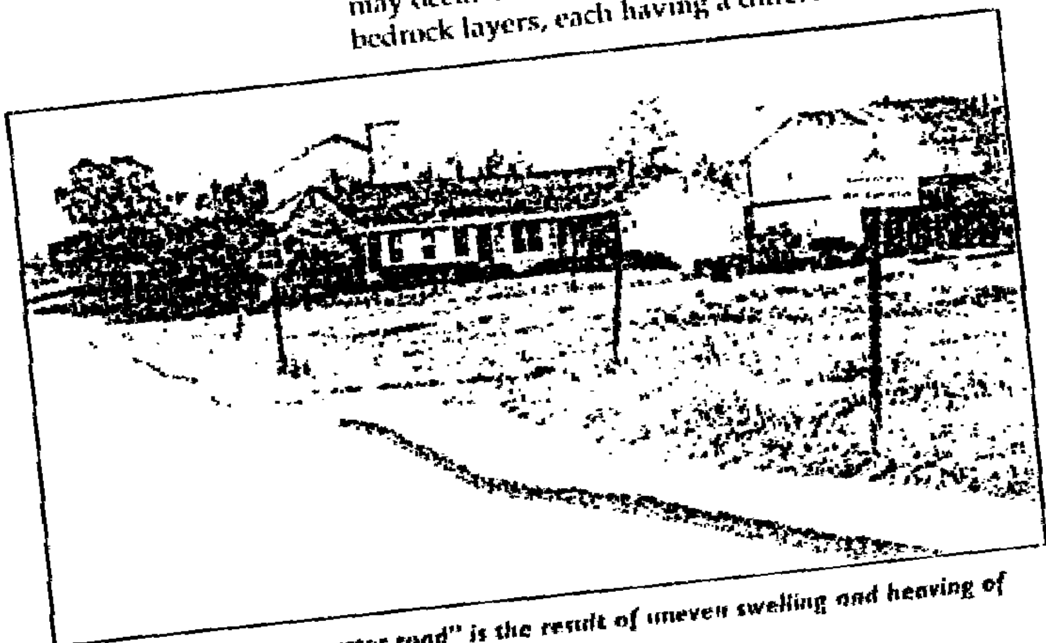


Figure 8. This "roller-coaster road" is the result of uneven swelling and heaving of steeply dipping bedrock layers.

Many construction designs commonly used to mitigate the impacts of swelling soils have met with limited success in areas of heaving bedrock. For example, drilled pier foundations (see Chapter 3) have been damaged in numerous cases. The basic assumption for those designs is that the bedrock is stable. This is not the case for heaving bedrock because the bedrock itself is moving. One method that may counteract the differential heaving is **overexcavation and fill replacement**, whereby a house is isolated from the heaving bedrock by a thick pad of engineered fill (see Chapter 3).

Jefferson and Douglas counties now require more detailed site investigation and specialized building techniques where heaving bedrock conditions exist. These areas are defined by overlay maps that show the extent of potentially heaving bedrock. Houses in the overlay areas constructed before 1995 may not have been built with current state-of-the-art construction practices. Similar geological conditions where heaving bedrock may occur exist at other locations along the Front Range foothills and on the Western Slope of Colorado.

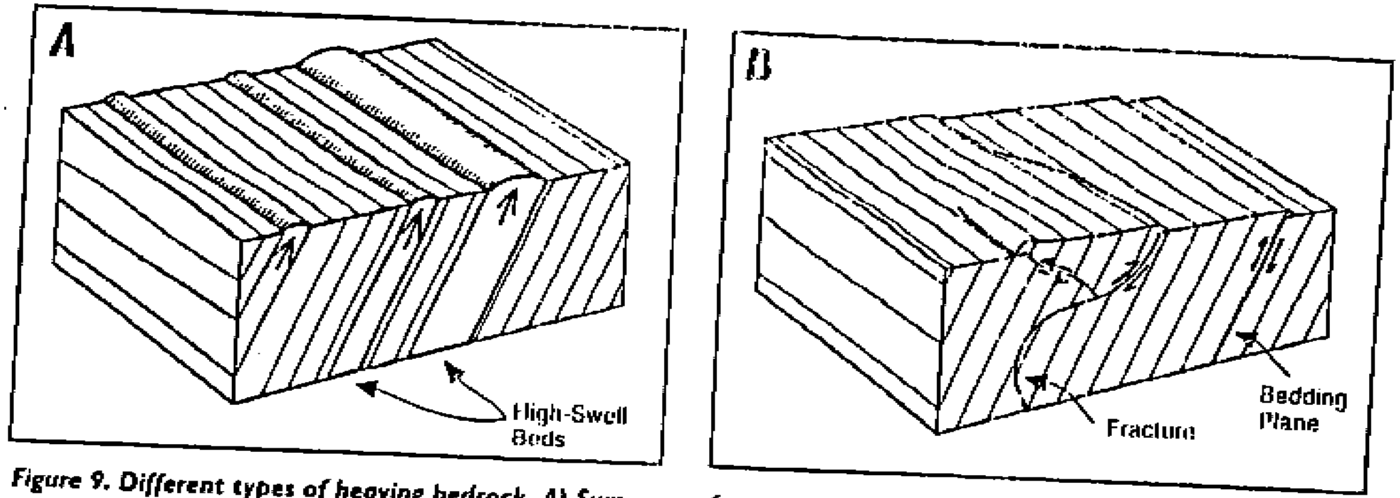


Figure 9. Different types of heaving bedrock. A) Symmetrical heave features caused by uneven swelling of individual bedrock layers. B) Asymmetrical heave features caused by shear-slip movement along bedding planes and/or fracture surfaces. (Modified from Noe and Dodson, 1995.)

