SOILS AND SOILS EXPLORATIONS

Bringing together project team design professionals, including geotechnical engineers, structural engineers, and architects to discuss the matter of soils and foundations is fundamental to ensure that the foundation selected satisfies the constraints of the project budget as well as the functionality of the structure.

Understanding the vocabulary of geotechnical science (for example, the difference between ''cohesive'' and ''cohesionless'' soils) is the first step toward fostering collaborative communication, which becomes increasingly important as the process continues. What should be tested, what the test should be, why it is important, and what the limitations of the test are must be addressed. Likewise, identifying foundation and ground modification alternatives (as well as their pros and cons) will aid in the preliminary design phase, when the building foundations are being developed.

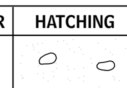
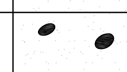
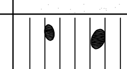
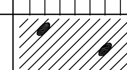
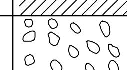
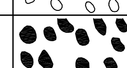
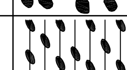
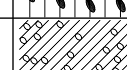
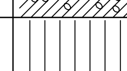
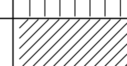
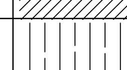
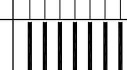
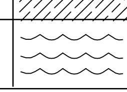
Understanding the geotechnical investigation report and geographical variations such as climate and seismic conditions will assist the design professionals in discussing important foundation issues.

SOILS DEFINITIONS: TERMS AND CLASSIFICATIONS

It is critical that geotechnical and structural engineering information be understood properly; to that end, the following definitions of common soils and other terms are included for reference:

- *Clay*: Determined by the size of particles and composition, clays are chemically different from their parent materials as a result of weathering. Clays are typically inorganic and have grain sizes less then 0.0002 in. in diameter. This material contains charged particles and has an affinity for water. Because of their size and chemical composition, clays exhibit cohesion and plasticity. Clays can be classified as stiff, medium, or soft, depending on the moisture content, with drier clays typically being stiffer. Clays make a satisfactory bearing material under some conditions. Long-term settlement can sometimes control the allowable bearing pressure. Because of the cohesive nature of clay, excavations can have steep slopes for short periods of time.
- *Silt*: Silt consists of inorganic particles between 0.003 in. and 0.0002 in. in diameter. These fine-grained particles are similar in composition to the rocks from which they are derived, and are not plastic in nature. Organic silt is found on the bottom of lakes and river deltas.
- *Sand*: Classifications of sand vary from fine to coarse, these rock particles range in size from 0.003 in. to 0.079 in. in diameter. Adequately compacted, sand makes an ideal bearing material. The coarser the sand, the higher the allowable bearing pressures. Fine sands are susceptible to becoming quick when subjected to unbalanced hydrostatic pressures, and may liquify when they are loose, saturated, or subjected to seismic forces. Settlement is usually immediate, with little long-term settlement.
- *Gravel*: Classifications of gravel vary from fine to coarse, and these unconsolidated rock fragments range from .75 in. to about 3 in. Except for gravels composed of shale, this material makes a good foundation material. Depending on the compactness and the underling material, very high bearing pressures are allowed by some building codes.
- *Cobbles*: Ranging in size from about 3 in. to about 10 in., these rock fragments can make reliable foundation-bearing materials, but can be difficult to properly compact when used for fill. Cobble-sized materials can interfere with pile driving and drilled-pier construction causing significant problems.
- *Boulders*: Typically classified as rock fragments greater than 10 in., boulders can be used as part of a fill mass if the voids between the boulders are filled with finer-grained sands and silts. These materials are generally not considered suitable for direct foundation support because of their size and shape, and the difficulty in excavating the material to desired shapes. As with cobbles, boulders can cause significant problems during construction.
- *Bedrock*: Unbroken hard rock that is not over any other material is considered bedrock. Depending upon its composition, it can be capable of withstanding extremely high bearing pressure, and is desirable for foundations supporting high loads. If the rock has been weathered or is cracked, its bearing capacity may be compromised. Settlement of buildings on bedrock is primarily limited to the elastic settlement of the foundation.
- *Residuum*: Residuum consists of soil derived from the in-place decomposition of bedrock materials. In general, these soils are more weathered near the surface, and gradually transition to a more rocklike material with depth. Where residual soils reveal evidence of the stratification and structure of the parent rock, they are known as *saprolitic* materials.
- *Alluvial soils*: Because materials are eroded, transported, and deposited through the action of flowing water, these soils are typically loose and saturated, hence often are unsuitable for support of structures or pavements.
- *Colluvial soils*: Because materials are transported by gravity, typically associated with landslides, these soils are generally irregular in composition and loose. They require improvement prior to being used to support buildings and pavements.
- *Aeolian soils*: These soils are transported and deposited by the wind. Typically, they consist of silt or sand-sized soils. Loess, one of the more common types of aeolian soils, is composed of fine cemented silt. While this material may be competent in place, it loses much of its strength when disturbed or recompacted.
- *Till*: Till is a mixture of clay, silt, sand, gravel, and boulders deposited by glaciers. Consolidated tills that are well graded (indicated by a uniform distribution of particle size) are exceptionally strong and make excellent foundation strata. Loose tills can cause differential settlements if used as a bearing material.
- *Loam:* This organic material, made up of humus and sand, silt, or clay, provides excellent material for agriculture but should not be used for foundations. Organic materials will settle a great deal over time, and even lightly loaded slabs on grade will settle if bearing on loam.
- *Cohesionless soils*: These types of soils consist of cobbles, gravels, sands, and nonplastic silts. They are generally formed from the mechanical weathering of bedrock brought about by water, ice, heat, and cold. They are typically composed of the same minerals as the parent rock. The strength of cohesionless materials is derived primarily from interparticle friction.
- *Cohesive soils*: These types of soils contain clay minerals with an unbalanced chemical charge. As a result, they tend to attract

