



- **Understanding Expansive Clay and Its Impact on Foundations**
Understanding Expansive Clay and Its Impact on Foundations Examining Sandy Loam for Residential Support Identifying Areas Vulnerable to Soil Erosion Evaluating Soil Moisture Fluctuations Beneath Homes Approaches for Chemical Soil Stabilization Techniques for Addressing Soil Heave Issues Managing Settlement with Targeted Soil Compaction Recognizing Soil Drainage Limitations Investigating Soil Stress Testing in Residential Sites Incorporating Root Barriers to Prevent Shifts Examining Seasonal Swelling and Shrinking of Soil Employing Sustainable Methods for Long Term Soil Health
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Overview of common causes for soil moisture fluctuations around homes

Soil moisture fluctuations around homes are a common issue that can lead to various problems, including foundation settlement, basement flooding, and landscaping issues. Foundation drainage solutions help prevent water-related damage **foundation crack repair service** building insulation. Understanding the causes behind these fluctuations is crucial for homeowners and property managers to mitigate potential damage and maintain a stable environment. Here, we explore some of the most common causes for soil moisture fluctuations beneath homes.

One primary cause of soil moisture fluctuation is natural weather patterns. Rainfall, snowfall, and changes in temperature can significantly impact soil moisture levels. During periods of heavy rain, soil can become saturated, leading to increased moisture content. Conversely, during dry spells, soil moisture can decrease, causing the soil to shrink and potentially leading to foundation issues.

Another significant factor is irrigation practices. Many homeowners use irrigation systems to maintain their lawns and gardens. While these systems are beneficial for plant growth, they can also contribute to soil moisture fluctuations. Over-irrigation can lead to excessive moisture, while under-irrigation can result in dry soil conditions. It's essential to balance irrigation to avoid extreme moisture levels.

Landscaping and grading around a home also play a crucial role in soil moisture fluctuations. Improper grading can cause water to pool around the foundation, leading to increased soil moisture. On the other hand, well-graded landscapes direct water away from the home, helping to maintain more stable soil moisture levels. Additionally, the type of vegetation planted can affect soil moisture; deep-rooted plants can help stabilize soil, while shallow-rooted plants may exacerbate moisture fluctuations.

Seasonal changes and the presence of nearby water bodies can also influence soil moisture levels. In colder climates, the freeze-thaw cycle can cause soil expansion and contraction, leading to moisture fluctuations. Homes near rivers, lakes, or groundwater sources may experience higher soil moisture levels due to the proximity of these water bodies.

Lastly, human activities such as construction and landscaping projects can disrupt natural soil conditions, leading to moisture fluctuations. Excavation and grading during construction can alter the soil's natural drainage patterns, while landscaping projects may introduce new plants and irrigation systems that affect soil moisture.

In conclusion, soil moisture fluctuations around homes are influenced by a variety of factors, including natural weather patterns, irrigation practices, landscaping and grading, seasonal changes, nearby water bodies, and human activities. By understanding these causes, homeowners and property managers can take proactive steps to manage soil moisture levels and prevent potential issues related to foundation stability and landscaping health.

Methods for evaluating soil moisture levels beneath residential properties

Evaluating soil moisture levels beneath residential properties is crucial for understanding the stability of the soil and the integrity of the foundation of homes. Various methods exist to assess these moisture levels, each with its own advantages and limitations. Here are some commonly used methods:

1. **Soil Sampling and Laboratory Analysis**:

This method involves taking soil samples from different depths beneath the property. These samples are then sent to a laboratory where they undergo various tests to determine moisture content, soil type, and other relevant properties. While this method is accurate, it can be time-consuming and costly.

2. **Moisture Meters**:

Moisture meters provide a quick and non-destructive way to measure soil moisture. These devices work by inserting probes into the soil, which then measure the electrical resistance or capacitance. Lower resistance or higher capacitance typically indicates higher moisture levels. This method is handy for quick assessments but may not provide detailed information about soil properties.

3. **Time Domain Reflectometry (TDR)**:

TDR is a more advanced technique that involves sending electromagnetic pulses through the soil and measuring the time it takes for the pulse to return. The speed of the pulse is affected by the soil's dielectric properties, which change with moisture content. TDR provides accurate measurements but requires specialized equipment and training.

4. **Ground-Penetrating Radar (GPR)**:

GPR uses high-frequency radio waves to create a subsurface image of the soil. By analyzing the reflected waves, one can infer moisture levels and other soil characteristics. GPR is non-invasive and can cover large areas quickly, but interpreting the data requires expertise.

5. **Remote Sensing**:

Satellite imagery and aerial photography can be used to monitor soil moisture over large areas. These methods rely on detecting surface moisture and inferring subsurface conditions. While useful for broad-scale assessments, they may not provide the detailed information needed for individual properties.

6. **Lysimeters**:

Lysimeters are devices that measure water movement through soil. They consist of a container filled with soil, placed in the ground, and equipped with sensors to monitor water content. This method provides continuous data but is limited to the specific location of the lysimeter.

Each of these methods has its own set of advantages and limitations. The choice of method

depends on factors such as the need for accuracy, the scale of assessment, budget constraints, and the specific conditions of the property. By employing these methods, homeowners and professionals can better understand soil moisture fluctuations and take appropriate measures to maintain the stability and safety of residential properties.

Impact of soil moisture changes on different types of residential foundations

Soil moisture is a critical factor in the stability and longevity of residential foundations. Understanding its impact is essential for homeowners, builders, and engineers alike. Let's explore how changes in soil moisture affect different types of residential foundations: slab-on-grade, crawl space, and basement foundations.

Slab-on-grade foundations, which are common in warmer climates, are directly poured onto the ground. They are particularly sensitive to soil moisture changes. When soil becomes overly saturated, it can lead to a phenomenon known as heave, where the soil expands and pushes upward on the foundation. Conversely, during dry periods, the soil can shrink, causing the foundation to settle unevenly. This can result in cracks in the foundation and, ultimately, structural issues within the home.

Crawl space foundations elevate the home above the ground, providing a space beneath for ventilation and storage. Changes in soil moisture can significantly impact these foundations. Excessive moisture can lead to mold growth, wood rot, and pest infestations. Additionally, if the soil beneath the crawl space becomes too moist, it can lose its bearing capacity, causing the foundation to settle. On the other hand, during dry spells, the soil can shrink, leading to sagging floors and potential structural damage.

Basement foundations are the most complex and are typically found in areas with colder climates. These foundations are below ground level and are surrounded by soil on all sides. Fluctuations in soil moisture can have severe consequences for basement foundations. High moisture levels can lead to water infiltration, causing dampness, mold, and even flooding. Prolonged exposure to moisture can weaken the foundation walls, leading to bowing or cracking. During dry periods, the soil can shrink, pulling away from the foundation walls and causing them to crack under the pressure.

In conclusion, soil moisture changes have a profound impact on different types of residential foundations. Homeowners must be vigilant about monitoring soil moisture levels and taking appropriate measures to mitigate potential issues. Regular inspections, proper drainage systems, and moisture barriers can help protect foundations from the adverse effects of soil moisture fluctuations, ensuring the stability and longevity of homes.

Case studies showcasing effects of soil moisture on home foundations

When it comes to evaluating the effects of soil moisture on home foundations, case studies provide invaluable insights. These real-life examples demonstrate how fluctuations in soil

moisture levels can lead to significant structural issues for homes.

One notable case study involves a suburban home in a region prone to heavy rainfall. Over several years, the homeowners noticed cracks forming in their foundation and walls. Upon investigation, soil tests revealed that the clay-rich soil around the house expanded significantly when wet, exerting pressure on the foundation. This phenomenon, known as heave, caused the foundation to lift unevenly, leading to the observed cracks. The solution involved installing a proper drainage system to manage rainwater and reduce soil moisture levels around the foundation.

Another compelling case is from a coastal area where homes are built on sandy soil. Here, the primary concern was not so much the expansion of soil but its erosion due to fluctuating moisture levels. During periods of high tide or heavy rain, the water table rose, saturating the soil and reducing its load-bearing capacity. This led to settling and sinking of the home's foundation. The case study highlighted the importance of using pilings driven deep into more stable soil layers to support the home, effectively mitigating the effects of soil moisture fluctuations.

In a third example, a home in a semi-arid region faced issues due to the opposite problem—desiccation of the soil. During prolonged dry spells, the soil shrank, creating voids beneath the foundation. This resulted in uneven settling and significant structural cracks. The solution involved regular monitoring of soil moisture levels and the implementation of irrigation systems to maintain consistent soil moisture, preventing extreme desiccation.

These case studies underscore the critical need for homeowners and builders to understand and manage soil moisture levels. By learning from these examples, we can better protect homes from the detrimental effects of soil moisture fluctuations, ensuring structural integrity and longevity.

Preventive measures homeowners can take to mitigate soil moisture issues

Certainly! Here's a human-like essay on preventive measures homeowners can take to mitigate soil moisture issues:

When it comes to maintaining the integrity of our homes, one often overlooked yet crucial factor is soil moisture. Fluctuations in soil moisture can lead to a host of problems, from foundation cracks to mold growth. Fortunately, there are several preventive measures homeowners can take to mitigate these issues and ensure a stable, healthy living environment.

First and foremost, proper landscaping is key. Ensuring that your yard is graded away from your home helps to direct water flow away from the foundation. This simple adjustment can significantly reduce the amount of moisture that accumulates around your home.

Additionally, installing French drains can further assist in diverting water away from the foundation, providing an effective solution for managing excess moisture.

Another important step is to maintain your gutters and downspouts. Clogged gutters can cause water to overflow and seep into the soil around your home, leading to increased moisture levels. Regularly cleaning gutters and ensuring that downspouts extend at least four to six feet away from the house can help prevent this issue.

Incorporating permeable materials in your landscaping can also make a big difference. Using gravel, mulch, or other permeable ground covers allows water to infiltrate the soil more gradually, reducing the risk of soil saturation. This not only helps manage moisture levels but also promotes healthier plant growth.

Homeowners should also consider the use of a vapor barrier in their basements or crawl spaces. A vapor barrier is a material that resists the passage of water vapor, helping to keep moisture levels in check. This is particularly important in areas prone to high humidity or frequent rainfall.

Lastly, regular inspections of your home's exterior can help identify potential moisture issues before they become serious problems. Look for signs of water pooling near the foundation, cracks in the walls, or musty odors, and address these issues promptly.

By taking these preventive measures, homeowners can effectively mitigate soil moisture issues, protecting their homes from potential damage and ensuring a safer, more stable living environment.

Professional services available for addressing soil moisture-related foundation problems

Certainly!

When it comes to evaluating soil moisture fluctuations beneath homes, it's essential to understand the role of professional services in addressing potential foundation problems. Soil moisture can have a profound impact on the stability of a home's foundation. When the soil around a foundation becomes too wet or too dry, it can lead to issues such as foundation cracking, sinking, or shifting. These problems can be both costly and dangerous if not addressed promptly.

Professional services specializing in soil moisture-related foundation problems offer a range of solutions tailored to the specific needs of each home. These experts start by conducting a thorough assessment of the soil conditions around the foundation. They use advanced equipment and techniques to measure soil moisture levels, identify areas of concern, and determine the root causes of any fluctuations.

Once the assessment is complete, these professionals provide detailed recommendations for remediation. This might include installing drainage systems to redirect water away from

the foundation, using moisture barriers to prevent water from seeping into the soil, or implementing aeration techniques to improve soil structure and drainage. In some cases, they may also suggest the use of chemical stabilizers to bind soil particles together, reducing the impact of moisture fluctuations.

Moreover, professional services don't just stop at remediation. They also offer ongoing monitoring and maintenance plans to ensure that soil moisture levels remain stable over time. This proactive approach helps prevent future foundation issues, saving homeowners both time and money in the long run.

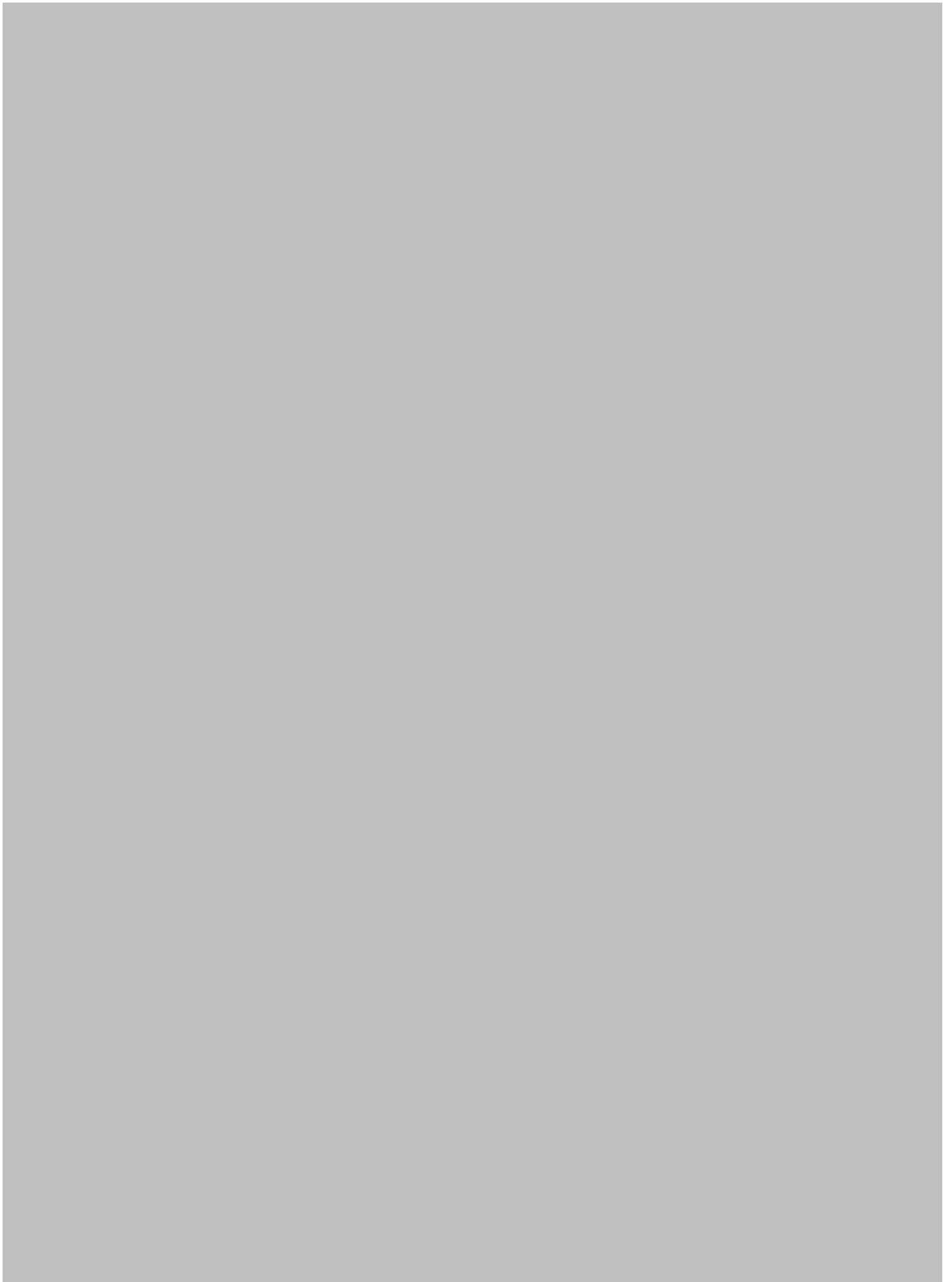
In conclusion, when dealing with soil moisture-related foundation problems, seeking the expertise of professional services is crucial. Their knowledge, experience, and specialized tools enable them to accurately assess, remediate, and monitor soil conditions, ensuring the long-term stability and safety of your home's foundation.