Subsurface Moisture

Chapter

We learned in the first chapter that swelling soils cause damage by attracting and absorbing water. This chapter will show how water exists in the ground under natural climatic conditions, and how the amount of subsurface moisture usually increases after development. In most cases where significant swelling soil damage occurs, the damage is triggered by an increase in subsurface moisture.

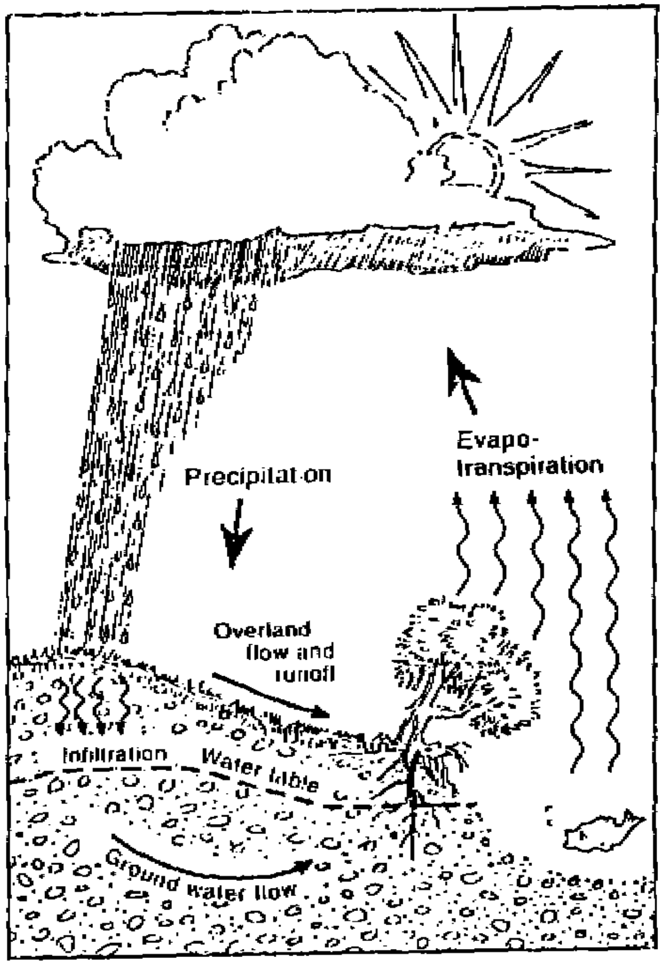


Figure 10. The hydrologic cycle.

The Hydrologic Cycle

Water exists as a vapor in the atmosphere, as a liquid in rivers and streams, and as a solid in the form of snow and ice. Water also exists beneath the ground surface. The natural transfer of water among all of these diverse settings is called the **hydrologic cycle** (Fig. 10). Water falls from the clouds as precipitation and enters the ground through **infiltration**. It can also leave the ground by vaporizing due to heating and drying (evaporation) or by being used by green plants (transpiration); the cumulative effect is called **evapotranspiration** or ET loss.

The mountainous areas of Colorado usually have a surplus of surface and subsurface water as a result of high rates of precipitation and a cool climate. The eastern plains and western valleys, where most of Colorado's swelling soils are found, receive less precipitation (8 to 16 inches per year, on average, for the major population centers; Colorado Climate Center, 1984), are hotter, and have high rates of evapotranspiration (30 to 40 inches, on average, for May-October shallow lake surface evaporation; Farnsworth et al., 1982). As a result, the lower-elevation areas of the state are characterized by an overall deficit of water during much of the year, and the near-surface soils are typically dry.

Types of Subsurface Moisture

Water exists beneath the ground surface in two forms. It is called **ground water** where the soil or rock is saturated, and **ground moisture** where the soil is unsaturated. Layers of saturated soil or rock that store and transmit water are called **aquifers**. The upper saturated surface of a shallow (unconfined) aquifer is called the water table. A **perched water table** may develop on top of impervious soil or bedrock as a result of subdivision construction and occupancy (Fig. 11). This type of situation may induce basement flooding and swelling soil heaving and damage.

Nearly all subsurface water was surface water at one time. Natural sources of subsurface water include infiltration from rainfall, snowmelt, and lakes and streams. Other significant sources are the by-products of human activities such as lawn and crop irrigation, and seepage from manmade ponds, ditches, and buried water and sewer lines.