SOIL TYPES AND THEIR PROPERTIES
1.1

	SYMBOLS				VALUE AS A		
DIVISION	LETTER	HATCHING	COLOR	SOIL DESCRIPTION	FOUNDATION MATERIAL	FROST ACTION	DRAINAGE
Gravel and gravelly soils	GW		Red	Well-graded gravel, or gravel sand mixture; little or no fines	Excellent	None	Excellent
	GP		Red	Poorly graded gravel, or gravel-sand mixtures; little or no fines	Good	None	Excellent
	GM		Yellow	Silty gravels, gravel sand-silt mixtures	Good	Slight	Poor
	GC		Yellow	Clayey gravels, gravel clay-sand mixtures	Good	Slight	Poor
Sand and sandy soils	SW		Red	Well-graded sands, or gravelly sands; little or no fines	Good	None	Excellent
	SP		Red	Poorly graded sands, or gravelly sands; little or no fines	Fair	None	Excellent
	SM		Yellow	Silty sands, sand-silt mixtures	Fair	Slight	Fair
	SC		Yellow	Clayey sands, sand-clay mixtures	Fair	Medium	Poor
Silts and clays Liquid Limit	ML		Green	Inorganic silt, rock flour, silty or clayey fine sands, or clayey silts with slight plasticity	Fair	Very high	Poor
	CL		Green	Inorganic clays of low to medium plasticity, gravelly clays, silty clays, lean clays	Fair	Medium	Impervious
	OL		Green	Organic silt-clays of low plasticity	Poor	High	Impervious
Silts and clays Liquid Limit >50	MH		Blue	Inorganic silts, micaceous ordiatamaceous fine sandy or silty soils, elastic silts	Poor	Very high	Poor
	CH		Blue	Inorganic clays of high plasticity, fat clays	Very poor	Medium	Impervious
	OH		Blue	Organic clays of medium to high plasticity, organic silts	Very poor	Medium	Impervious
Highly organic soils	Pt		Orange	Peat and other highly organic soil	Not suitable	Slight	Poor

water and bond together. The strength of cohesive materials is derived from a combination of these chemical bonds and from interparticle friction.

- *Consolidation*: When soils are subjected to loads, water within the void spaces initially supports the change in stress through an increase in pressure. Excess pressures gradually dissipate in proportion to the permeability of the soil. Coarse-grained materials drain rapidly, while finer-grained silts and clays drain more slowly. As the excess pore pressures dissipate, the void spaces compress and transfer the loads to the soil grains. The resulting reduction in volume over time is known as *consolidation*.
- *Underconsolidated soils*: Soils that have built up in river deltas and other water bodies are deposited in a very loose state. These soils are often underconsolidated, in that they have never experienced stresses equal to or greater than current overburden stresses. These materials tend to consolidate under their own weight over time, until all excess pore pressures have been dissipated and the soils become "normally consolidated." Foundations bearing on underconsolidated soils can typically expect large short- and long-term settlement.
- *Overconsolidated soils*: Unlike many other types of materials, soils are not elastic. When stresses are applied to soils, they compress. However, when the same stress is removed, they do not rebound to the same height. When reloaded, the soils "remember" previously loaded conditions and compress to their historical level of stress. Soils that have previously been loaded to stresses above those created by the current soil overburden are considered to be overconsolidated. Foundations bearing on overconsolidated soils can typically expect less short- and long-term settlements.
- *Desiccation*: All soils typically contain some moisture within the voids between soil particles. When soils are dried, capillary tension tends to pull the soil grains together, causing the soil to shrink and lose volume. This action can cause the soil to become overconsolidated, as the capillary tension results in stress.