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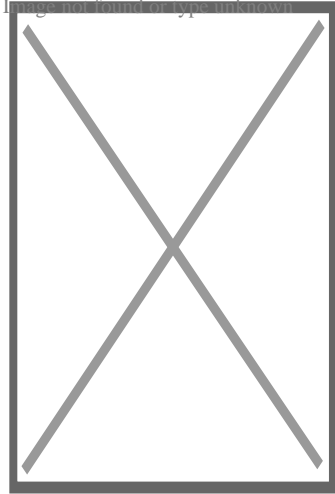
Strong Foundations, Strong Homes



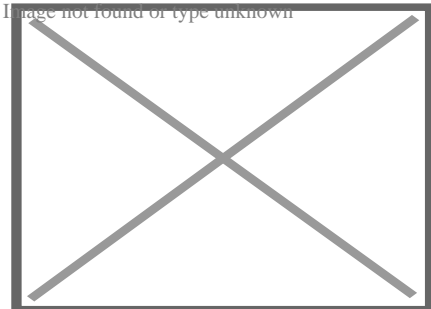
About soil mechanics



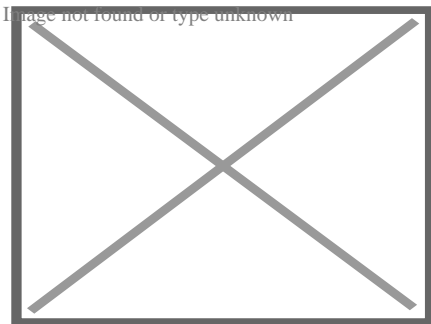
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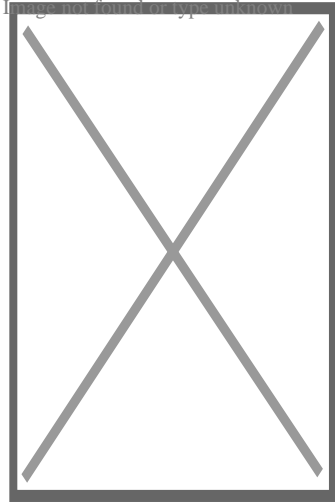
The Leaning Tower of Pisa – an example of a problem due to deformation of soil



Slope instability issues for a temporary flood control levee in North Dakota, 2009



Earthwork in Germany



Fox Glacier, New Zealand: Soil produced and transported by intense weathering and erosion

Soil mechanics is a branch of soil physics and applied mechanics that describes the behavior of soils. It differs from fluid mechanics and solid mechanics in the sense that soils consist of a heterogeneous mixture of fluids (usually air and water) and particles (usually clay, silt, sand, and gravel) but soil may also contain organic solids and other matter.^{[1][2][3][4]} Along with rock mechanics, soil mechanics provides the theoretical basis for analysis in geotechnical engineering,^[5] a subdiscipline of civil engineering, and engineering geology, a subdiscipline of geology. Soil mechanics is used to analyze the deformations of and flow of fluids within natural and man-made structures that are supported on or made of soil, or structures that are buried in soils.^[6] Example applications are building and bridge foundations, retaining walls, dams, and buried pipeline systems. Principles of soil mechanics are also used in related disciplines such as geophysical engineering, coastal engineering, agricultural engineering, and hydrology.

This article describes the genesis and composition of soil, the distinction between *pore water pressure* and inter-granular *effective stress*, capillary action of fluids in the soil pore spaces, *soil classification*, *seepage* and *permeability*, time dependent change of volume due to squeezing water out of tiny pore spaces, also known as *consolidation*, *shear strength* and stiffness of soils. The shear strength of soils is primarily derived from friction between the particles and interlocking, which are very sensitive to the effective stress.^{[7][6]} The article concludes with some examples of applications of the principles of soil mechanics such as slope stability, lateral earth pressure on retaining walls, and bearing capacity of foundations.

Genesis and composition of soils

[edit]

Genesis

[edit]

The primary mechanism of soil creation is the weathering of rock. All rock types (igneous rock, metamorphic rock and sedimentary rock) may be broken down into small particles to create soil. Weathering mechanisms are physical weathering, chemical weathering, and biological weathering [1][2][3] Human activities such as excavation, blasting, and waste disposal, may also create soil. Over geologic time, deeply buried soils may be altered by pressure and temperature to become metamorphic or sedimentary rock, and if melted and solidified again, they would complete the geologic cycle by becoming igneous rock.[3]

Physical weathering includes temperature effects, freeze and thaw of water in cracks, rain, wind, impact and other mechanisms. Chemical weathering includes dissolution of matter composing a rock and precipitation in the form of another mineral. Clay minerals, for example can be formed by weathering of feldspar, which is the most common mineral present in igneous rock.

The most common mineral constituent of silt and sand is quartz, also called silica, which has the chemical name silicon dioxide. The reason that feldspar is most common in rocks but silica is more prevalent in soils is that feldspar is much more soluble than silica.

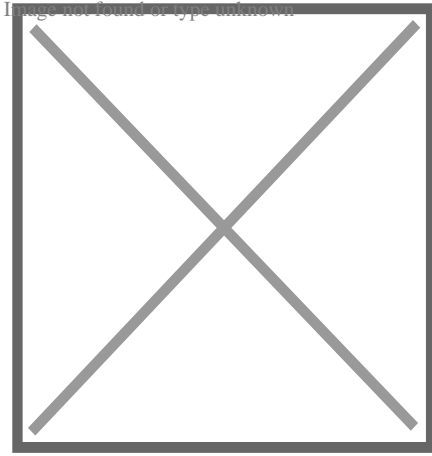
Silt, Sand, and Gravel are basically little pieces of broken rocks.

According to the Unified Soil Classification System, silt particle sizes are in the range of 0.002 mm to 0.075 mm and sand particles have sizes in the range of 0.075 mm to 4.75 mm.

Gravel particles are broken pieces of rock in the size range 4.75 mm to 100 mm. Particles larger than gravel are called cobbles and boulders.[1][2]

Transport

[edit]



Example soil horizons. a) top soil and colluvium b) mature residual soil c) young residual soil d) weathered rock

Soil deposits are affected by the mechanism of transport and deposition to their location. Soils that are not transported are called residual soils—they exist at the same location as the rock from which they were generated. Decomposed granite is a common example of a residual soil. The common mechanisms of transport are the actions of gravity, ice, water, and wind. Wind blown soils include dune sands and loess. Water carries particles of different size depending on the speed of the water, thus soils transported by water are graded according to their size. Silt and clay may settle out in a lake, and gravel and sand collect at the bottom of a river bed. Wind blown soil deposits (aeolian soils) also tend to be sorted according to their grain size. Erosion at the base of glaciers is powerful enough to pick up large rocks and boulders as well as soil; soils dropped by melting ice can be a well graded mixture of widely varying particle sizes. Gravity on its own may also carry particles down from the top of a mountain to make a pile of soil and boulders at the base; soil deposits transported by gravity are called colluvium.^{[1][2]}

The mechanism of transport also has a major effect on the particle shape. For example, low velocity grinding in a river bed will produce rounded particles. Freshly fractured colluvium particles often have a very angular shape.

Soil composition

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Soil mineralogy

[edit]

Silts, sands and gravels are classified by their size, and hence they may consist of a variety of minerals. Owing to the stability of quartz compared to other rock minerals, quartz is the most common constituent of sand and silt. Mica, and feldspar are other common minerals present in sands and silts.^[1] The mineral constituents of gravel may be more similar to that of the parent rock.

The common clay minerals are montmorillonite or smectite, illite, and kaolinite or kaolin. These minerals tend to form in sheet or plate like structures, with length typically ranging between $10^{?7}$ m and $4 \times 10^{?6}$ m and thickness typically ranging between $10^{?9}$ m and $2 \times 10^{?6}$ m, and they have a relatively large specific surface area. The specific surface area (SSA) is defined as the ratio of the surface area of particles to the mass of the particles. Clay minerals typically have specific surface areas in the range of 10 to 1,000 square meters per gram of solid.^[3] Due to the large surface area available for chemical, electrostatic, and van der Waals interaction, the mechanical behavior of clay minerals is very sensitive to the amount of pore fluid available and the type and amount of dissolved ions in the pore fluid.^[1]

The minerals of soils are predominantly formed by atoms of oxygen, silicon, hydrogen, and aluminum, organized in various crystalline forms. These elements along with calcium, sodium, potassium, magnesium, and carbon constitute over 99 per cent of the solid mass of soils.^[1]

Grain size distribution

[edit]

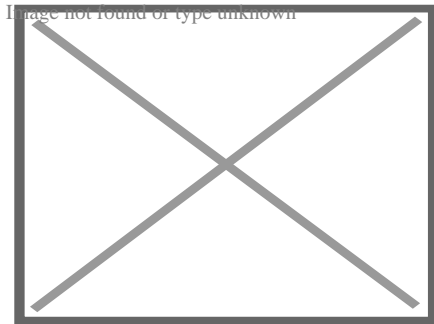
Main article: Soil gradation

Soils consist of a mixture of particles of different size, shape and mineralogy. Because the size of the particles obviously has a significant effect on the soil behavior, the grain size and grain size distribution are used to classify soils. The grain size distribution describes the relative proportions of particles of various sizes. The grain size is often visualized in a cumulative distribution graph which, for example, plots the percentage of particles finer than a given size as a function of size. The median grain size, d_{50} , which 50% of the particle mass consists of finer particles. Soil behavior, especially the hydraulic conductivity, tends to be dominated by the smaller particles, hence, the term "effective size", denoted by d_{10} the size for which 10% of the particle mass consists of finer particles.

Sands and gravels that possess a wide range of particle sizes with a smooth distribution of particle sizes are called *well graded* soils. If the soil particles in a sample are predominantly in a relatively narrow range of sizes, the sample is *uniformly graded*. If a soil sample has distinct gaps in the gradation curve, e.g., a mixture of gravel and fine sand, with no coarse sand, the sample may be *gap graded*. *Uniformly graded* and *gap graded* soils are both considered to be *poorly graded*. There are many methods for measuring particle-size distribution. The two traditional methods are sieve analysis and hydrometer analysis.

Sieve analysis

[edit]



Sieve

The size distribution of gravel and sand particles are typically measured using sieve analysis. The formal procedure is described in ASTM D6913-04(2009).^[8] A stack of sieves with accurately dimensioned holes between a mesh of wires is used to separate the particles into size bins. A known volume of dried soil, with clods broken down to individual particles, is put into the top of a stack of sieves arranged from coarse to fine. The stack of sieves is shaken for a standard period of time so that the particles are sorted into size bins. This method works reasonably well for particles in the sand and gravel size range. Fine particles tend to stick to each other, and hence the sieving process is not an effective method. If there are a lot of fines (silt and clay) present in the soil it may be necessary to run water through the sieves to wash the coarse particles and clods through.

A variety of sieve sizes are available. The boundary between sand and silt is arbitrary. According to the Unified Soil Classification System, a #4 sieve (4 openings per inch) having 4.75 mm opening size separates sand from gravel and a #200 sieve with an 0.075 mm opening separates sand from silt and clay. According to the British standard, 0.063 mm is the boundary between sand and silt, and 2 mm is the boundary between sand and gravel.^[3]

Hydrometer analysis

[edit]

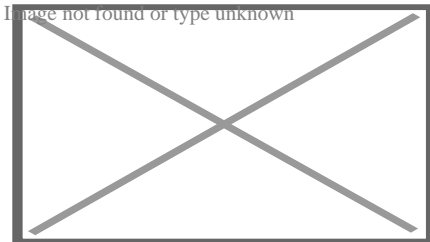
The classification of fine-grained soils, i.e., soils that are finer than sand, is determined primarily by their Atterberg limits, not by their grain size. If it is important to determine the grain size distribution of fine-grained soils, the hydrometer test may be performed. In the hydrometer tests, the soil particles are mixed with water and shaken to produce a dilute suspension in a glass cylinder, and then the cylinder is left to sit. A hydrometer is used to measure the density of the suspension as a function of time. Clay particles may take several

hours to settle past the depth of measurement of the hydrometer. Sand particles may take less than a second. Stokes' law provides the theoretical basis to calculate the relationship between sedimentation velocity and particle size. ASTM provides the detailed procedures for performing the Hydrometer test.