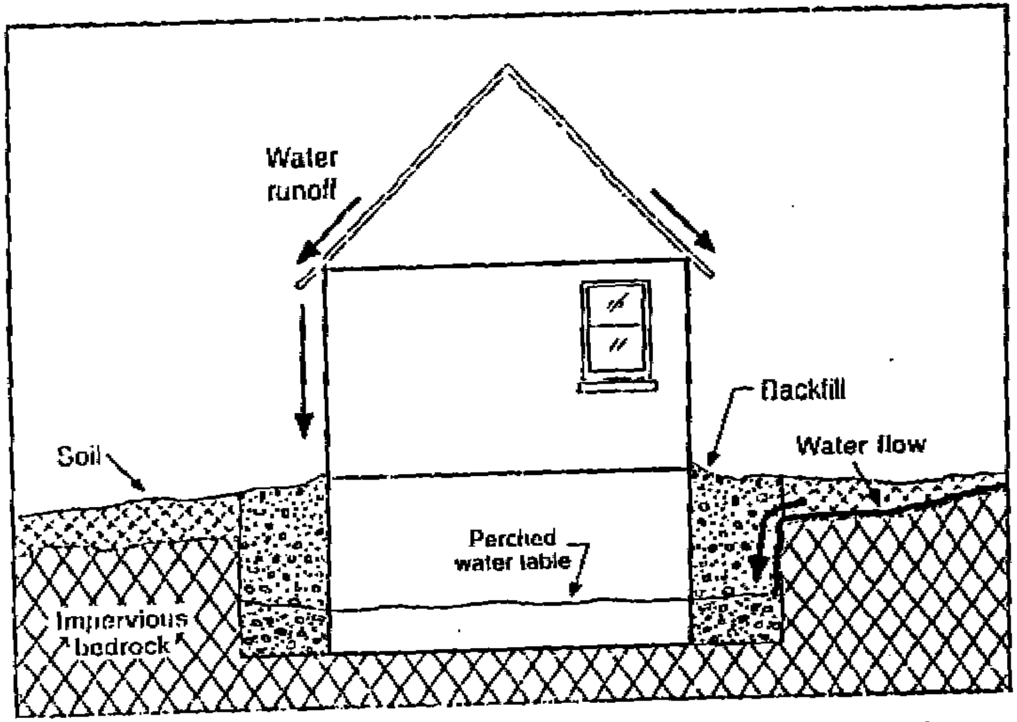


Figure 11. Perched water table in a house excavation dug into impervious bedrock (modified from Jochim, 1987). This is an unwanted situation because runoff water is filling the excavation and infiltrating the bedrock.

How Subsurface Moisture Affects Swelling Soils

The presence of subsurface moisture can cause serious problems for a house built on potentially swelling soils. The amount and distribution of subsurface water may vary seasonally under natural conditions. The amount of subsurface moisture increases during the late winter and spring, when rates of precipitation and infiltration are high, and during periods of artificial irrigation. During the dry season it may decrease again. Similarly, the water table may rise during wet periods and fall during dry periods. The depth below the ground surface where soils undergo seasonal wetting-drying cycles is called the active **zone or zone of moisture** change. The natural active zone along Colorado's eastern plains is typically 7 to 10 feet deep.

Under natural conditions, seasonal wetting and drying cycles cause swelling soils to swell and shrink to some extent. This is not a problem if the land is being used for agriculture or is undeveloped. However, building a subdivision in an area can significantly alter the natural moisture content of the soil. Water infiltration increases due to irrigation of lawns and gardens and, in some cases, leakage from septic systems and water or sewer pipes. At the same time, evaporation is reduced by impervious roadways, parking lots, driveways, sidewalks, and buildings. Off-site water may migrate into an area through backfilled trenches and gravel bedding. A perched water table may develop. The overall result is a net increase in soil moisture. The post-construction zone of wetting typically increases to depths of 10 to 15 feet along Colorado's eastern plains. In areas of steeply dipping bedrock, the zone of wetting may increase to depths of 35 feet after a subdivision is built and the houses are occupied. If newly introduced subsurface water comes into contact with potentially swelling soils beneath a house, the soils may swell and cause damage.

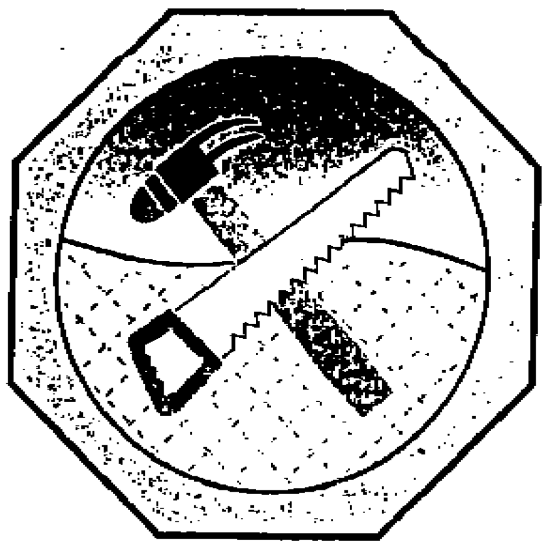
One of the most important means of reducing the risk of swelling soils damage is to control the amount of moisture that infiltrates the soil. Structures built on swelling soils should, in every case, have adequate surface and subsurface drainage systems. Successful design, construction, landscaping, and maintenance practices for swelling soils all depend to a large degree on reducing the effects of subsurface water, as we will see in the following chapters.

Droughts and Shrinking Soils

Colorado is subject to occasional periods of drought. During a drought, evapotranspiration will exceed water infiltration, and the active zone will dry out. If swelling soils are present in the active zone, they will undergo volume shrinkage. This may reverse the direction of heaving and reduce the amount of damage that has occurred during earlier periods of swelling, or it may cause additional damage due to near-surface settlement of the soil.