SOIL STUDIES AND REPORTS

READING A SOILS REPORT

A geotechnical report helps the design team understand the site on which the structure is to be built. Most geotechnical reports contain the following information, based on the previously defined scope of exploration:

- Report summary
- Project information
- Exploration methods
- Description of soil and groundwater conditions
- Design recommendations
- Construction considerations
- Appendix
- Location diagram
- Soil-boring or test pit logs
- Soil profiles
- Laboratory test results

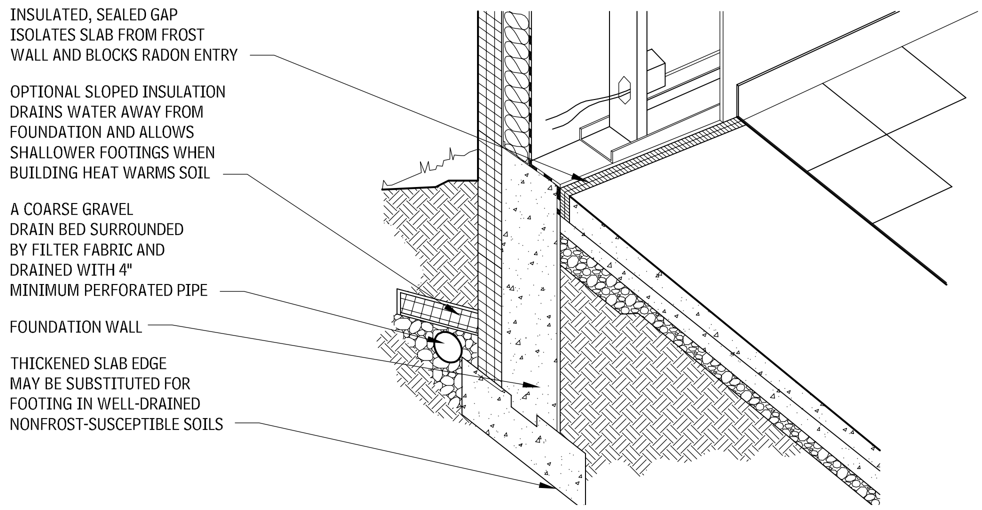
The report summary is generally one to two pages long, and provides the most salient information and recommendations of the report. Use the summary as quick reference, but read the entire report for details and qualifications/limitations. Most reports can be read within 30 minutes. Check and verify the project information and criteria (i.e., building height, structural loads, floor/basement levels, and so on). The scope of the evaluation and recommendations are based on this information. Also included in the report would be project information describing the building and site characteristics such as number of stories, building construction materials, foundation loadings, basement data if applicable, and grades. The exploration section defines how the geotechnical engineer obtained the soil information required to describe the foundation this would include number, location and depth of soil borings and test pits, and laboratory and field testing to be performed.

The general soil and groundwater conditions include a general overview of the results of the geotechnical engineer's tests. More detailed information is contained in the soil-boring and test pit logs, which can be reviewed when required.

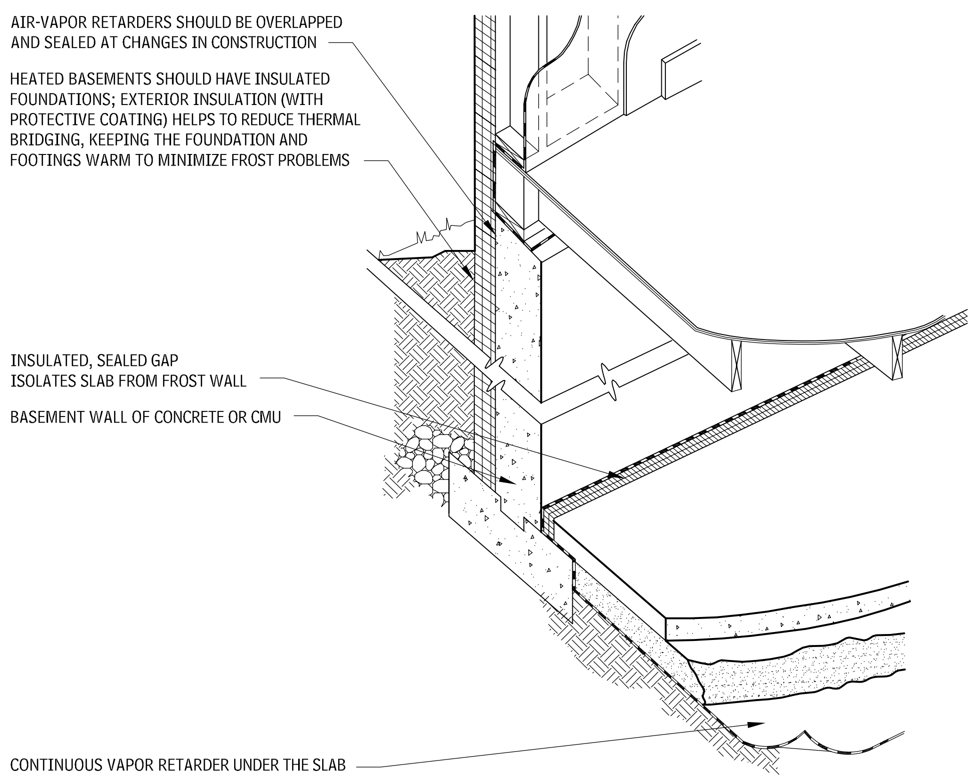
The design recommendations section is of greatest interest to the project design team, as it makes specific recommendations concerning the design of foundations, grade slab, walls, drainage requirements, and other key building components. It should be read together with the section on construction considerations, which identifies potential problems during construction that can be avoided or minimized by both the design team and contractor when everyone understands the challenges for the project.