Clay particles can be sufficiently small that they never settle because they are kept in suspension by Brownian motion, in which case they may be classified as colloids.

Mass-volume relations

[edit]



A phase diagram of soil indicating the masses and volumes of air, solid, water, and voids

There are a variety of parameters used to describe the relative proportions of air, water and solid in a soil. This section defines these parameters and some of their interrelationships.^{[2][6]} The basic notation is as follows:

V_a, V_w, V_s are the volumes of air, water and solids in a soil mixture;

W_a, W_w, W_s are the weights of air, water and solids in a soil mixture;

M_a, M_w, M_s are the masses of air, water and solids in a soil mixture;

ρ_a, ρ_w, ρ_s represent the densities of the constituents (air, water and solids) in a soil mixture;

Note that the weights, W , can be obtained by multiplying the mass, M , by the acceleration due to gravity, g ; e.g., $W_s = M_s g$

Specific Gravity is the ratio of the density of one material compared to the density of pure water ($\rho_w = 1 \text{ g/cm}^3$)

$$G_s = \frac{\rho_s}{\rho_w}$$

Specific gravity of solids, Image not found or type unknown

Note that specific weight, conventionally denoted by the symbol γ , may be obtained by multiplying the density (ρ) of a material by the acceleration due to gravity, g .

Density, bulk density, or wet density, ρ , are different names for the density of the mixture, i.e., the total mass of air, water, solids divided by the total volume of air water and solids (the mass of air is assumed to be zero for practical purposes):

$$\rho = \frac{M_s + M_w}{V_s + V_w + V_a} = \frac{M_t}{V_t}$$

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Dry density, ρ_d , is the mass of solids divided by the total volume of air water and solids:

$$\rho_d = \frac{M_s}{V_s + V_w + V_a} = \frac{M_s}{V_t}$$

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Buoyant density, ρ' , defined as the density of the mixture minus the density of water is useful if the soil is submerged under water:

$$\rho' = \rho - \rho_w$$

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where ρ_w is the density of water

Water content, w , is the ratio of mass of water to mass of solid. It is easily measured by weighing a sample of the soil, drying it out in an oven and re-weighing. Standard procedures are described by ASTM.

$$w = \frac{M_w}{M_s} = \frac{W_w}{W_s}$$

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Void ratio, e , is the ratio of the volume of voids to the volume of solids:

$$e = \frac{V_v}{V_s} = \frac{V_v}{V_t - V_v} = \frac{n}{1-n}$$

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Porosity, n , is the ratio of volume of voids to the total volume, and is related to the void ratio:

$$n = \frac{V_v}{V_t} = \frac{V_v}{V_s + V_v} = \frac{e}{1+e}$$

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Degree of saturation, S , is the ratio of the volume of water to the volume of voids:

$$S = \frac{V_w}{V_v}$$

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From the above definitions, some useful relationships can be derived by use of basic algebra.

$$\rho = \frac{G_s + Se}{\rho_w(1+e)}$$

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$$\rho = \frac{(1+w)G_s}{\rho_w(1+e)}$$

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$$w = \frac{Se}{G_s}$$

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Soil classification

[edit]

Geotechnical engineers classify the soil particle types by performing tests on disturbed (dried, passed through sieves, and remolded) samples of the soil. This provides information about the characteristics of the soil grains themselves. Classification of the types of grains present in a soil does not ^[clarification needed] account for important effects of the *structure* or *fabric* of the soil, terms that describe compactness of the particles and patterns in the arrangement of particles in a load carrying framework as well as the pore size and pore fluid distributions. Engineering geologists also classify soils based on their genesis and depositional history.

Classification of soil grains

[edit]

In the US and other countries, the Unified Soil Classification System (USCS) is often used for soil classification. Other classification systems include the British Standard BS 5930 and the AASHTO soil classification system.^[3]

Classification of sands and gravels

[edit]

In the USCS, gravels (given the symbol *G*) and sands (given the symbol *S*) are classified according to their grain size distribution. For the USCS, gravels may be given the classification symbol *GW* (well-graded gravel), *GP* (poorly graded gravel), *GM* (gravel with a large amount of silt), or *GC* (gravel with a large amount of clay). Likewise sands may be

classified as being *SW*, *SP*, *SM* or *SC*. Sands and gravels with a small but non-negligible amount of fines (5–12%) may be given a dual classification such as *SW-SC*.

Atterberg limits

[edit]

Clays and Silts, often called 'fine-grained soils', are classified according to their Atterberg limits; the most commonly used Atterberg limits are the *liquid limit* (denoted by *LL* or w_L) and *plastic limit* (denoted by *PL* or w_p) and *shrinkage limit* (denoted by *SL*).

The liquid limit is the water content at which the soil behavior transitions from a plastic solid to a liquid. The plastic limit is the water content at which the soil behavior transitions from that of a plastic solid to a brittle solid. The Shrinkage Limit corresponds to a water content below which the soil will not shrink as it dries. The consistency of fine grained soil varies in proportional to the water content in a soil.

As the transitions from one state to another are gradual, the tests have adopted arbitrary definitions to determine the boundaries of the states. The liquid limit is determined by measuring the water content for which a groove closes after 25 blows in a standard test.^[9]^[clarification needed] Alternatively, a fall cone test apparatus may be used to measure the liquid limit. The undrained shear strength of remolded soil at the liquid limit is approximately 2 kPa.^[4]^[10] The plastic limit is the water content below which it is not possible to roll by hand the soil into 3 mm diameter cylinders. The soil cracks or breaks up as it is rolled down to this diameter. Remolded soil at the plastic limit is quite stiff, having an undrained shear strength of the order of about 200 kPa.^[4]^[10]

The *plasticity index* of a particular soil specimen is defined as the difference between the liquid limit and the plastic limit of the specimen; it is an indicator of how much water the soil particles in the specimen can absorb, and correlates with many engineering properties like permeability, compressibility, shear strength and others. Generally, the clay having high plasticity have lower permeability and also they are also difficult to be compacted.

Classification of silts and clays

[edit]

According to the Unified Soil Classification System (USCS), silts and clays are classified by plotting the values of their plasticity index and liquid limit on a plasticity chart. The A-Line on the chart separates clays (given the USCS symbol *C*) from silts (given the symbol *M*). $LL=50\%$ separates high plasticity soils (given the modifier symbol *H*) from low plasticity soils (given the modifier symbol *L*). A soil that plots above the A-line and has $LL>50\%$ would, for

example, be classified as *CH*. Other possible classifications of silts and clays are *ML*, *CL* and *MH*. If the Atterberg limits plot in the "hatched" region on the graph near the origin, the soils are given the dual classification 'CL-ML'.

Indices related to soil strength

[edit]

Liquidity index

[edit]

The effects of the water content on the strength of saturated remolded soils can be quantified by the use of the *liquidity index*, *LI*:

$$LI = \frac{w - P_L}{P_L - P_U}$$

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When the LI is 1, remolded soil is at the liquid limit and it has an undrained shear strength of about 2 kPa. When the soil is at the plastic limit, the LI is 0 and the undrained shear strength is about 200 kPa.^[4]^[11]

Relative density

[edit]

The density of sands (cohesionless soils) is often characterized by the relative density, D_r .

$$D_r = \frac{e_{max} - e - e_{min}}{e_{max} - e_{min}} 100\%$$

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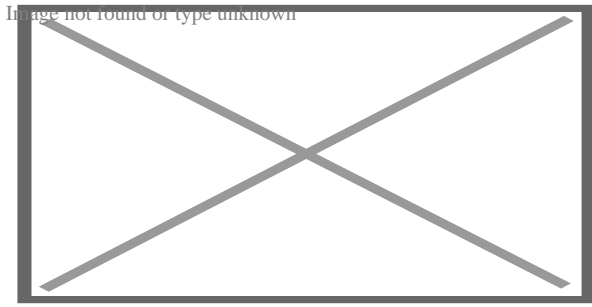
where: e_{max} is the "maximum void ratio" corresponding to a very loose state, e_{min} is the "minimum void ratio" corresponding to a very dense state and e is the *in situ* void ratio. Methods used to calculate relative density are defined in ASTM D4254-00(2006).^[12]

Thus if $D_r = 100\%$ the sand or gravel is very dense, and if $D_r = 0\%$ the soil is extremely loose and unstable.

Seepage: steady state flow of water

[edit]

This section is an excerpt from Seepage.[edit]

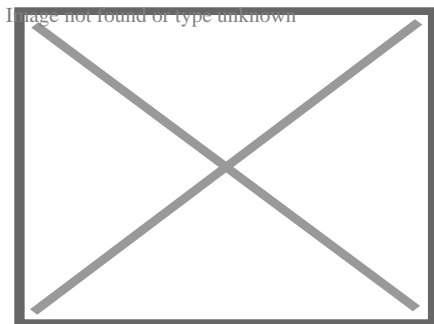


A cross section showing the water table varying with surface topography as well as a perched water table

In soil mechanics, seepage is the movement of water through soil. If fluid pressures in a soil deposit are uniformly increasing with depth according to $\rho_w g z$, where z is the depth below the water table, then hydrostatic conditions will prevail and the fluids will *not* be flowing through the soil. However, if the water table is sloping or there is a perched water table as indicated in the accompanying sketch, then seepage will occur. For steady state seepage, the seepage velocities are not varying with time. If the water tables are changing levels with time, or if the soil is in the process of consolidation, then steady state conditions do not apply.

Effective stress and capillarity: hydrostatic conditions

[edit]



Spheres immersed in water, reducing effective stress

Main article: Effective stress

To understand the mechanics of soils it is necessary to understand how normal stresses and shear stresses are shared by the different phases. Neither gas nor liquid provide significant resistance to shear stress. The shear resistance of soil is provided by friction and interlocking of the particles. The friction depends on the intergranular contact stresses between solid particles. The normal stresses, on the other hand, are shared by the fluid and the particles.^[7] Although the pore air is relatively compressible, and hence takes little normal stress in most geotechnical problems, liquid water is relatively incompressible and if the voids are saturated with water, the pore water must be squeezed out in order to pack the particles closer together.

The principle of effective stress, introduced by Karl Terzaghi, states that the effective stress σ' (i.e., the average intergranular stress between solid particles) may be calculated by a simple subtraction of the pore pressure from the total stress:

$$\sigma' = \sigma - u,$$

where σ is the total stress and u is the pore pressure. It is not practical to measure σ' directly, so in practice the vertical effective stress is calculated from the pore pressure and vertical total stress. The distinction between the terms pressure and stress is also important. By definition, pressure at a point is equal in all directions but stresses at a point can be different in different directions. In soil mechanics, compressive stresses and pressures are considered to be positive and tensile stresses are considered to be negative, which is different from the solid mechanics sign convention for stress.

Total stress

[edit]

For level ground conditions, the total vertical stress at a point, σ_v , on average, is the weight of everything above that point per unit area. The vertical stress beneath a uniform surface layer with density ρ and thickness H is

$$\sigma_v = \rho gH = \gamma H$$

where g is the acceleration due to gravity, and γ is the unit weight of the overlying layer. If there are multiple layers of soil or water above the point of interest, the vertical stress may be calculated by summing the product of the unit weight and thickness of all of the overlying layers. Total stress increases with increasing depth in proportion to the density of the overlying soil.

It is not possible to calculate the horizontal total stress in this way. Lateral earth pressures are addressed elsewhere.

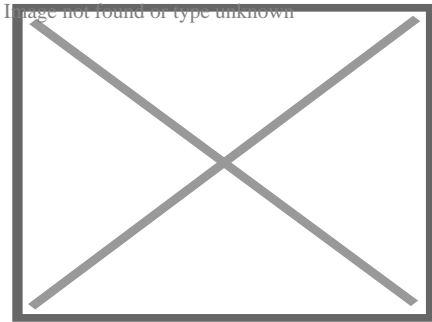
Pore water pressure

[edit]

Main article: Pore water pressure

Hydrostatic conditions

[edit]



Water is drawn into a small tube by surface tension. Water pressure, u , is negative above and positive below the free water surface.

If the soil pores are filled with water that is not flowing but is static, the pore water pressures will be hydrostatic. The water table is located at the depth where the water pressure is equal to the atmospheric pressure. For hydrostatic conditions, the water pressure increases linearly with depth below the water table:

$$u = \rho_w g z_w$$

where ρ_w is the density of water, and z_w is the depth below the water table.

Capillary action

[edit]

Due to surface tension, water will rise up in a small capillary tube above a free surface of water. Likewise, water will rise up above the water table into the small pore spaces around the soil particles. In fact the soil may be completely saturated for some distance above the water table. Above the height of capillary saturation, the soil may be wet but the water content will decrease with elevation. If the water in the capillary zone is not moving, the water pressure obeys the equation of hydrostatic equilibrium, $u = \rho_w g z_w$, but note that z_w is negative above the water table. Hence, hydrostatic water pressures are negative above the water table. The thickness of the zone of capillary saturation depends on the pore size, but typically, the heights vary between a centimeter or so for coarse sand to tens of meters for a silt or clay.^[3] In fact the pore space of soil is a uniform fractal e.g. a set of uniformly distributed D-dimensional fractals of average linear size L. For the clay soil it has been found that $L=0.15$ mm and $D=2.7$.^[13]

The surface tension of water explains why the water does not drain out of a wet sand castle or a moist ball of clay. Negative water pressures make the water stick to the particles and pull the particles to each other, friction at the particle contacts make a sand castle stable. But as soon as a wet sand castle is submerged below a free water surface, the negative pressures are lost and the castle collapses. Considering the effective stress equation, $\displaystyle \sigma' = \sigma - u$, the water pressure is negative, the effective stress may be positive, even on a free surface (a surface where the total normal stress is zero). The negative pore pressure pulls the particles together and causes compressive particle to particle contact forces. Negative pore pressures in clayey soil can be much more powerful than those in sand. Negative pore pressures explain why clay soils shrink when they dry and swell as they are wetted. The swelling and shrinkage can cause major distress, especially to light structures and roads.^[14]

Later sections of this article address the pore water pressures for seepage and consolidation problems.