Desiccation cracks (Fig. 6A) typically form when near-surface swelling soils dry out. Large cracks, with depths of up to several feet, may form during extended dry periods. These larger cracks play an important role in swelling soil behavior, as they allow deep penetration of water during subsequent wet periods.

Certain types of trees and plants will pull large amounts of moisture out of the soil during drought periods. This may cause localized shrinkage and settling of the ground surface in the immediate area of the tree. Damage to structures may occur if the tree is located close to a house foundation. Chapter 4 gives tips on how to avoid this type of problem by using proper landscaping techniques.



Construction on Swelling Soils

Chapter 3

This chapter describes the advantages (and some of the pitfalls) of certain specialized designs used in house construction for various degrees of soil swell potential. Swelling soils influence the preparation and grading of the site, as well as the design and construction of foundations, floors, interior walls and piping, and subsurface and surface drainage systems. Quality control of construction is crucial for each step of the construction process.

The design and construction of a house and its individual elements should ideally reflect the condition of the soils beneath it. The actual designs are usually chosen by the homebuilder after considering recommendations from engineers and taking other factors, such as house affordability, into account. A prospective homebuyer should be aware of swelling soils and the types of designs and precautions used to control swelling soil problems. Many variations of a design are possible, and the actual designs used for any particular house may differ to some degree from those shown in this chapter.

Ground Preparation and Grading

Before any houses can be built in a new subdivision, the site is usually graded and shaped, and utilities and roads are installed. This may involve cutting away topographically high areas such as hills and filling in lower areas. Swelling soils or bedrock may be exposed or brought nearer to the surface in grading cuts, and they may make up a sizable portion of the materials used to construct fill pads for houses and roads. There are several methods of site preparation available to reduce the potential swelling of fills and natural soils. The effectiveness of any particular method depends on the actual conditions at each subdivision or site.

Fills. It is common engineering practice to reduce the swelling potential of graded fills by controlling their moisture and density. The fill soils are typically spread out on the ground surface in thin layers. Water is added to each new layer to induce a certain amount of swelling. Afterwards, a machine compacts the layer to a recommended density. The final moisture content of an engineered fill is almost always greater than for most Colorado soils in their natural condition. As a result, the fills may be less prone to swell. Construction of engineered fills may result in mixing of non-swelling materials such as sand or low-swell clays with higher-swell clays, which may effectively reduce the overall concentration of swelling clays.

Cuts. Cut areas exposed by grading are susceptible to swelling because the natural restraining loads have been removed, exposing soil or bedrock layers that have not previously swelled to their full potential. Such areas can dry out to some depth after grading, thereby increasing the swell potential. In some cases, grading exposes fractures or other water conduits that were not open to moisture intrusion prior to grading (Fig. 12).

The **overexcavation method of cutting and fill replacement** is sometimes used in areas of highly swelling soils and bedrock. Overexcavation involves cutting and removing the soils to a prescribed depth, usually 3 to 10 feet below the anticipated lowest foundation or road level. The cut is then fully or partially filled with uniform layers of original or imported soils under controlled moisture and density conditions. This fill creates a buffer between the foundation or road and the underlying swelling soils. Overexcavations and deep fills may be recommended in certain Colorado counties where steeply dipping, heaving bedrock is encountered.

Chemical treatments. Another means of reducing swell potential is to mix or inject chemicals into the soil. This is typically done after site grading. Chemical treatments are specially formulated to change the clay chemistry and mineralogy so that the clays become less expansive. Chemical treatments are used mainly for roads and larger commercial building sites. They are less commonly used for single-family residential dwellings. A main drawback of chemical treatments is that the treatments may not penetrate very deeply or uniformly into most swelling soil and bedrock due to the presence of fractures, low-permeability layers, and other geological complexities. Another drawback is that the chemicals may be leached out of the soils over time.

FOUNDATIONS

House foundations must be properly engineered to account for geological conditions at any given homesite. Depending on the site's swell potential, swelling soils may or may not be a primary consideration. Several different types of foundations are commonly used in areas of swelling soils in Colorado. The actual choice of foundation type depends on numerous geologic and non-geologic factors, and may reflect common regional practices and individual preferences of foundation engineers.

The foundation of a typical house consists of a basal element that is in direct contact with the soil, and a wall element that rests upon or spans the basal elements and retains the backfill along the side of the house. These elements are made from concrete and may contain steel bars as reinforcement. The foundation ideally transfers the weight of the house to the soil in such a way that the house will not heave or settle significantly.

Foundations are termed "shallow" or "deep" depending on the configuration of their basal