Often reports will provide a transverse section of the soil profile, combining the soil-boring information in a convenient picture. This will enable the reader to better understand approximately how the soil properties vary across the site.

SLAB-ON-GRADE CONSTRUCTION IN COLD CLIMATES
1.2



BASEMENT CONSTRUCTION IN COLD CLIMATES
1.3

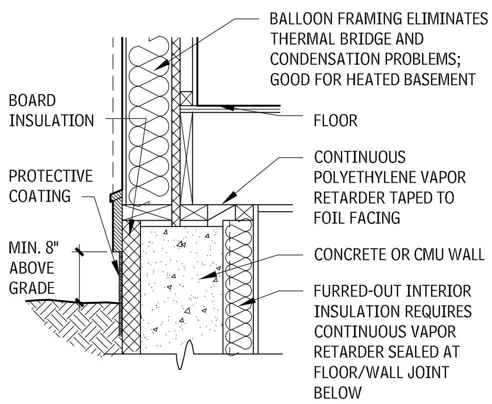


CLIMATIC FOUNDATION ISSUES

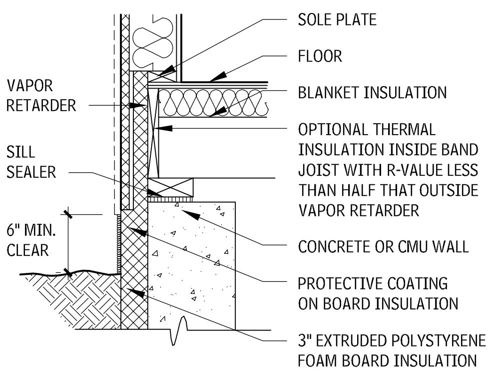
DESIGNING FOR COLD AND UNDERHEATED CLIMATES

Cold and underheated climate conditions occur over the northern half of the United States and in mountainous regions. These conditions can be generally quantified as where the frost depth is 12 in. or greater. Designing foundations for these conditions is treated in a more typical manner, such as: providing a foundation below the frost depth, including a basement, and providing insulation on the exterior to reduce the chances of cold ground temperatures reaching the structure.