Water at particle contacts

○

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Water at
particle
contacts

- Intergranular contact force due to surface tension

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Intergranular
contact force due
to surface tension
Shrinkage caused by drying

○

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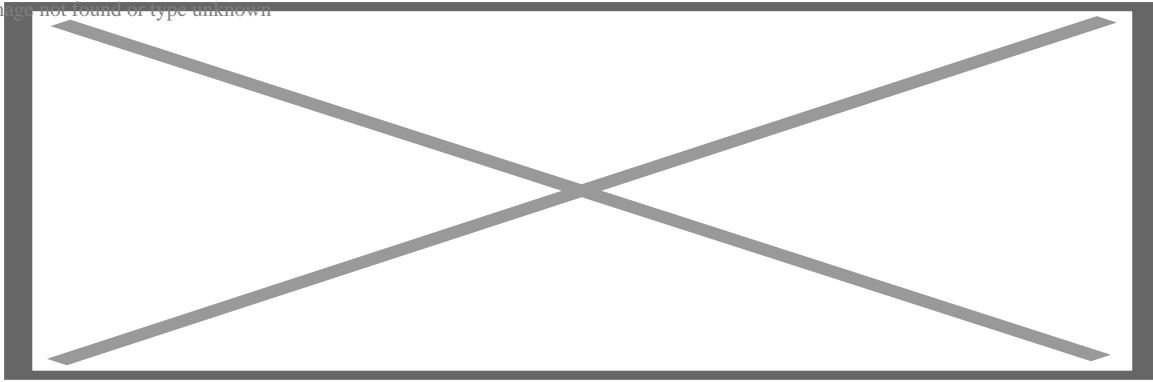
Shrinkage caused
by drying

Consolidation: transient flow of water

[edit]

Main article: Consolidation (soil)

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Consolidation analogy. The piston is supported by water underneath and a spring. When a load is applied to the piston, water pressure increases to support the load. As the water slowly leaks through the small hole, the load is transferred from the water pressure to the spring force.

Consolidation is a process by which soils decrease in volume. It occurs when stress is applied to a soil that causes the soil particles to pack together more tightly, therefore reducing volume. When this occurs in a soil that is saturated with water, water will be squeezed out of the soil. The time required to squeeze the water out of a thick deposit of clayey soil layer might be years. For a layer of sand, the water may be squeezed out in a matter of seconds. A building foundation or construction of a new embankment will cause the soil below to consolidate and this will cause settlement which in turn may cause distress to the building or embankment. Karl Terzaghi developed the theory of one-dimensional consolidation which enables prediction of the amount of settlement and the time required for the settlement to occur.^[15] Afterwards, Maurice Biot fully developed the three-dimensional soil consolidation theory, extending the one-dimensional model previously developed by Terzaghi to more general hypotheses and introducing the set of basic equations of Poroelasticity.^[7] Soils are tested with an oedometer test to determine their compression index and coefficient of consolidation.

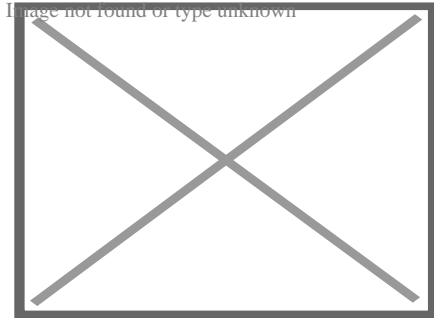
When stress is removed from a consolidated soil, the soil will rebound, drawing water back into the pores and regaining some of the volume it had lost in the consolidation process. If the stress is reapplied, the soil will re-consolidate again along a recompression curve, defined by the recompression index. Soil that has been consolidated to a large pressure and has been subsequently unloaded is considered to be *overconsolidated*. The maximum past vertical effective stress is termed the *preconsolidation stress*. A soil which is currently experiencing the maximum past vertical effective stress is said to be *normally consolidated*. The *overconsolidation ratio*, (OCR) is the ratio of the maximum past vertical effective stress to the current vertical effective stress. The OCR is significant for two reasons: firstly, because the compressibility of normally consolidated soil is significantly larger than that for overconsolidated soil, and secondly, the shear behavior and dilatancy of clayey soil are related to the OCR through critical state soil mechanics; highly overconsolidated clayey soils

are dilatant, while normally consolidated soils tend to be contractive.^{[2][3][4]}

Shear behavior: stiffness and strength

[edit]

Main article: shear strength (soil)



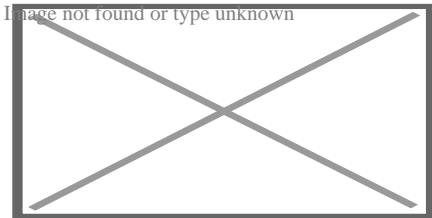
Typical stress strain curve for a drained dilatant soil

The shear strength and stiffness of soil determines whether or not soil will be stable or how much it will deform. Knowledge of the strength is necessary to determine if a slope will be stable, if a building or bridge might settle too far into the ground, and the limiting pressures on a retaining wall. It is important to distinguish between failure of a soil element and the failure of a geotechnical structure (e.g., a building foundation, slope or retaining wall); some soil elements may reach their peak strength prior to failure of the structure. Different criteria can be used to define the "shear strength" and the "yield point" for a soil element from a stress–strain curve. One may define the peak shear strength as the peak of a stress–strain curve, or the shear strength at critical state as the value after large strains when the shear resistance levels off. If the stress–strain curve does not stabilize before the end of shear strength test, the "strength" is sometimes considered to be the shear resistance at 15–20% strain.^[14] The shear strength of soil depends on many factors including the effective stress and the void ratio.

The shear stiffness is important, for example, for evaluation of the magnitude of deformations of foundations and slopes prior to failure and because it is related to the shear wave velocity. The slope of the initial, nearly linear, portion of a plot of shear stress as a function of shear strain is called the shear modulus

Friction, interlocking and dilation

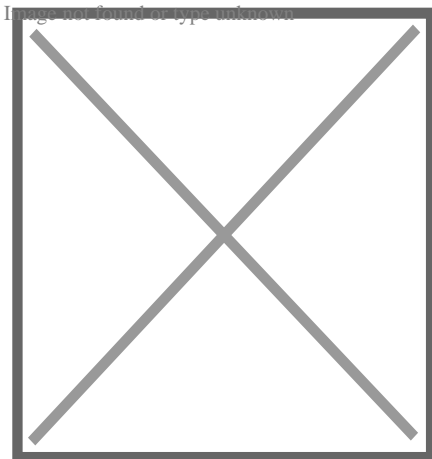
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Angle of repose

Soil is an assemblage of particles that have little to no cementation while rock (such as sandstone) may consist of an assembly of particles that are strongly cemented together by chemical bonds. The shear strength of soil is primarily due to interparticle friction and therefore, the shear resistance on a plane is approximately proportional to the effective normal stress on that plane.^[3] The angle of internal friction is thus closely related to the maximum stable slope angle, often called the angle of repose.

But in addition to friction, soil derives significant shear resistance from interlocking of grains. If the grains are densely packed, the grains tend to spread apart from each other as they are subject to shear strain. The expansion of the particle matrix due to shearing was called dilatancy by Osborne Reynolds.^[11] If one considers the energy required to shear an assembly of particles there is energy input by the shear force, T , moving a distance, x and there is also energy input by the normal force, N , as the sample expands a distance, y .^[11] Due to the extra energy required for the particles to dilate against the confining pressures, dilatant soils have a greater peak strength than contractive soils. Furthermore, as dilatant soil grains dilate, they become looser (their void ratio increases), and their rate of dilation decreases until they reach a critical void ratio. Contractive soils become denser as they shear, and their rate of contraction decreases until they reach a critical void ratio.



A critical state line separates the dilatant and contractive states for soil.

The tendency for a soil to dilate or contract depends primarily on the confining pressure and the void ratio of the soil. The rate of dilation is high if the confining pressure is small and the void ratio is small. The rate of contraction is high if the confining pressure is large and the void ratio is large. As a first approximation, the regions of contraction and dilation are separated by the critical state line.

Failure criteria

[edit]

After a soil reaches the critical state, it is no longer contracting or dilating and the shear stress on the failure plane τ_{crit} is determined by the effective normal stress on the failure plane σ'_n and critical state friction angle ϕ_{crit}

$$\tau_{crit} = \sigma'_n \tan \phi_{crit}$$

The peak strength of the soil may be greater, however, due to the interlocking (dilatancy) contribution. This may be stated:

$$\tau_{peak} = \sigma'_n \tan \phi_{peak}$$

where $\phi_{peak} > \phi_{crit}$. However, use of a friction angle greater than the critical state value for design requires care. The peak strength will not be mobilized everywhere at the same time in a practical problem such as a foundation, slope or retaining wall. The critical state friction angle is not nearly as variable as the peak friction angle and hence it can be relied upon with confidence.^{[3][4][11]}

Not recognizing the significance of dilatancy, Coulomb proposed that the shear strength of soil may be expressed as a combination of adhesion and friction components:^[11]

$$\tau_f = c' + \sigma'_f \tan \phi'$$

It is now known that the ϕ' and c' parameters in the last equation are not fundamental soil properties.^{[3][6][11][16]} In particular, ϕ' and c' are different depending on the magnitude of effective stress.^{[6][16]} According to Schofield (2006),^[11] the longstanding use of c' practice has led many engineers to wrongly believe that c' is a fundamental parameter. This assumption that ϕ' and c' are constant can lead to overestimation of peak strengths.^{[3][16]}

Structure, fabric, and chemistry

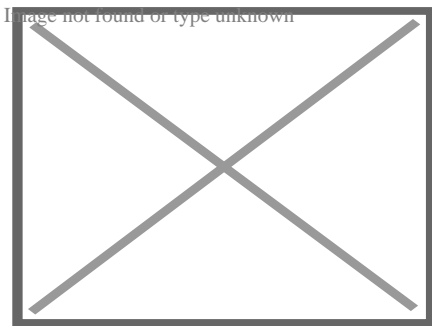
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In addition to the friction and interlocking (dilatancy) components of strength, the structure and fabric also play a significant role in the soil behavior. The structure and fabric include

factors such as the spacing and arrangement of the solid particles or the amount and spatial distribution of pore water; in some cases cementitious material accumulates at particle-particle contacts. Mechanical behavior of soil is affected by the density of the particles and their structure or arrangement of the particles as well as the amount and spatial distribution of fluids present (e.g., water and air voids). Other factors include the electrical charge of the particles, chemistry of pore water, chemical bonds (i.e. cementation -particles connected through a solid substance such as recrystallized calcium carbonate) ^{[1][16]}

Drained and undrained shear

[edit]



Moist sand along the shoreline is originally densely packed by the draining water. Foot pressure on the sand causes it to dilate (see: *Reynolds dilatancy*), drawing water from the surface into the pores.

The presence of nearly incompressible fluids such as water in the pore spaces affects the ability for the pores to dilate or contract.

If the pores are saturated with water, water must be sucked into the dilating pore spaces to fill the expanding pores (this phenomenon is visible at the beach when apparently dry spots form around feet that press into the wet sand). ^[clarification needed]

Similarly, for contractive soil, water must be squeezed out of the pore spaces to allow contraction to take place.

Dilation of the voids causes negative water pressures that draw fluid into the pores, and contraction of the voids causes positive pore pressures to push the water out of the pores. If the rate of shearing is very large compared to the rate that water can be sucked into or squeezed out of the dilating or contracting pore spaces, then the shearing is called *undrained shear*, if the shearing is slow enough that the water pressures are negligible, the shearing is called *drained shear*. During undrained shear, the water pressure u changes depending on volume change tendencies. From the effective stress equation, the change in u directly effects the effective stress by the equation:

$$\sigma' = \sigma - u,$$

and the strength is very sensitive to the effective stress. It follows then that the undrained shear strength of a soil may be smaller or larger than the drained shear strength depending upon whether the soil is contractive or dilative.

Shear tests

[edit]

Strength parameters can be measured in the laboratory using direct shear test, triaxial shear test, simple shear test, fall cone test and (hand) shear vane test; there are numerous other devices and variations on these devices used in practice today. Tests conducted to characterize the strength and stiffness of the soils in the ground include the Cone penetration test and the Standard penetration test.

Other factors

[edit]

The stress–strain relationship of soils, and therefore the shearing strength, is affected by:^[17]

1. *soil composition* (basic soil material): mineralogy, grain size and grain size distribution, shape of particles, pore fluid type and content, ions on grain and in pore fluid.
2. *state* (initial): Defined by the initial void ratio, effective normal stress and shear stress (stress history). State can be described by terms such as: loose, dense, overconsolidated, normally consolidated, stiff, soft, contractive, dilative, etc.
3. *structure*: Refers to the arrangement of particles within the soil mass; the manner in which the particles are packed or distributed. Features such as layers, joints, fissures, slickensides, voids, pockets, cementation, etc., are part of the structure. Structure of soils is described by terms such as: undisturbed, disturbed, remolded, compacted, cemented; flocculent, honey-combed, single-grained; flocculated, deflocculated; stratified, layered, laminated; isotropic and anisotropic.
4. *Loading conditions*: Effective stress path - drained, undrained, and type of loading - magnitude, rate (static, dynamic), and time history (monotonic, cyclic).

Applications

[edit]

Lateral earth pressure

[edit]

Main article: Lateral earth pressure

Lateral earth stress theory is used to estimate the amount of stress soil can exert perpendicular to gravity. This is the stress exerted on retaining walls. A lateral earth stress coefficient, K , is defined as the ratio of lateral (horizontal) effective stress to vertical effective stress for cohesionless soils ($K = \sigma'_h / \sigma'_v$). There are three coefficients: at-rest, active, and passive. At-rest stress is the lateral stress in the ground before any disturbance takes place. The active stress state is reached when a wall moves away from the soil under the influence of lateral stress, and results from shear failure due to reduction of lateral stress. The passive stress state is reached when a wall is pushed into the soil far enough to cause shear failure within the mass due to increase of lateral stress. There are many theories for estimating lateral earth stress; some are empirically based, and some are analytically derived.