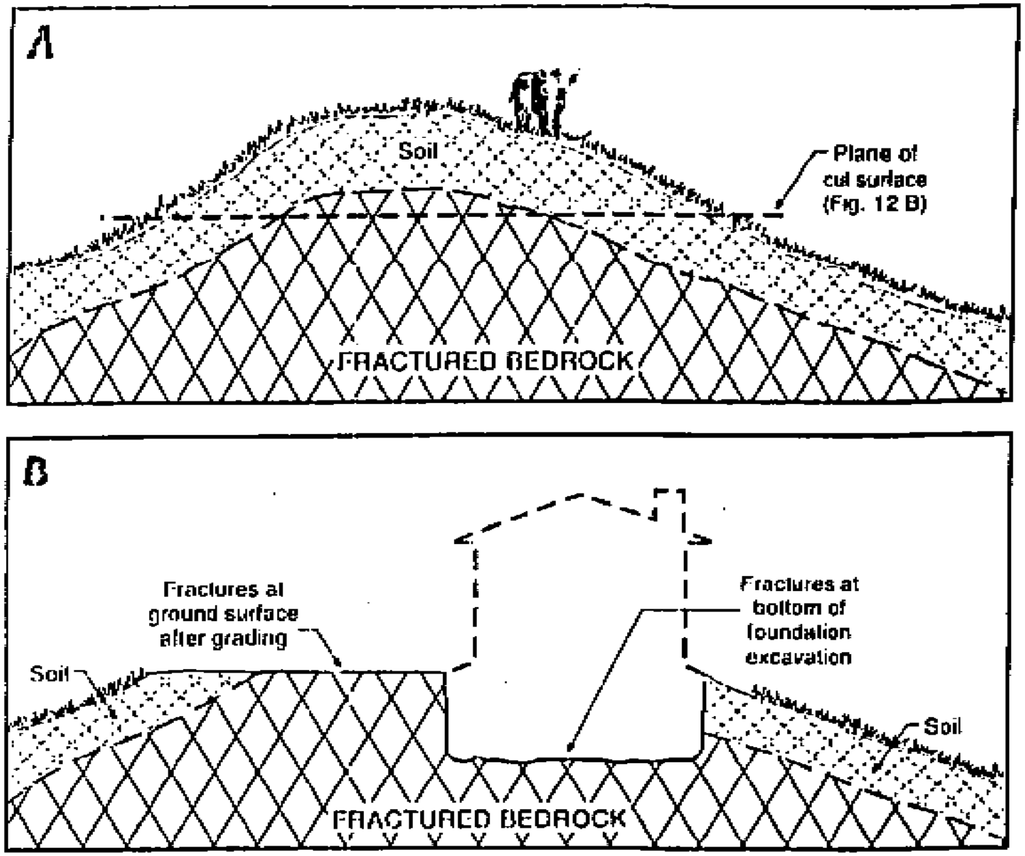


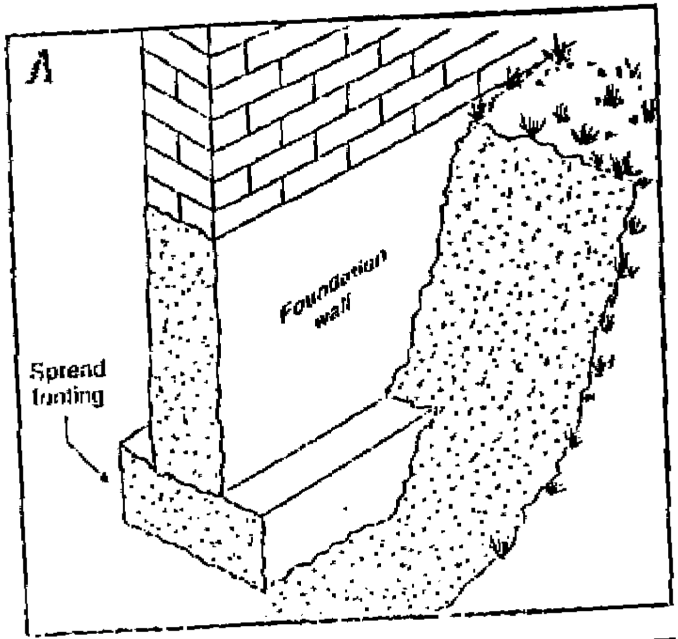
Figure 12. How bedrock fractures are exposed by grading cuts. A) Under natural conditions, fractures are covered by soils and are not directly exposed to water infiltration. B) After grading and cutting the fractures are exposed at the surface, and water can now infiltrate more easily into the ground through the exposed fractures.

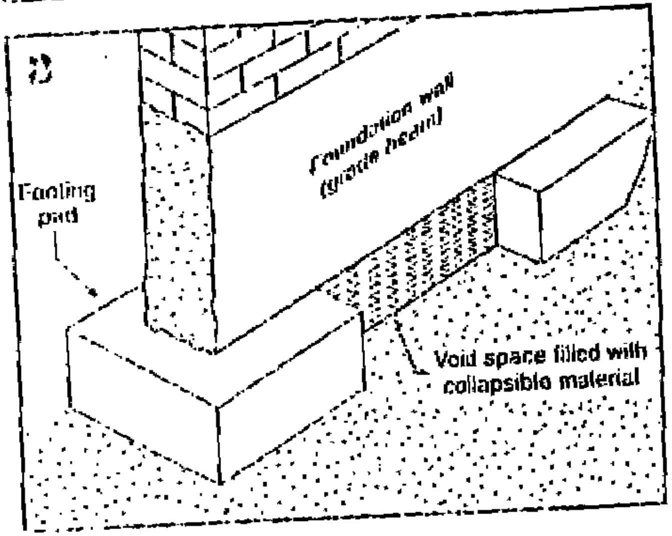
elements. **Shallow foundations** have basal elements that are directly supported by soil, bedrock, or fill along the bottom of the founda-tion excavation. They are used in many areas of Colorado where the soil has negligible to moder-ate swell potential, or in conjunction with overex-cavated and replaced fills where highly expansive soils and/or rock are present. **Deep foundations** have basal elements that penetrate the soil and/or rock to some depth below the base of the foundation wall, essentially anchoring the foun-dation into the ground and transferring much of the load to deeper strata. Deep, drilled pier foun-dations are used in many areas of Colorado where the soils are expansive or otherwise unstable.