ENERGY-EFFICIENT WALL SECTIONS FOR UNDERHEATED CLIMATES
1.4



INSULATION ON INSIDE OF CONSTRUCTION



INSULATION ON OUTSIDE OF CONSTRUCTION

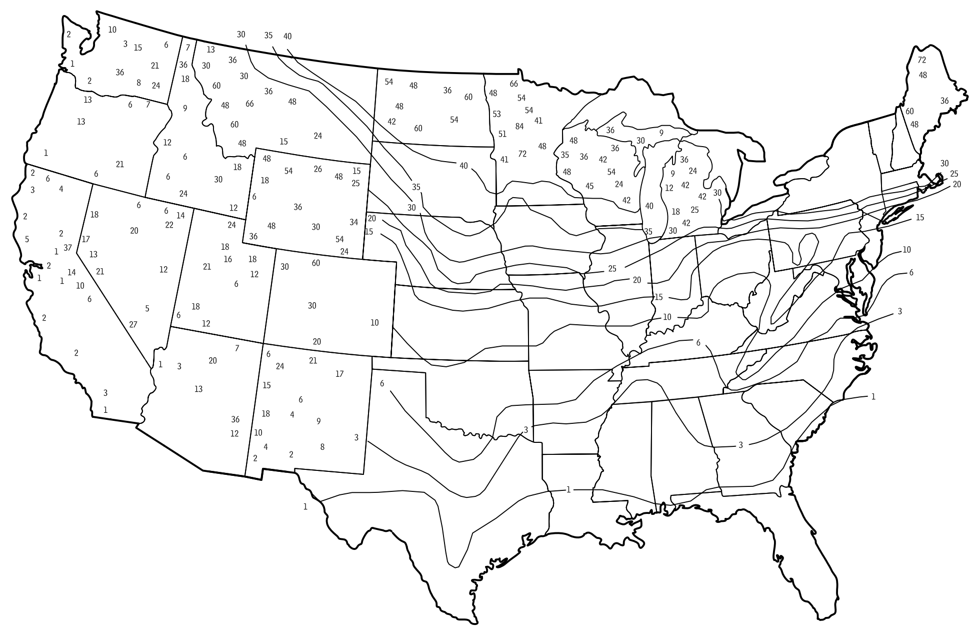
FROST ISSUES

Detrimental frost action in soils is obviously limited to those areas of the United States where subfreezing temperatures occur on a regular basis and for extended periods of time. "Frost action," as used in this context, is the lateral or vertical movement of structures supported on or in the soil. Frozen soil is, in itself, not necessarily detrimental to the supported structures. It becomes detrimental when, through the growth of ice lenses, the soil, and whatever is resting on the soil above the ice lenses, heaves upward. This causes foundations and the structures supported by the foundations to distort and suffer distress. Other common problems are the heaving of sidewalks, pavements, steps, retaining walls, fence poles, and architectural features.

The depth of frost penetration is directly related to the intensity and duration of the freezing conditions, a measure that is termed the *freezing degree day index.* In milder climates in the United States, the local building codes might stipulate a frost protection depth for foundations of 12 in. In the northern portions of the United States, the frost protection depth might be 42 to 60 in. as required by local building codes. These guidelines are usually conservative, but there are situations where deeper frost protection depths are warranted. For instance, if the emergency entrance to a hospital is on the north side of the hospital, where the sun never warms the pavement adjacent to the building, and the pavement is kept 100 percent snow-free for safety reasons, then the frost penetration can easily exceed the code requirements.

Carefully evaluate exposure conditions to see if a special condition exists. Grass and snow are very effective insulators for the ground below. Avoid the use of sloping exterior faces on grade beams or foundations that give the freezing forces something to push against when the frost heave situation develops.

AVERAGE DEPTH OF FROST PENETRATION (IN.)
1.5



DESIGNING FOR HOT, ARID CLIMATES

CLIMATE IMPLICATIONS

Though classified as arid and overheated, severe desert climates in the United States typically have four distinct periods for determining comfort strategies:

- The *hot dry season*, occurring in late spring, early summer, and early fall, has dry, clear atmospheres that provide high insulation levels, high daytime air temperatures, very high sol-air temperatures, and large thermal radiation losses at night, producing a 30° to 40°F daily range. Nighttime temperatures may fall below the comfort limits and are useful for cooling. Low humidity allows effective evaporative cooling.
- The *hot humid season* occurs in July and August. In addition to high insulation, it is characterized by high dew point temperatures (above 55°F), reducing the usefulness of evaporative cooling for comfort conditioning. Cloudiness and haze prevent nighttime thermal reradiation, resulting in only a 20°F or less daily range. Lowest nighttime temperatures are frequently higher than the comfort limits. Thus, refrigeration or dehumidification may be needed to meet comfort standards.
- The *winter season* typically has clear skies, cold nights, very low dew point temperatures, a daily range of nearly 40°F, and the opportunity for passively meeting all heating requirements from isolation.
- The *transitional* or *thermal sailing season* occurs before and after the winter season and requires no intervention by environmental control systems. This season can be extended by the passive features of the building. Other desert climates have similar seasons but in different proportions and at cooler scales.

CONSTRUCTION DETAILS

Capitalize on conditions climatic conditions by incorporating construction practices that respond in beneficial ways to the environment, including:

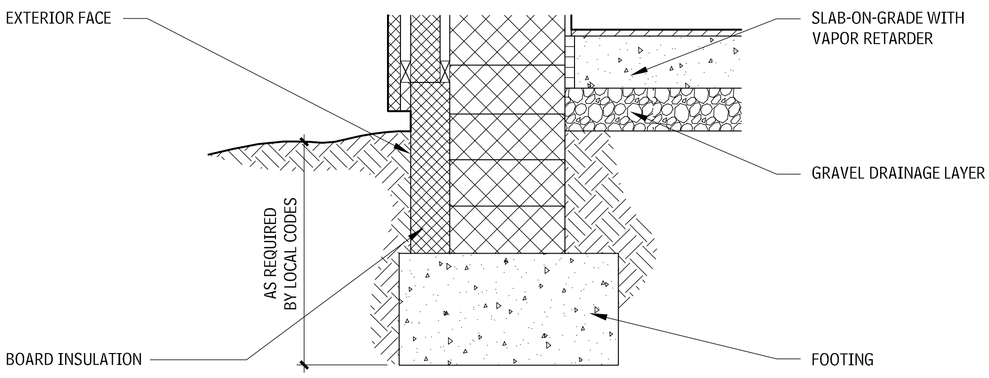
- Insulate coolant and refrigerant pipes from remote evaporative towers and condensers for their entire length.
- In hot locations, use roof construction similar to the cold climate roof detail.
- Do not use exposed wood (especially in small cross sections) and many plastics, as they deteriorate from excessive heat and high ultraviolet exposure.
- Although vapor retarders may not be critical to control condensation, implement them as a building wrap or wind shield, both to control dust penetration and to avoid convective leaks from high temperature differentials.
- Avoid thermal bridges such as extensive cantilevered slabs.
- Radiant barriers and details appropriate to humid overheated climates are at least as effective as vapor retarders, but avoid holes in assembly where convection would leak their thermal advantage.
- Ventilate building skin (attic or roof, walls) to relieve sol-air heat transfer.

DESIGNING FOR HUMID, OVERHEATED CLIMATES

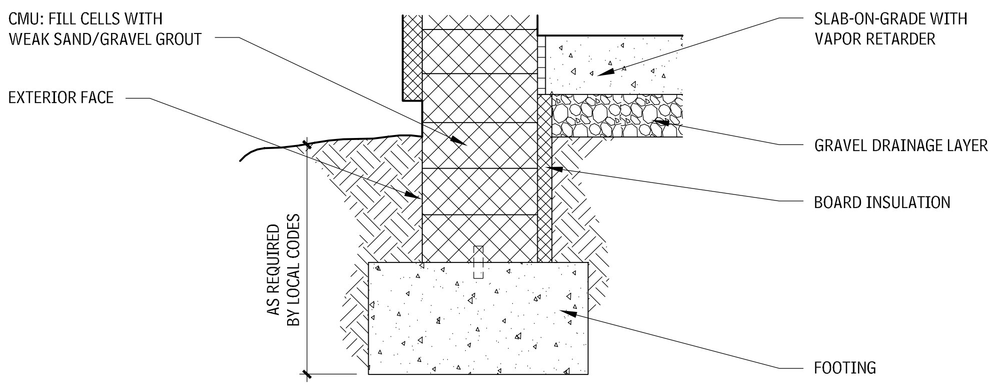
Humid, overheated conditions are most severe along the Gulf Coast, but occur across the entire southeastern United States. Atmospheric moisture limits radiation exchange, resulting in daily temperature ranges less than 20°F. High insulation gives first priority to shading. Much of the overheated period is only a few degrees above comfort limits, so air movement can cool the body. Ground temperatures are generally too high for the Earth to be useful as a heat sink, although slab-on-grade floor mass is useful. The strategies are to resist solar and conductive heat gains and to take best advantage of ventilation.

Contributors:
Richard O. Anderson, PE, Somat Engineering, Taylor, Michigan; Eric K. Beach, Rippeteau Architects, PC, Washington DC; Stephen N. Flanders and Wayne Tobiasson, U.S. Army Corps of Engineers, Hanover, New Hampshire; Donald Watson, FAIA, Rensselaer Polytechnic Institute, Troy, New York; Kenneth Labs, New Haven, Connecticut; Jeffrey Cook, Arizona State University, Tempe, Arizona; K. Clark and P. Paylore, *Desert Housing: Balancing Experience and Technology for Dwelling in Hot Arid Zones,* Office of Arid Land Studies, University of Arizona, Tucson, Arizona, 1980. J. Cook, *Cool Houses for Desert Suburbs,* Arizona Solar Energy Commission, Phoenix, Arizona, 1984.