Bearing capacity

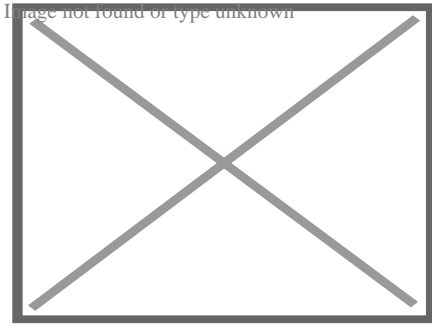
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Main article: Bearing capacity

The bearing capacity of soil is the average contact stress between a foundation and the soil which will cause shear failure in the soil. Allowable bearing stress is the bearing capacity divided by a factor of safety. Sometimes, on soft soil sites, large settlements may occur under loaded foundations without actual shear failure occurring; in such cases, the allowable bearing stress is determined with regard to the maximum allowable settlement. It is important during construction and design stage of a project to evaluate the subgrade strength. The California Bearing Ratio (CBR) test is commonly used to determine the suitability of a soil as a subgrade for design and construction. The field Plate Load Test is commonly used to predict the deformations and failure characteristics of the soil/subgrade and modulus of subgrade reaction (k_s). The Modulus of subgrade reaction (k_s) is used in foundation design, soil-structure interaction studies and design of highway pavements.^{*[citation needed]*}

Slope stability

[edit]



Simple slope slip section

Main article: Slope stability

The field of slope stability encompasses the analysis of static and dynamic stability of slopes of earth and rock-fill dams, slopes of other types of embankments, excavated slopes, and natural slopes in soil and soft rock.^[18]

As seen to the right, earthen slopes can develop a cut-spherical weakness zone. The probability of this happening can be calculated in advance using a simple 2-D circular analysis package.^[19] A primary difficulty with analysis is locating the most-probable slip plane for any given situation.^[20] Many landslides have been analyzed only after the fact. Landslides vs. Rock strength are two factors for consideration.

Recent developments

[edit]

A recent finding in soil mechanics is that soil deformation can be described as the behavior of a dynamical system. This approach to soil mechanics is referred to as Dynamical Systems based Soil Mechanics (DSSM). DSSM holds simply that soil deformation is a Poisson process in which particles move to their final position at random shear strains.

The basis of DSSM is that soils (including sands) can be sheared till they reach a steady-state condition at which, under conditions of constant strain-rate, there is no change in shear stress, effective confining stress, and void ratio. The steady-state was formally defined^[21] by Steve J. Poulos Archived 2020-10-17 at the Wayback Machine an associate professor at the Soil Mechanics Department of Harvard University, who built off a hypothesis that Arthur Casagrande was formulating towards the end of his career. The steady state condition is not the same as the "critical state" condition. It differs from the critical state in that it specifies a statistically constant structure at the steady state. The steady-state values are also very slightly dependent on the strain-rate.

Many systems in nature reach steady states, and dynamical systems theory describes such systems. Soil shear can also be described as a dynamical system.^{[22][23]} The physical basis of the soil shear dynamical system is a Poisson process in which particles move to the

steady-state at random shear strains.^[24] Joseph^[25] generalized this—particles move to their final position (not just steady-state) at random shear-strains. Because of its origins in the steady state concept, DSSM is sometimes informally called "Harvard soil mechanics."

DSSM provides for very close fits to stress–strain curves, including for sands. Because it tracks conditions on the failure plane, it also provides close fits for the post failure region of sensitive clays and silts something that other theories are not able to do. Additionally DSSM explains key relationships in soil mechanics that to date have simply been taken for granted, for example, why normalized undrained peak shear strengths vary with the log of the overconsolidation ratio and why stress–strain curves normalize with the initial effective confining stress; and why in one-dimensional consolidation the void ratio must vary with the log of the effective vertical stress, why the end-of-primary curve is unique for static load increments, and why the ratio of the creep value C_c to the compression index C_c must be approximately constant for a wide range of soils.^[26]

See also

[edit]

- Critical state soil mechanics
- Earthquake engineering
- Engineering geology
- Geotechnical centrifuge modeling
- Geotechnical engineering
- Geotechnical engineering (Offshore)
- Geotechnics
- Hydrogeology, aquifer characteristics closely related to soil characteristics
- International Society for Soil Mechanics and Geotechnical Engineering
- Rock mechanics
- Slope stability analysis

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[edit]

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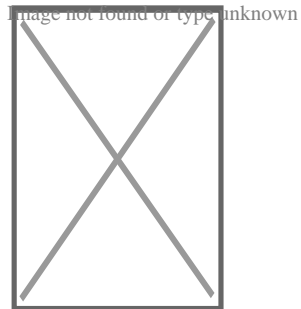
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- Australian Society of Soil Science Incorporated
- Canadian Society of Soil Science
- Central Soil Salinity Research Institute (India)
- German Soil Science Society
- Indian Institute of Soil Science
- International Union of Soil Sciences
- International Year of Soil
- National Society of Consulting Soil Scientists (US)
- OPAL Soil Centre (UK)
- Soil Science Society of Poland
- Soil and Water Conservation Society (US)
- Soil Science Society of America
- World Congress of Soil Science

Scientific journals

- *Acta Agriculturae Scandinavica B*
- *Journal of Soil and Water Conservation*
- *Plant and Soil*
- *Pochvovedenie*
- *Soil Research*
- *Soil Science Society of America Journal*

See also

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- UTEXAS
- Plaxis

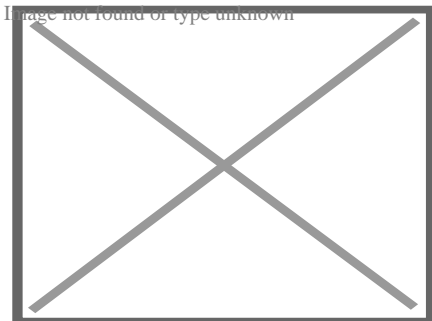
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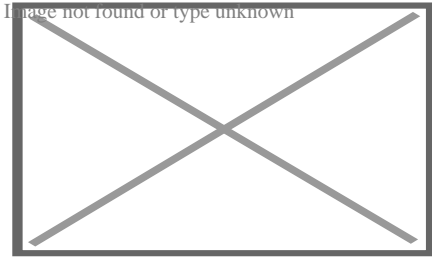
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About concrete slab



Suspended slab under construction, with the formwork still in place



Suspended slab formwork and rebar in place, ready for concrete pour.

A **concrete slab** is a common structural element of modern buildings, consisting of a flat, horizontal surface made of cast concrete. Steel-reinforced slabs, typically between 100 and 500 mm thick, are most often used to construct floors and ceilings, while thinner *mud slabs* may be used for exterior paving (see below).^{[1][2]}

In many domestic and industrial buildings, a thick concrete slab supported on foundations or directly on the subsoil, is used to construct the ground floor. These slabs are generally classified as *ground-bearing* or *suspended*. A slab is ground-bearing if it rests directly on the foundation, otherwise the slab is suspended.^[3] For multi-story buildings, there are several common slab designs (

see § Design for more types):

- Beam and block, also referred to as *rib and block*, is mostly used in residential and industrial applications. This slab type is made up of pre-stressed beams and hollow blocks and are temporarily propped until set, typically after 21 days.^[4]
- A hollow core slab which is precast and installed on site with a crane
- In high rise buildings and skyscrapers, thinner, pre-cast concrete slabs are slung between the steel frames to form the floors and ceilings on each level. Cast in-situ slabs are used in high rise buildings and large shopping complexes as well as houses. These in-situ slabs are cast on site using shutters and reinforced steel.

On technical drawings, reinforced concrete slabs are often abbreviated to "r.c.c. slab" or simply "r.c.". Calculations and drawings are often done by structural engineers in CAD software.

Thermal performance

[edit]

Energy efficiency has become a primary concern for the construction of new buildings, and the prevalence of concrete slabs calls for careful consideration of its thermal properties in order to minimise wasted energy.^[5] Concrete has similar thermal properties to masonry products, in that it has a relatively high thermal mass and is a good conductor of heat.

In some special cases, the thermal properties of concrete have been employed, for example as a heatsink in nuclear power plants or a thermal buffer in industrial freezers.^[6]

Thermal conductivity

[edit]

Thermal conductivity of a concrete slab indicates the rate of heat transfer through the solid mass by conduction, usually in regard to heat transfer to or from the ground. The coefficient of thermal conductivity, k , is proportional to density of the concrete, among other factors.^[5] The primary influences on conductivity are moisture content, type of aggregate, type of cement, constituent proportions, and temperature. These various factors complicate the theoretical evaluation of a k -value, since each component has a different conductivity when isolated, and the position and proportion of each components affects the overall conductivity. To simplify this, particles of aggregate may be considered to be suspended in the homogeneous cement. Campbell-Allen and Thorne (1963) derived a formula for the theoretical thermal conductivity of concrete.^[6] In practice this formula is rarely applied, but remains relevant for theoretical use. Subsequently, Valore (1980) developed another formula in terms of overall density.^[7] However, this study concerned hollow concrete blocks and its results are unverified for concrete slabs.

The actual value of k varies significantly in practice, and is usually between 0.8 and 2.0 W m⁻¹ K⁻¹.^[8] This is relatively high when compared to other materials, for example the conductivity of wood may be as low as 0.04 W m⁻¹ K⁻¹. One way of mitigating the effects of thermal conduction is to introduce insulation (

see § Insulation).

Thermal mass

[edit]

The second consideration is the high thermal mass of concrete slabs, which applies similarly to walls and floors, or wherever concrete is used within the thermal envelope. Concrete has a relatively high thermal mass, meaning that it takes a long time to respond to changes in ambient temperature.^[9] This is a disadvantage when rooms are heated intermittently and require a quick response, as it takes longer to warm the entire building, including the slab. However, the high thermal mass is an advantage in climates with large daily temperature

swings, where the slab acts as a regulator, keeping the building cool by day and warm by night.

Typically concrete slabs perform better than implied by their R-value.^[5] The R-value does not consider thermal mass, since it is tested under constant temperature conditions. Thus, when a concrete slab is subjected to fluctuating temperatures, it will respond more slowly to these changes and in many cases increase the efficiency of a building.^[5] In reality, there are many factors which contribute to the effect of thermal mass, including the depth and composition of the slab, as well as other properties of the building such as orientation and windows.

Thermal mass is also related to thermal diffusivity, heat capacity and insulation. Concrete has low thermal diffusivity, high heat capacity, and its thermal mass is negatively affected by insulation (e.g. carpet).^[5]

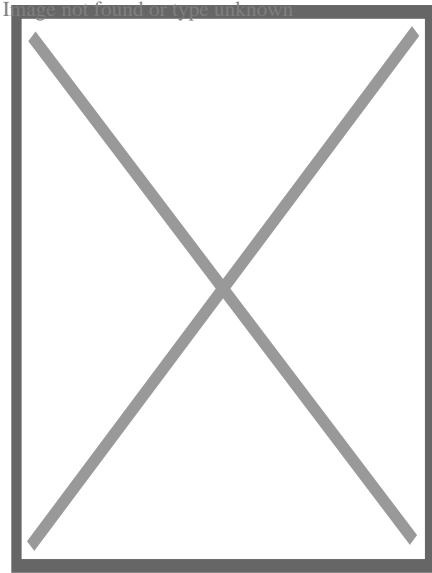
Insulation

[edit]

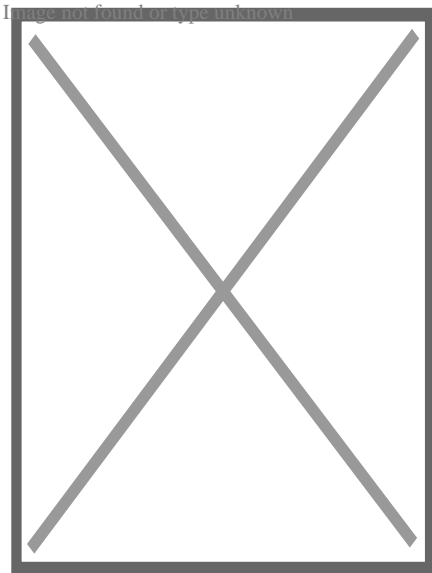
Without insulation, concrete slabs cast directly on the ground can cause a significant amount of extraneous energy transfer by conduction, resulting in either lost heat or unwanted heat. In modern construction, concrete slabs are usually cast above a layer of insulation such as expanded polystyrene, and the slab may contain underfloor heating pipes.^[10] However, there are still uses for a slab that is not insulated, for example in outbuildings which are not heated or cooled to room temperature (

see § Mud slabs). In these cases, casting the slab directly onto a substrate of aggregate will maintain the slab near the temperature of the substrate throughout the year, and can prevent both freezing and overheating.

A common type of insulated slab is the beam and block system (mentioned above) which is modified by replacing concrete blocks with expanded polystyrene blocks.^[11] This not only allows for better insulation but decreases the weight of slab which has a positive effect on load bearing walls and foundations.



Formwork set for concrete pour.



Concrete poured into formwork. This slab is ground-bearing and reinforced with steel rebar.