Different foundation types commonly used in Colorado and their suitability for swelling soil areas are discussed in the following paragraphs.

Shallow Foundations

A spread footing foundation (Fig. 13a) consists of a continuous strip of concrete, typically 16 inches wide but occasionally narrower or wider (between 12 and 20 inches wide), upon which the foundation wall is placed. The footing has a rela-tively large bearing area (basal area) in contact with the ground, which spreads out rather than concentrates the weight of the house. This type of foundation works best in loose, non-swelling soils to reduce settlement. It is generally not recom-mended where moderately to highly swelling soils are encountered, unless it is used as part of an overexcavation and fill replacement design.





A footing pad foundation (Fig. 13b) consists of discontinuous concrete pads that are spaced apart

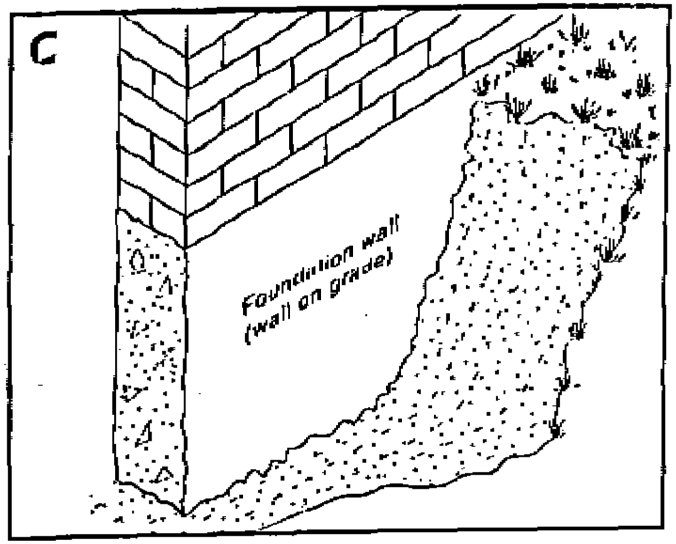


Figure 13. Shallow footing-and-wall type foundation systems. A) Spread footing foundation. B) Discontinuous footing pad foundation. C) Wall-on-grade foundation. (Modified from Holtz and Hart, 1978.)

at specified intervals. Between the pads are void spaces filled with a collapsible material that does not transmit loads. The pads and void spaces are spanned by a grade beam, a steel-reinforced foundation wall. The load of the house is supported by the grade beam and pads. This type of foundation may be appropriate for soils having very low to moderate swell potentials.

A wall-on-grade foundation (Fig. 13c) consists of a continuous foundation wall that rests directly on the soil. The wall exerts a moderate pressure on the soil due to its rather small bearing area. This type of foundation has been used in Colorado for soils having low to moderate swell potentials. It is becoming less common in construction in most areas of the state.

A voided wall-on-grade foundation differs from a wall-on-grade foundation in that rectangular void spaces are formed into the bottom of the wall at specified intervals. The decreased bearing area concentrates the house load on the underlying soils. This type of foundation has been used in Colorado for soils having moderate to high swelling pressures. However, in recent years it has been largely supplanted for new construction by drilled pier foundations.

A mat foundation, or raft foundation, is a distinct type of shallow foundation that includes some type of concrete slab. One type of mat foundation used for swelling soils in Colorado is a **post-tensioned slab-on-grade** (Fig. 14). It consists of a concrete element that has waffle-like beams along the lower side and is smooth on the upper side. Strong steel cables, called tendons, cross through the slab. These tendons are tightened

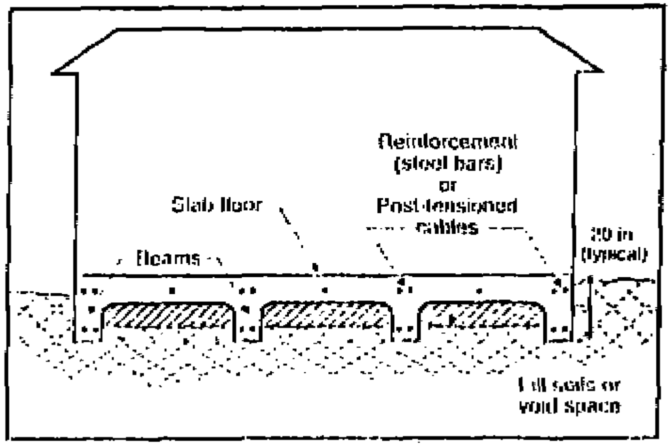


Figure 14. Post-tensioned slab-on-grade foundation. The bottom of the slab has a waffle-like pattern of longitudinal and transverse beams that extend downward a foot or more below the slab.

(tensioned) at intervals of time after the concrete is placed, so that the slab becomes stronger and more rigid as the concrete cures. The load-bearing walls of the building rest on the upper surface of the slab. Post-tensioned slabs have relatively large bearing areas and may be uplifted by moderately to highly swelling soils. However, the rigidity of the slab may allow the building to move as a unit to reduce damage. This type of foundation is most often used in Colorado for commercial or multi-family buildings that have large floor areas. It is rarely used for residential buildings with basements.