TYPICAL WALL SECTIONS FOR HOT, ARID CLIMATES
1.6

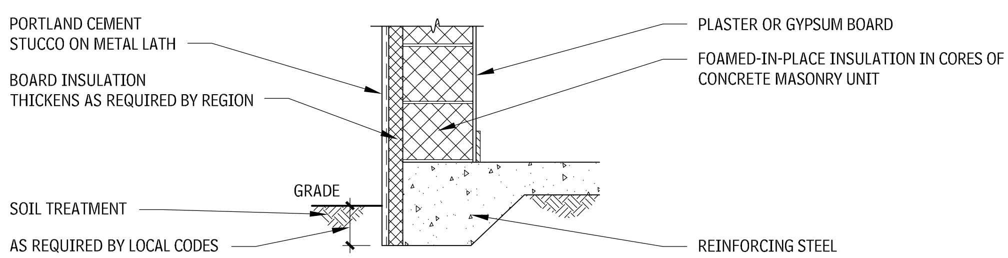


HIGH ENERGY–EFFICIENT

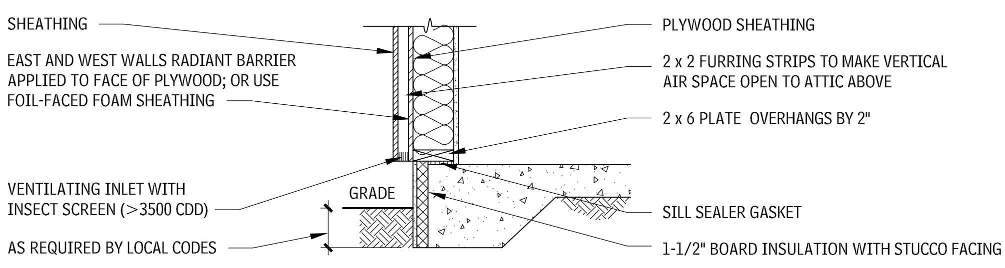


ECONOMIC ENERGY–EFFICIENT

ENERGY-EFFICIENT WALL SECTION: VENTED SKIN MASONRY WALL WITH INSIDE INSULATION FOR HUMID, OVERHEATED CLIMATES
1.7



ENERGY-EFFICIENT WALL SECTION: VENTED SKIN WALL WITH RADIANT BARRIER FOR HUMID, OVERHEATED CLIMATES
1.8



SEISMIC FOUNDATION ISSUES

INTRODUCTION TO SEISMIC DESIGN

According to the theory of plate tectonics, the Earth's crust is divided into constantly moving plates. Earthquakes occur when, as a result of slowly accumulating pressure, the ground slips abruptly along a geological fault plane on or near a plate boundary. The resulting waves of vibration within the Earth create ground motions at the surface, which, in turn, induce movement within buildings. The frequency, magnitude, and duration of the ground motion; physical characteristics of the building; and geology of a site determine how these forces affect a building.

DESIGN JUDGMENT

During a seismic event, buildings designed to the minimum levels required by model codes often sustain damage, even significant structural damage. Early discussions with an owner should explore the need to limit property loss in an earthquake, and the desirability of attempting to ensure continued building operation immediately afterward. To achieve these results, it may be necessary to make design decisions that are more carefully tuned to the seismic conditions of a site than the code requires.

The relationship between the period of ground motion and the period of building motion is of great importance to building design. Fundamental periods of motion in structures range from 0.1 second for a one-story building to 4.0 seconds or more for a high-rise building. Ground generally vibrates for a period of between 0.5 and 1.0 second. If the period of ground motion and the natural period of motion in a building coincide, the building may resonate, and the loads will be increased. Theoretically, one part of the seismic design solution is to "tune" the building so that its own period of motion falls outside the estimated range of ground motion frequency. In practice, this tuning is very seldom carried out. Rather, design professionals rely on increased load effects required by the applicable code to take care of the problem.

SEISMIC CODES

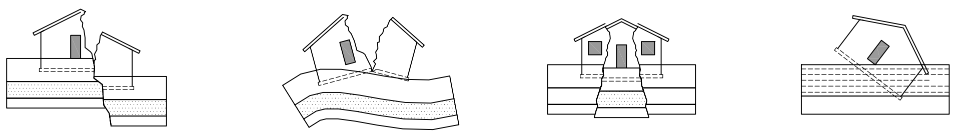
The building code adopted in most jurisdictions in the United States is International Building Code (IBC). There are some significant changes to the seismic forces determined by this code compared to seismic forces determined by previous building codes. The IBC 2006 code seismic provisions are designed around a level of earthquake that is expected to be exceeded only 2 percent of the time in the next 50 years. The level of seismic design for most structures, per the IBC, is based on a "collapse protection" strategy (commonly referred to as a "life safety" level), which assumes that there may be significant damage to the structure up to the point of collapse but that the structure does not collapse.

The structural engineer will design a lateral force-resisting structural assembly to resist a design-level earthquake. These designs are developed from detailed maps that indicate the ground spectral accelerations of buildings, which are based upon known past seismic events, in combination with probability studies. These maps typically include known fault locations, which help to determine the distance of the building from any known fault. The ground accelerations can typically be found down to the county level in the United States. The geotechnical engineer works with the design team to develop the site coefficient, which is dependent on the local soils layers and depths.