Design

[edit]

Further information: Marcus' method

Ground-bearing slabs

[edit]

See also: Shallow foundation § Slab on grade

Ground-bearing slabs, also known as "on-ground" or "slab-on-grade", are commonly used for ground floors on domestic and some commercial applications. It is an economical and quick construction method for sites that have non-reactive soil and little slope.[¹²]

For ground-bearing slabs, it is important to design the slab around the type of soil, since some soils such as clay are too dynamic to support a slab consistently across its entire area. This results in cracking and deformation, potentially leading to structural failure of any members attached to the floor, such as wall studs.[¹²]

Levelling the site before pouring concrete is an important step, as sloping ground will cause the concrete to cure unevenly and will result in differential expansion. In some cases, a naturally sloping site may be levelled simply by removing soil from the uphill site. If a site has a more significant grade, it may be a candidate for the "cut and fill" method, where soil from the higher ground is removed, and the lower ground is built up with fill.[¹³]

In addition to filling the downhill side, this area of the slab may be supported on concrete piers which extend into the ground. In this case, the fill material is less important structurally as the dead weight of the slab is supported by the piers. However, the fill material is still necessary to support the curing concrete and its reinforcement.

There are two common methods of filling - *controlled fill* and *rolled fill*.[¹³]

- **Controlled fill:** Fill material is compacted in several layers by a vibrating plate or roller. Sand fills areas up to around 800 mm deep, and clay may be used to fill areas up to 400 mm deep. However, clay is much more reactive than sand, so it should be used sparingly and carefully. Clay must be moist during compaction to homogenise it.[¹³]
- **Rolled fill:** Fill is repeatedly compacted by an excavator, but this method of compaction is less effective than a vibrator or roller. Thus, the regulations on maximum depth are typically stricter.

Proper curing of ground-bearing concrete is necessary to obtain adequate strength. Since these slabs are inevitably poured on-site (rather than precast as some suspended slabs are), it can be difficult to control conditions to optimize the curing process. This is usually aided by a membrane, either plastic (temporary) or a liquid compound (permanent).[¹⁴]

Ground-bearing slabs are usually supplemented with some form of reinforcement, often steel rebar. However, in some cases such as concrete roads, it is acceptable to use an unreinforced slab if it is adequately engineered (

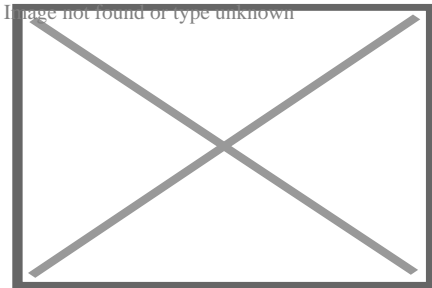
see below).

Suspended slabs

[edit]

For a suspended slab, there are a number of designs to improve the strength-to-weight ratio. In all cases the top surface remains flat, and the underside is modulated:

- A *corrugated slab* is designed when the concrete is poured into a corrugated steel tray, more commonly called decking. This steel tray improves strength of the slab, and prevents the slab from bending under its own weight. The corrugations run in one direction only.
- A *ribbed slab* gives considerably more strength in one direction. This is achieved with concrete beams bearing load between piers or columns, and thinner, integral ribs in the perpendicular direction. An analogy in carpentry would be a subfloor of bearers and joists. Ribbed slabs have higher load ratings than corrugated or flat slabs, but are inferior to waffle slabs.^[15]
- A *waffle slab* gives added strength in both directions using a matrix of recessed segments beneath the slab.^[16] This is the same principle used in the ground-bearing version, the waffle slab foundation. Waffle slabs are usually deeper than ribbed slabs of equivalent strength, and are heavier hence require stronger foundations. However, they provide increased mechanical strength in two dimensions, a characteristic important for vibration resistance and soil movement.^[17]



The exposed underside of a waffle slab used in a multi-storey building

Unreinforced slabs

[edit]

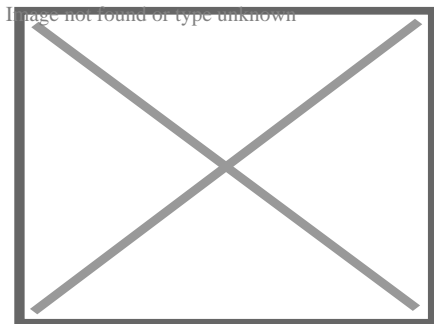
Unreinforced or "plain"^[18] slabs are becoming rare and have limited practical applications, with one exception being the mud slab (

see below). They were once common in the US, but the economic value of reinforced ground-bearing slabs has become more appealing for many engineers.^[10] Without reinforcement, the entire load on these slabs is supported by the strength of the concrete, which becomes a vital factor. As a result, any stress induced by a load, static or dynamic, must be within the limit of the concrete's flexural strength to prevent cracking.^[19] Since unreinforced concrete is relatively very weak in tension, it is important to consider the effects of tensile stress caused by reactive soil, wind uplift, thermal expansion, and cracking.^[20] One of the most common applications for unreinforced slabs is in concrete roads.

Mud slabs

[edit]

Mud slabs, also known as *rat slabs*, are thinner than the more common suspended or ground-bearing slabs (usually 50 to 150 mm), and usually contain no reinforcement.^[21] This makes them economical and easy to install for temporary or low-usage purposes such as subfloors, crawlspaces, pathways, paving, and levelling surfaces.^[22] In general, they may be used for any application which requires a flat, clean surface. This includes use as a base or "sub-slab" for a larger structural slab. On uneven or steep surfaces, this preparatory measure is necessary to provide a flat surface on which to install rebar and waterproofing membranes.^[10] In this application, a mud slab also prevents the plastic bar chairs from sinking into soft topsoil which can cause spalling due to incomplete coverage of the steel. Sometimes a mud slab may be a substitute for coarse aggregate. Mud slabs typically have a moderately rough surface, finished with a float.^[10]



Substrate and rebar prepared for pouring a mud slab

Axes of support

[edit]

One-way slabs

[edit]

A *one-way slab* has moment-resisting reinforcement only in its short axis, and is used when the moment in the long axis is negligible.^[23] Such designs include corrugated slabs and ribbed slabs. Non-reinforced slabs may also be considered one-way if they are supported on only two opposite sides (i.e. they are supported in one axis). A one-way reinforced slab may be stronger than a two-way non-reinforced slab, depending on the type of load.

The calculation of reinforcement requirements for a one-way slab can be extremely tedious and time-consuming, and one can never be completely certain of the best design.^[citation needed] Even minor changes to the project can necessitate recalculation of the reinforcement requirements. There are many factors to consider during the structural structure design of one-way slabs, including:

- Load calculations
- Bending moment calculation
- Acceptable depth of flexure and deflection
- Type and distribution of reinforcing steel

Two-way slabs

[edit]

A *two-way slab* has moment resisting reinforcement in both directions.^[24] This may be implemented due to application requirements such as heavy loading, vibration resistance, clearance below the slab, or other factors. However, an important characteristic governing the requirement of a two-way slab is the ratio of the two horizontal lengths. If $\frac{L_x}{L_y} < 2$ $\frac{L_y}{L_x}$ dimension and $\frac{L_x}{L_y}$ dimension, then moment in both directions should be considered in design.^[25] In other words, if the axial ratio is greater than two, a two-way slab is required.

A non-reinforced slab is two-way if it is supported in both horizontal axes.

Construction

[edit]

A concrete slab may be prefabricated (precast), or constructed on site.

Prefabricated

[edit]

Prefabricated concrete slabs are built in a factory and transported to the site, ready to be lowered into place between steel or concrete beams. They may be pre-stressed (in the factory), post-stressed (on site), or unstressed.^[10] It is vital that the wall supporting structure is built to the correct dimensions, or the slabs may not fit.

On-site

[edit]

On-site concrete slabs are built on the building site using formwork, a type of boxing into which the wet concrete is poured. If the slab is to be reinforced, the rebars, or metal bars, are positioned within the formwork before the concrete is poured in.^[26] Plastic-tipped metal or plastic bar chairs, are used to hold the rebar away from the bottom and sides of the formwork, so that when the concrete sets it completely envelops the reinforcement. This concept is known as concrete cover. For a ground-bearing slab, the formwork may consist only of side walls pushed into the ground. For a suspended slab, the formwork is shaped like a tray, often supported by a temporary scaffold until the concrete sets.

The formwork is commonly built from wooden planks and boards, plastic, or steel. On commercial building sites, plastic and steel are gaining popularity as they save labour.^[27] On low-budget or small-scale jobs, for instance when laying a concrete garden path, wooden planks are very common. After the concrete has set the wood may be removed.

Formwork can also be permanent, and remain in situ post concrete pour. For large slabs or paths that are poured in sections, this permanent formwork can then also act as isolation joints within concrete slabs to reduce the potential for cracking due to concrete expansion or movement.

In some cases formwork is not necessary. For instance, a ground slab surrounded by dense soil, brick or block foundation walls, where the walls act as the sides of the tray and hardcore (rubble) acts as the base.

See also

[edit]

- Shallow foundation (Commonly used for ground-bearing slabs)
- Hollow-core slab (Voided slab, one-way spanning)
- Beam and block (voided slab, one way spanning)
- Voided biaxial slab (Voided slab, two-way spanning)
- Formwork
- Precast concrete
- Reinforced concrete
- Rebar
- Concrete cover

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 - o Concrete cover
 - o Cover meter
 - o Rebar

Construction

- Precast
- Cast-in-place
- Formwork
- Climbing formwork
- Slip forming
- Screed
- Power screed
- Finisher
- Grinder
- Power trowel
- Pump
- Float
- Sealer
- Tremie

Science

- Properties
- Durability
- Degradation
- Environmental impact
- Recycling
- Segregation
- Alkali–silica reaction

Types

- AstroCrete
- Fiber-reinforced
- Filigree
- Foam
- Lunarcrete
- Mass
- Nanoconcrete
- Pervious
- Polished
- Polymer
- Prestressed
- Ready-mix
- Reinforced
- Roller-compacting
- Self-consolidating
- Self-leveling
- Sulfur
- Tabby
- Translucent
- Waste light
- Aerated
 - AAC
 - RAAC

Applications

- Slab
 - waffle
 - hollow-core
 - voided biaxial
 - slab on grade
- Concrete block
- Step barrier
- Roads
- Columns
- Structures

Organizations

- American Concrete Institute
- Concrete Society
- Institution of Structural Engineers
- Indian Concrete Institute
- Nanocem
- Portland Cement Association
- International Federation for Structural Concrete

Standards

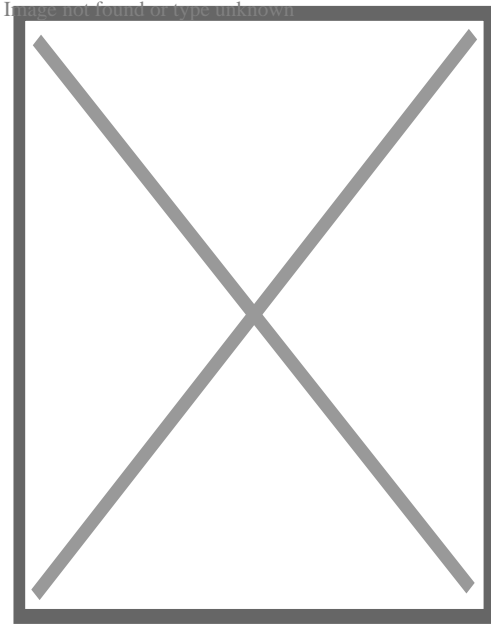
- Eurocode 2
- EN 197-1
- EN 206-1
- EN 10080

See also

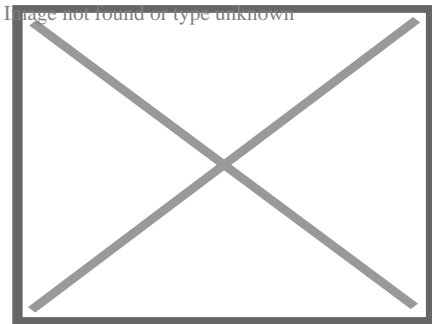
- Hempcrete

-  **Category:Concrete**

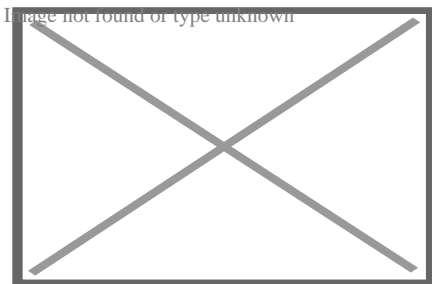
About geotechnical engineering



Boston's Big Dig presented geotechnical challenges in an urban environment.



Precast concrete retaining wall



A typical cross-section of a slope used in two-dimensional analyzes.

Geotechnical engineering, also known as **geotechnics**, is the branch of civil engineering concerned with the engineering behavior of earth materials. It uses the principles of soil mechanics and rock mechanics to solve its engineering problems. It also relies on knowledge of geology, hydrology, geophysics, and other related sciences.

Geotechnical engineering has applications in military engineering, mining engineering, petroleum engineering, coastal engineering, and offshore construction. The fields of geotechnical engineering and engineering geology have overlapping knowledge areas.

However, while geotechnical engineering is a specialty of civil engineering, engineering geology is a specialty of geology.

History

[edit]

Humans have historically used soil as a material for flood control, irrigation purposes, burial sites, building foundations, and construction materials for buildings. Dykes, dams, and canals dating back to at least 2000 BCE—found in parts of ancient Egypt, ancient Mesopotamia, the Fertile Crescent, and the early settlements of Mohenjo Daro and Harappa in the Indus valley—provide evidence for early activities linked to irrigation and flood control. As cities expanded, structures were erected and supported by formalized foundations. The ancient Greeks notably constructed pad footings and strip-and-raft foundations. Until the 18th century, however, no theoretical basis for soil design had been developed, and the discipline was more of an art than a science, relying on experience.^[1]

Several foundation-related engineering problems, such as the Leaning Tower of Pisa, prompted scientists to begin taking a more scientific-based approach to examining the subsurface. The earliest advances occurred in the development of earth pressure theories for the construction of retaining walls. Henri Gautier, a French royal engineer, recognized the "natural slope" of different soils in 1717, an idea later known as the soil's angle of repose. Around the same time, a rudimentary soil classification system was also developed based on a material's unit weight, which is no longer considered a good indication of soil type.^{[1][2]}

The application of the principles of mechanics to soils was documented as early as 1773 when Charles Coulomb, a physicist and engineer, developed improved methods to determine the earth pressures against military ramparts. Coulomb observed that, at failure, a distinct slip plane would form behind a sliding retaining wall and suggested that the maximum shear stress on the slip plane, for design purposes, was the sum of the soil cohesion, c , and the friction $\sigma \tan(\phi)$, where σ is the normal stress on the slip plane and ϕ is the friction angle of the soil. By combining Coulomb's theory with Christian Otto Mohr's 2D stress state, the theory became known as Mohr-Coulomb theory. Although it is now recognized that precise determination of cohesion is impossible because c is not a fundamental soil property, the Mohr-Coulomb theory is still used in practice today.^[3]

In the 19th century, Henry Darcy developed what is now known as Darcy's Law, describing the flow of fluids in a porous media. Joseph Boussinesq, a mathematician and physicist, developed theories of stress distribution in elastic solids that proved useful for estimating stresses at depth in the ground. William Rankine, an engineer and physicist, developed an alternative to Coulomb's earth pressure theory. Albert Atterberg developed the clay consistency indices that are still used today for soil classification.^{[1][2]} In 1885, Osborne Reynolds recognized that shearing causes volumetric dilation of dense materials and

contraction of loose granular materials.