Deep Foundations

Drilled pier foundations (Fig. 15) are the deep foundation systems most often used in areas of moderately to very highly swelling soils in Colorado. Drilled piers for houses are typically constructed by drilling specifically positioned holes, usually 8 to 16 inches in diameter, into the ground. Steel reinforcement rods are lowered into the hole, after which the hole is filled with concrete. After the concrete hardens sufficiently, a grade beam is constructed over the piers to create a load-bearing span between them. Void spaces, filled with collapsible material such as corrugated cardboard, are created between the piers to separate the top of the soil from the bottom of the grade beam. Drilled piers typically range between 10 and 30 feet in length from top to bottom, depending on the soil and subsurface moisture conditions.

Drilled pier foundations have been specifically adapted for different swelling soil conditions. The design allows the load of the house to be concentrated on a relatively small number of piers. This allows the piers to resist uplift pressures from swelling soils. The piers must be drilled to a depth below the zone of expected post-construction moisture penetration (Fig. 16), or else they may heave and damage the house. Drilled pier foundations may reduce the effects of swelling soils when designed and constructed properly. There are certain geological situations in Colorado, however, where drilled piers may not be the most appropriate foundation design (e.g., in areas of steeply dipping bedrock, where the

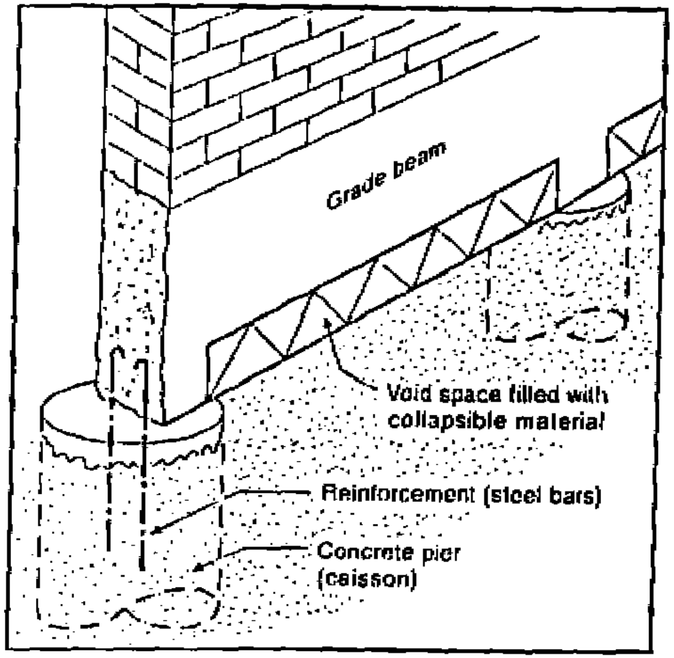


Figure 15. Drilled pier foundation. (Modified from Holtz and Hart, 1978.)

bedrock may be unstable to depths of more than 30 feet).

Several types of drilled pier configurations are typically used in Colorado. They may be straight-shafted or may have grooves cut near the base of each pier (Fig. 16). **End-bearing drilled piers** are drilled into bedrock, at least for the lower-most several feet. The load-carrying capacity of the pier is developed against a socket of stable bedrock at the bottom of the pier. (However, not all bedrock is stable; especially in areas having steeply dipping bedrock.) **Friction drilled piers** are drilled in thick soil deposits where the underlying bedrock is too deep to be reached. The load-carrying capacity of the pier is developed by friction along the shaft of the drilled pier. **Helical steel piers** (Fig. 16) are used in areas of Colorado as a remedial installation to replace previously damaged foundation elements. Helical piers consist of a steel shaft with auger-like blades near the tip. The tip is advanced into the ground by rotation until it meets a prescribed torque resistance or depth.

Lateral Support for Foundation Walls

Foundation walls require reinforcement or additional supports to resist **lateral pressures** exerted by the adjacent soils and backfill. This is especially true when the soils and backfill are composed of swell-prone clays. The exact design depends on the length, height, and general configuration of the walls, as well as soil and subsurface water conditions. **Reinforcement** may be provided by steel bars or beams or by wing-like walls (buttresses or counterforts) that extend outward from the foundation wall at a right angle. An improperly designed wall is at risk of buckling or bow-