Modern geotechnical engineering is said to have begun in 1925 with the publication of *Erdbaumechanik* by Karl von Terzaghi, a mechanical engineer and geologist. Considered by many to be the father of modern soil mechanics and geotechnical engineering, Terzaghi developed the principle of effective stress, and demonstrated that the shear strength of soil is controlled by effective stress.^[4] Terzaghi also developed the framework for theories of bearing capacity of foundations, and the theory for prediction of the rate of settlement of clay layers due to consolidation.^{[1][3][5]} Afterwards, Maurice Biot fully developed the three-dimensional soil consolidation theory, extending the one-dimensional model previously developed by Terzaghi to more general hypotheses and introducing the set of basic equations of Poroelasticity.

In his 1948 book, Donald Taylor recognized that the interlocking and dilation of densely packed particles contributed to the peak strength of the soil. Roscoe, Schofield, and Wroth, with the publication of *On the Yielding of Soils* in 1958, established the interrelationships between the volume change behavior (dilation, contraction, and consolidation) and shearing behavior with the theory of plasticity using critical state soil mechanics. Critical state soil mechanics is the basis for many contemporary advanced constitutive models describing the behavior of soil.^[6]

In 1960, Alec Skempton carried out an extensive review of the available formulations and experimental data in the literature about the effective stress validity in soil, concrete, and rock in order to reject some of these expressions, as well as clarify what expressions were appropriate according to several working hypotheses, such as stress-strain or strength behavior, saturated or non-saturated media, and rock, concrete or soil behavior.

Roles

[edit]

Geotechnical investigation

[edit]

Main article: Geotechnical investigation

Geotechnical engineers investigate and determine the properties of subsurface conditions and materials. They also design corresponding earthworks and retaining structures, tunnels, and structure foundations, and may supervise and evaluate sites, which may further involve site monitoring as well as the risk assessment and mitigation of natural hazards.^{[7][8]}

Geotechnical engineers and engineering geologists perform geotechnical investigations to obtain information on the physical properties of soil and rock underlying and adjacent to a site to design earthworks and foundations for proposed structures and for the repair of distress to earthworks and structures caused by subsurface conditions. Geotechnical investigations involve surface and subsurface exploration of a site, often including subsurface sampling and laboratory testing of retrieved soil samples. Sometimes, geophysical methods are also used to obtain data, which include measurement of seismic waves (pressure, shear, and Rayleigh waves), surface-wave methods and downhole methods, and electromagnetic surveys (magnetometer, resistivity, and ground-penetrating radar). Electrical tomography can be used to survey soil and rock properties and existing underground infrastructure in construction projects.^[9]

Surface exploration can include on-foot surveys, geologic mapping, geophysical methods, and photogrammetry. Geologic mapping and interpretation of geomorphology are typically completed in consultation with a geologist or engineering geologist. Subsurface exploration usually involves in-situ testing (for example, the standard penetration test and cone penetration test). The digging of test pits and trenching (particularly for locating faults and slide planes) may also be used to learn about soil conditions at depth. Large-diameter borings are rarely used due to safety concerns and expense. Still, they are sometimes used to allow a geologist or engineer to be lowered into the borehole for direct visual and manual examination of the soil and rock stratigraphy.

Various soil samplers exist to meet the needs of different engineering projects. The standard penetration test, which uses a thick-walled split spoon sampler, is the most common way to collect disturbed samples. Piston samplers, employing a thin-walled tube, are most commonly used to collect less disturbed samples. More advanced methods, such as the Sherbrooke block sampler, are superior but expensive. Coring frozen ground provides high-quality undisturbed samples from ground conditions, such as fill, sand, moraine, and rock fracture zones.^[10]

Geotechnical centrifuge modeling is another method of testing physical-scale models of geotechnical problems. The use of a centrifuge enhances the similarity of the scale model tests involving soil because soil's strength and stiffness are susceptible to the confining pressure. The centrifugal acceleration allows a researcher to obtain large (prototype-scale) stresses in small physical models.

Foundation design

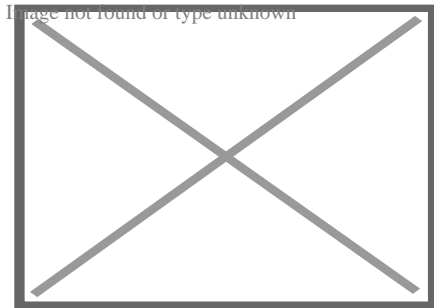
[edit]

Main article: Foundation (engineering)

The foundation of a structure's infrastructure transmits loads from the structure to the earth. Geotechnical engineers design foundations based on the load characteristics of the structure and the properties of the soils and bedrock at the site. Generally, geotechnical engineers first estimate the magnitude and location of loads to be supported before developing an investigation plan to explore the subsurface and determine the necessary soil parameters through field and lab testing. Following this, they may begin the design of an engineering foundation. The primary considerations for a geotechnical engineer in foundation design are bearing capacity, settlement, and ground movement beneath the foundations.^[11]

Earthworks

[edit]



A compactor/roller operated by U.S. Navy Seabees

See also: Earthworks (engineering)

Geotechnical engineers are also involved in the planning and execution of earthworks, which include ground improvement,^[11] slope stabilization, and slope stability analysis.

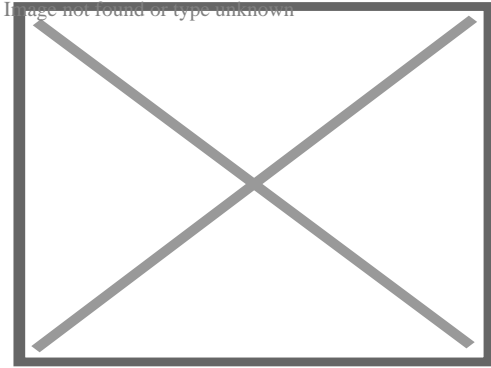
Ground improvement

[edit]

Various geotechnical engineering methods can be used for ground improvement, including reinforcement geosynthetics such as geocells and geogrids, which disperse loads over a larger area, increasing the soil's load-bearing capacity. Through these methods, geotechnical engineers can reduce direct and long-term costs.^[12]

Slope stabilization

[edit]



Simple slope slip section.

Main article: Slope stability

Geotechnical engineers can analyze and improve slope stability using engineering methods. Slope stability is determined by the balance of shear stress and shear strength. A previously stable slope may be initially affected by various factors, making it unstable. Nonetheless, geotechnical engineers can design and implement engineered slopes to increase stability.

Slope stability analysis

[edit]

Main article: Slope stability analysis

Stability analysis is needed to design engineered slopes and estimate the risk of slope failure in natural or designed slopes by determining the conditions under which the topmost mass of soil will slip relative to the base of soil and lead to slope failure.^[13] If the interface between the mass and the base of a slope has a complex geometry, slope stability analysis is difficult and numerical solution methods are required. Typically, the interface's exact geometry is unknown, and a simplified interface geometry is assumed. Finite slopes require three-dimensional models to be analyzed, so most slopes are analyzed assuming that they are infinitely wide and can be represented by two-dimensional models.

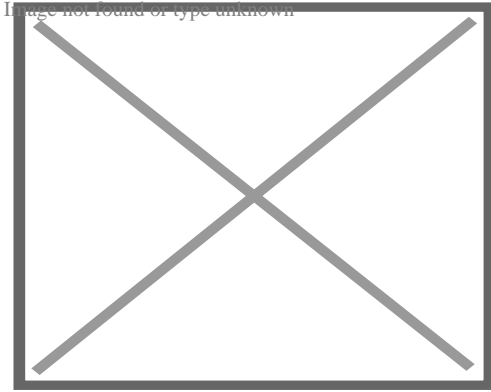
Sub-disciplines

[edit]

Geosynthetics

[edit]

Main article: Geosynthetics



A collage of geosynthetic products.

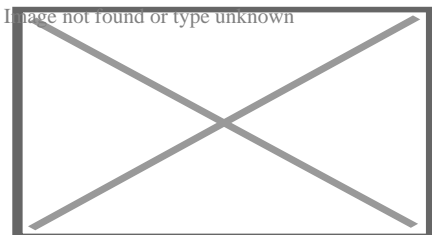
Geosynthetics are a type of plastic polymer products used in geotechnical engineering that improve engineering performance while reducing costs. This includes geotextiles, geogrids, geomembranes, geocells, and geocomposites. The synthetic nature of the products make them suitable for use in the ground where high levels of durability are required. Their main functions include drainage, filtration, reinforcement, separation, and containment.

Geosynthetics are available in a wide range of forms and materials, each to suit a slightly different end-use, although they are frequently used together. Some reinforcement geosynthetics, such as geogrids and more recently, cellular confinement systems, have shown to improve bearing capacity, modulus factors and soil stiffness and strength.^[14] These products have a wide range of applications and are currently used in many civil and geotechnical engineering applications including roads, airfields, railroads, embankments, piled embankments, retaining structures, reservoirs, canals, dams, landfills, bank protection and coastal engineering.^[15]

Offshore

[edit]

Main article: Offshore geotechnical engineering



Platforms offshore Mexico.

Offshore (or *marine*) *geotechnical engineering* is concerned with foundation design for human-made structures in the sea, away from the coastline (in opposition to *onshore* or

nearshore engineering). Oil platforms, artificial islands and submarine pipelines are examples of such structures.^[16]

There are a number of significant differences between onshore and offshore geotechnical engineering.^{[16][17]} Notably, site investigation and ground improvement on the seabed are more expensive; the offshore structures are exposed to a wider range of geohazards; and the environmental and financial consequences are higher in case of failure. Offshore structures are exposed to various environmental loads, notably wind, waves and currents. These phenomena may affect the integrity or the serviceability of the structure and its foundation during its operational lifespan and need to be taken into account in offshore design.

In subsea geotechnical engineering, seabed materials are considered a two-phase material composed of rock or mineral particles and water.^{[18][19]} Structures may be fixed in place in the seabed—as is the case for piers, jetties and fixed-bottom wind turbines—or may comprise a floating structure that remains roughly fixed relative to its geotechnical anchor point. Undersea mooring of human-engineered floating structures include a large number of offshore oil and gas platforms and, since 2008, a few floating wind turbines. Two common types of engineered design for anchoring floating structures include tension-leg and catenary loose mooring systems.^[20]

Observational method

[edit]

First proposed by Karl Terzaghi and later discussed in a paper by Ralph B. Peck, the observational method is a managed process of construction control, monitoring, and review, which enables modifications to be incorporated during and after construction. The method aims to achieve a greater overall economy without compromising safety by creating designs based on the most probable conditions rather than the most unfavorable.^[21] Using the observational method, gaps in available information are filled by measurements and investigation, which aid in assessing the behavior of the structure during construction, which in turn can be modified per the findings. The method was described by Peck as "learn-as-you-go".^[22]

The observational method may be described as follows:^[22]

1. General exploration sufficient to establish the rough nature, pattern, and properties of deposits.
2. Assessment of the most probable conditions and the most unfavorable conceivable deviations.
3. Creating the design based on a working hypothesis of behavior anticipated under the most probable conditions.
4. Selection of quantities to be observed as construction proceeds and calculating their anticipated values based on the working hypothesis under the most unfavorable

conditions.