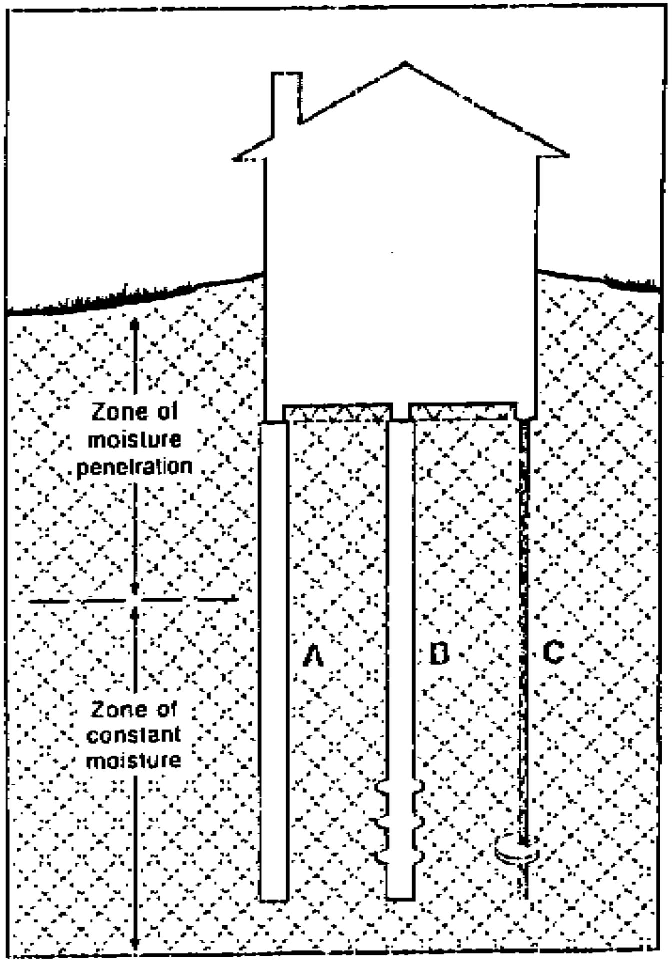


Figure 16. Three types of drilled piers commonly used in Colorado. A) Straight-shafted concrete pier; B) Concrete pier with grooves near base; C) Helical steel pier. All piers should extend well below the anticipated zone of moisture penetration.

ing inward when exposed to soils that have moderate to very high swelling pressures.

Floor Construction

There are two primary types of floors used in Colorado when swelling soils are present. **Floating slab floors** lie in contact with the soil and are designed to accommodate some amount of soil heaving, while **structural floors** are completely isolated from the soil surface. These floor systems are used for basements in many areas, especially in the Front Range urban corridor, but may be used for at-grade construction in cases where basements are not used. A short description of each floor type follows:

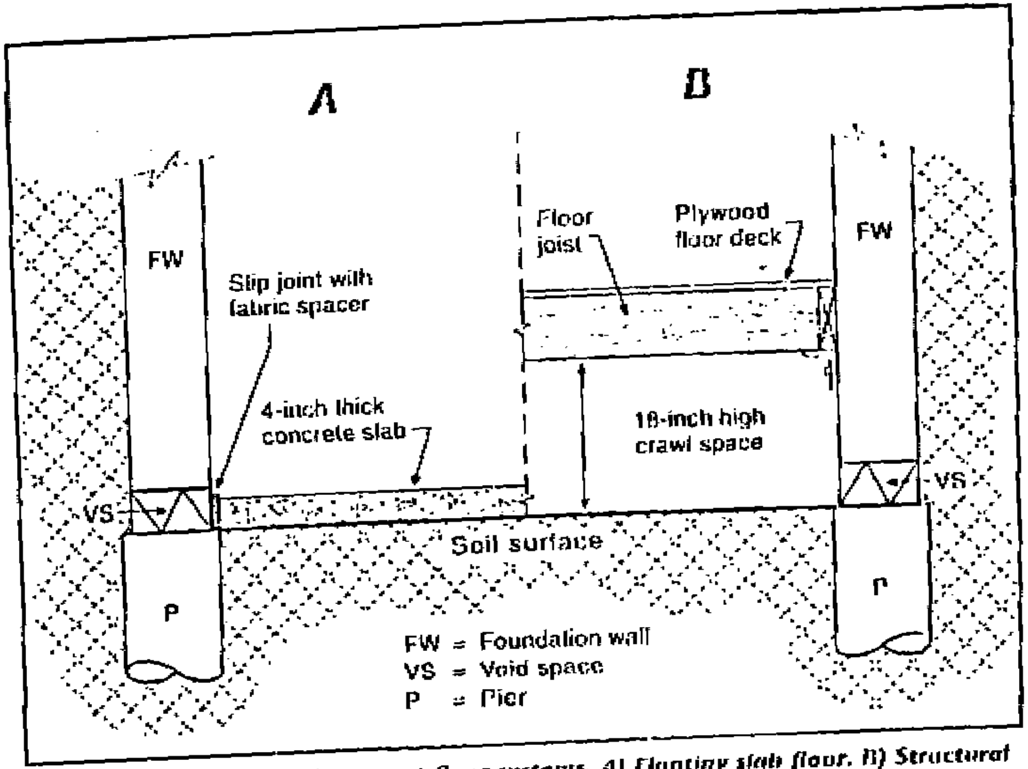


Figure 17. Two types of basement floor systems. A) Floating slab floor. B) Structural floor and crawl space.

Floating slab floors are the oldest type of flooring designed specifically for swelling soils. They usually consist of a non-reinforced concrete slab that rests directly on soil or fill (Fig. 17A). The slab is isolated from the outer foundation walls by a slip joint. The slip joint allows the slab to move up and down, or "float", independently from the foundation as the soils below swell and shrink. This design allows the floor to undergo 2 to 4 inches of vertical heaving without causing appreciable damage to the rest of the house. Special interior construction is necessary when floating slab floors are used (as explained in the next section).

Floating slab floors perform well for soils that are non-swelling or have low to moderate swell potential. They are also commonly used in conjunction with overexcavations, where a thick layer of non- to moderately swelling material separates the slab from the underlying soils. However, floating slabs installed directly upon highly swelling soils may undergo significant heaving, cracking, and buckling. This is because they do not weigh enough to resist the uplift pressure generated when the soils are wetted. As a result, floating slab floors are most commonly installed where the swell potential is low to moderate, and structural floors are most commonly used where the swell potential is high to very high. Floating slab floors are especially prone to