5. Selection, in advance, of a course of action or design modification for every foreseeable significant deviation of the observational findings from those predicted.
6. Measurement of quantities and evaluation of actual conditions.
7. Design modification per actual conditions

The observational method is suitable for construction that has already begun when an unexpected development occurs or when a failure or accident looms or has already happened. It is unsuitable for projects whose design cannot be altered during construction. [22]

See also

[edit]

 Image from Commons [Engineering portal](#)

- Civil engineering
- Deep Foundations Institute
- Earthquake engineering
- Earth structure
- Effective stress
- Engineering geology
- Geological Engineering
- Geoprofessions
- Hydrogeology
- International Society for Soil Mechanics and Geotechnical Engineering
- Karl von Terzaghi
- Land reclamation
- Landfill
- Mechanically stabilized earth
- Offshore geotechnical engineering
- Rock mass classifications
- Sediment control
- Seismology
- Soil mechanics
- Soil physics
- Soil science

Notes

[edit]

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External links

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- Worldwide Geotechnical Literature Database
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Engineering

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**Specialties
and
interdisciplinarity**

Civil

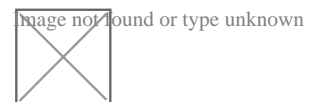
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- Energy
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- Tribology

Electrical

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- Telecommunications



Engineering education

- Bachelor of Engineering
- Bachelor of Science
- Master's degree
- Doctorate
- Graduate certificate
- Engineer's degree
- Licensed engineer

Related topics

- Engineer

Glossaries

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 - M–Z
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- Civil engineering
- Electrical and electronics engineering
- Mechanical engineering
- Structural engineering

Other

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 - Clinical
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 - Pharmaceutical
 - Rehabilitation
- Building services
 - MEP
- Design
- Explosives
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- Logistics
- Management
- Mathematics
- Mechatronics
- Military
- Nuclear
- Ontology
- Packaging
- Physics
- Privacy
- Safety
- Security
- Survey
- Sustainability
- Systems
- Textile

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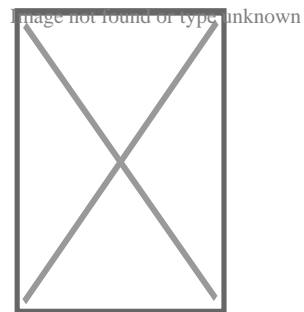
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Soil science

- History
- Index

Main fields

- Pedology
- Edaphology
- Soil biology
- Soil microbiology
- Soil zoology
- Soil ecology
- Soil physics
- Soil mechanics
- Soil chemistry
- Environmental soil science
- Agricultural soil science



Soil topics

- Soil
- Pedosphere
 - Soil morphology
 - Pedodiversity
 - Soil formation
- Soil erosion
- Soil contamination
- Soil retrogression and degradation
- Soil compaction
 - Soil compaction (agriculture)
- Soil sealing
- Soil salinity
 - Alkali soil
- Soil pH
 - Soil acidification
- Soil health
- Soil life
- Soil biodiversity
- Soil quality
- Soil value
- Soil fertility
- Soil resilience
- Soil color
- Soil texture
- Soil structure
 - Pore space in soil
 - Pore water pressure
- Soil crust
- Soil horizon
- Soil biomantle
- Soil carbon
- Soil gas
 - Soil respiration
- Soil organic matter
- Soil moisture
 - Soil water (retention)

- **v**
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Soil classification

World Reference Base for Soil Resources (1998–)

- Acrisols
- Alisols
- Andosols
- Anthrosols
- Arenosols
- Calcisols
- Cambisols
- Chernozem
- Cryosols
- Durisols
- Ferralsols
- Fluvisols
- Gleysols
- Gypsisols
- Histosol
- Kastanozems
- Leptosols
- Lixisols
- Luvisols
- Nitisols
- Phaeozems
- Planosols
- Plinthosols
- Podzols
- Regosols
- Retisols
- Solonchaks
- Solonetz
- Stagnosol
- Technosols
- Umbrisols
- Vertisols

USDA soil

- Alfisols
- Andisols
- Aridisols
- Entisols
- Gelisols
- Histosols

Applications

- Soil conservation
- Soil management
- Soil guideline value
- Soil survey
- Soil test
- Soil governance
- Soil value
- Soil salinity control
- Erosion control
- Agroecology
- Liming (soil)

Related fields

- Geology
- Geochemistry
- Petrology
- Geomorphology
- Geotechnical engineering
- Hydrology
- Hydrogeology
- Biogeography
- Earth materials
- Archaeology
- Agricultural science
 - Agrology

Societies, Initiatives




- Australian Society of Soil Science Incorporated
- Canadian Society of Soil Science
- Central Soil Salinity Research Institute (India)
- German Soil Science Society
- Indian Institute of Soil Science
- International Union of Soil Sciences
- International Year of Soil
- National Society of Consulting Soil Scientists (US)
- OPAL Soil Centre (UK)
- Soil Science Society of Poland
- Soil and Water Conservation Society (US)
- Soil Science Society of America
- World Congress of Soil Science

Scientific journals

- *Acta Agriculturae Scandinavica B*
- *Journal of Soil and Water Conservation*
- *Plant and Soil*
- *Pochvovedenie*
- *Soil Research*
- *Soil Science Society of America Journal*

See also

- Land use
- Land conversion
- Land management
- Vegetation
- Infiltration (hydrology)
- Groundwater
- Crust (geology)
- Impervious surface/Surface runoff
- Petrichor

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-  [Category soil](#)
- [Category soil science](#)
-  [List of soil scientists](#)





















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Geotechnical engineering

Offshore geotechnical engineering

**Investigation
and
instrumentation**

Field (*in situ*)

-  Core drill
-  Cone penetration test
-  Geo-electrical sounding
-  Permeability test
-  Load test
 - Static
 - Dynamic
 - Statnamic
-  Pore pressure measurement
 - Piezometer
 - Well
-  Ram sounding
-  Rock control drilling
-  Rotary-pressure sounding
-  Rotary weight sounding
-  Sample series
-  Screw plate test
- Deformation monitoring
 -  Inclinator
 -  Settlement recordings
-  Shear vane test
-  Simple sounding
-  Standard penetration test
-  Total sounding
-  Trial pit
-  Visible bedrock
- Nuclear densometer test
- Exploration geophysics

Soil

Types

- Clay
- Silt
- Sand
- Gravel
- Peat
- Loam
- Loess

Properties

- Hydraulic conductivity
- Water content
- Void ratio
- Bulk density
- Thixotropy
- Reynolds' dilatancy
- Angle of repose
- Friction angle
- Cohesion
- Porosity
- Permeability
- Specific storage
- Shear strength
- Sensitivity

**Structures
(Interaction)**

Natural features

- Topography
- Vegetation
- Terrain
- Topsoil
- Water table
- Bedrock
- Subgrade
- Subsoil

Earthworks

- Shoring structures
 - Retaining walls
 - Gabion
 - Ground freezing
 - Mechanically stabilized earth
 - Pressure grouting
 - Slurry wall
 - Soil nailing
 - Tieback
- Land development
- Landfill
- Excavation
- Trench
- Embankment
- Cut
- Causeway
- Terracing
- Cut-and-cover
- Cut and fill
- Fill dirt
- Grading
- Land reclamation
- Track bed
- Erosion control
- Earth structure
- Expanded clay aggregate
- Crushed stone
- Geosynthetics
 - Geotextile
 - Geomembrane
 - Geosynthetic clay liner
 - Cellular confinement
- Infiltration

Foundations

- Shallow

Forces

- Effective stress
- Pore water pressure
- Lateral earth pressure
- Overburden pressure
- Preconsolidation pressure

Mechanics

Phenomena/ problems

- Permafrost
- Frost heaving
- Consolidation
- Compaction
- Earthquake
 - Response spectrum
 - Seismic hazard
 - Shear wave
- Landslide analysis
 - Stability analysis
 - Mitigation
 - Classification
 - Sliding criterion
 - Slab stabilisation
- Bearing capacity * Stress distribution in soil

Numerical analysis software

- SEEP2D
- STABL
- SVFlux
- SVSlope
- UTEXAS
- Plaxis

Related fields

- Geology
- Geochemistry
- Petrology
- Earthquake engineering
- Geomorphology
- Soil science
- Hydrology
- Hydrogeology
- Biogeography
- Earth materials
- Archaeology
- Agricultural science
 - Agrology

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Construction

Types

- Home construction
- Offshore construction
- Underground construction
 - Tunnel construction

History

- Architecture
- Construction
- Structural engineering
- Timeline of architecture
- Water supply and sanitation

Professions

- Architect
- Building engineer
- Building estimator
- Building officials
- Chartered Building Surveyor
- Civil engineer
- Civil estimator
- Clerk of works
- Project manager
- Quantity surveyor
- Site manager
- Structural engineer
- Superintendent

Trades workers (List)

- Banksman
- Boilermaker
- Bricklayer
- Carpenter
- Concrete finisher
- Construction foreman
- Construction worker
- Electrician
- Glazier
- Ironworker
- Millwright
- Plasterer
- Plumber
- Roofer
- Steel fixer
- Welder

Organizations

- American Institute of Constructors (AIC)
- American Society of Civil Engineers (ASCE)
- Asbestos Testing and Consultancy Association (ATAC)
- Associated General Contractors of America (AGC)
- Association of Plumbing and Heating Contractors (APHC)
- Build UK
- Construction History Society
- Chartered Institution of Civil Engineering Surveyors (CICES)
- Chartered Institute of Plumbing and Heating Engineering (CIPHE)
- Civil Engineering Contractors Association (CECA)
- The Concrete Society
- Construction Management Association of America (CMAA)
- Construction Specifications Institute (CSI)
- FIDIC
- Home Builders Federation (HBF)
- Lighting Association
- National Association of Home Builders (NAHB)
- National Association of Women in Construction (NAWIC)
- National Fire Protection Association (NFPA)
- National Kitchen & Bath Association (NKBA)
- National Railroad Construction and Maintenance Association (NRC)
- National Tile Contractors Association (NTCA)
- Railway Tie Association (RTA)
- Royal Institution of Chartered Surveyors (RICS)
- Scottish Building Federation (SBF)
- Society of Construction Arbitrators

By country

- India
- Iran
- Japan
- Romania
- Turkey
- United Kingdom
- United States

Regulation

- Building code
- Construction law
- Site safety
- Zoning

Architecture

- Style
 - List
- Industrial architecture
 - British
- Indigenous architecture
- Interior architecture
- Landscape architecture
- Vernacular architecture

Engineering

- Architectural engineering
- Building services engineering
- Civil engineering
 - Coastal engineering
 - Construction engineering
 - Structural engineering
- Earthquake engineering
- Environmental engineering
- Geotechnical engineering

Methods

- List
- Earthbag construction
- Modern methods of construction
- Monocrete construction
- Slip forming

- Building material
 - List of building materials
 - Millwork
- Construction bidding
- Construction delay
- Construction equipment theft
- Construction loan
- Construction management
- Construction waste
- Demolition
- Design–build
- Design–bid–build
- DfMA
- Heavy equipment
- Interior design
- Lists of buildings and structures
 - List of tallest buildings and structures
- Megaproject
- Megastructure
- Plasterwork
 - Damp
 - Proofing
 - Parge coat
 - Roughcast
 - Harling
- Real estate development
- Stonemasonry
- Sustainability in construction
- Unfinished building
- Urban design
- Urban planning

Other topics

 [Outline](#)  [Category](#)

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About Cook County

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Things To Do in Cook County

Photo

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Sand Ridge Nature Center

4.8 (96)

Photo

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River Trail Nature Center

4.6 (235)

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Palmisano (Henry) Park

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Driving Directions in Cook County

Driving Directions From Palmisano (Henry) Park to

Driving Directions From Lake Katherine Nature Center and Botanic Gardens to

Driving Directions From Navy Pier to

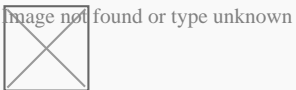
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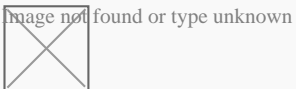
Reviews for



Jeffery James

(5)

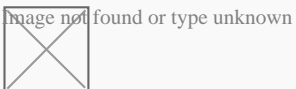
Very happy with my experience. They were prompt and followed through, and very helpful in fixing the crack in my foundation.



Sarah McNeily

(5)

USS was excellent. They are honest, straightforward, trustworthy, and conscientious. They thoughtfully removed the flowers and flower bulbs to dig where they needed in the yard, replanted said flowers and spread the extra dirt to fill in an area of the yard. We've had other services from different companies and our yard was really a mess after. They kept the job site meticulously clean. The crew was on time and friendly. I'd recommend them any day! Thanks to Jessie and crew.

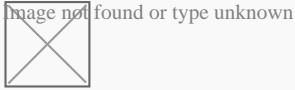


Jim de Leon

(5)

It was a pleasure to work with Rick and his crew. From the beginning, Rick listened to my concerns and what I wished to accomplish. Out of the 6 contractors that quoted the project, Rick seemed the MOST willing to accommodate my wishes. His pricing was definitely more than fair as well. I had 10 push piers installed to stabilize and lift an addition of my house. The project commenced at the date that Rick had disclosed initially and it was completed within the same time period expected (based on Rick's original assessment). The crew was well informed, courteous, and hard working. They were not loud (even while equipment was being utilized) and were well spoken. My neighbors were very impressed on how polite they were when they entered / exited my property (saying hello or good morning each day when they crossed paths). You can tell they care about the customer concerns. They ensured that the property would be put back as clean as possible by placing MANY sheets of plywood down prior to excavating. They compacted the dirt back in the holes extremely well to avoid large stock piles of soils. All the while, the main office was

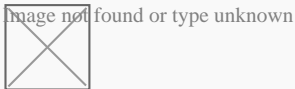
calling me to discuss updates and expectations of completion. They provided waivers of lien, certificates of insurance, properly acquired permits, and JULIE locates. From a construction background, I can tell you that I did not see any flaws in the way they operated and this an extremely professional company. The pictures attached show the push piers added to the foundation (pictures 1, 2 & 3), the amount of excavation (picture 4), and the restoration after dirt was placed back in the pits and compacted (pictures 5, 6 & 7). Please notice that they also sealed two large cracks and steel plated these cracks from expanding further (which you can see under my sliding glass door). I, as well as my wife, are extremely happy that we chose United Structural Systems for our contractor. I would happily tell any of my friends and family to use this contractor should the opportunity arise!



Chris Abplanalp

(5)

USS did an amazing job on my underpinning on my house, they were also very courteous to the proximity of my property line next to my neighbor. They kept things in order with all the dirt/mud they had to excavate. They were done exactly in the timeframe they indicated, and the contract was very details oriented with drawings of what would be done. Only thing that would have been nice, is they left my concrete a little muddy with boot prints but again, all-in-all a great job



Dave Kari

(5)

What a fantastic experience! Owner Rick Thomas is a trustworthy professional. Nick and the crew are hard working, knowledgeable and experienced. I interviewed every company in the area, big and small. A homeowner never wants to hear that they have foundation issues. Out of every company, I trusted USS the most, and it paid off in the end. Highly recommend.

Evaluating Soil Moisture Fluctuations Beneath Homes [View GBP](#)

Check our other pages :

- [Examining Sandy Loam for Residential Support](#)
- [Techniques for Addressing Soil Heave Issues](#)
- [Employing Sustainable Methods for Long Term Soil Health](#)
- [Minimizing Subsurface Water Accumulation Around Foundations](#)
- [Understanding Swale Placement for Controlled Water Flow](#)

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