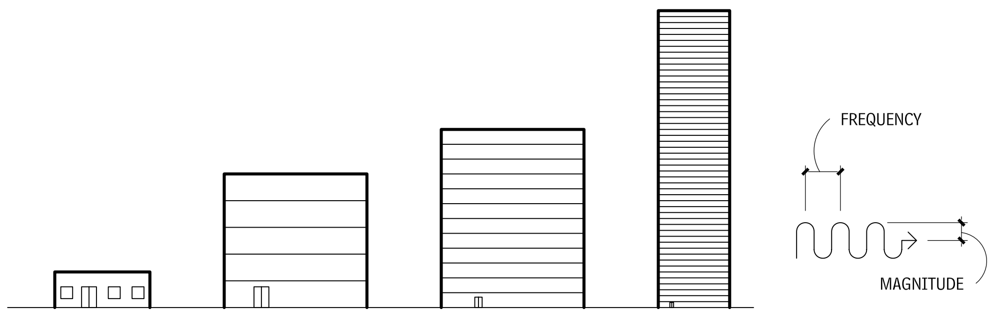
The following information is based on the requirements in the IBC 2006 Building Code, which in turn is based on the 2000 National Earthquake Hazards Reduction Program (NEHRP). Detached one- and two-family dwellings are exempt from seismic regulations in areas other than those with high seismicity. (Note: Seismic codes are constantly evolving, so consult the applicable code before beginning a project.)

Contributors:
Donald Watson, FAIA, Rensselaer Polytechnic Institute, Troy, New York; Kenneth Labs, New Haven, Connecticut; Subrato Chandra, Philip W. Fairey, Michael M. Houston, and Florida Solar Energy Center, *Cooling with Ventilation,* Solar Energy Research Institute, Golden, Colorado. 1982.; K. E. Wilkes, *Radiant Barrier Fact Sheet,* CAREIRS, Silver Spring, Maryland; P. Fairey, S. Chandra, A. Kerestecioglu, *Ventilative Cooling in Southern Residences: A Parametric Analysis,* PF-108-86, Florida, Solar Energy Center, Cape Canaveral, Florida 1986; William W. Stewart, FAIA, Stewart-Schaberg Architects, Clayton, Missouri.

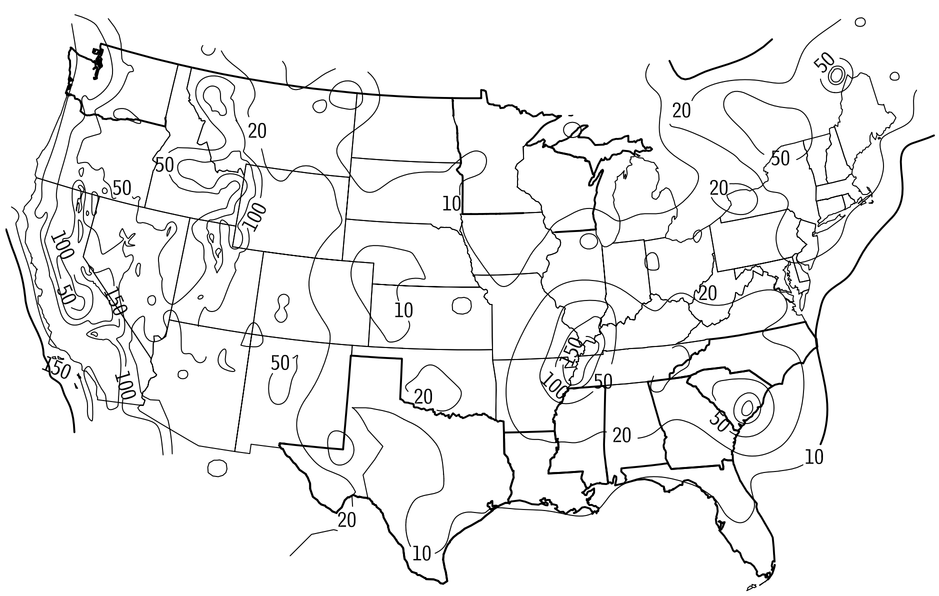
MAIN CAUSES OF FOUNDATION FAILURE
1.9



FUNDAMENTAL PERIODS
1.10



SEISMIC ACCELERATION FOR LOW BUILDINGS EXPRESSED AS A PERCENTAGE OF GRAVITY
1.11



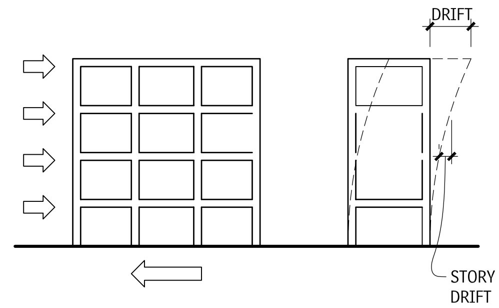
Source: Map courtesy of the U.S. Geological Survey, National Seismic Hazard Mapping Project (June 1996)

TERMS

The seismic community has an extensive set of terms that describe common conditions in the field. Here is a short list of these terms and their definitions:

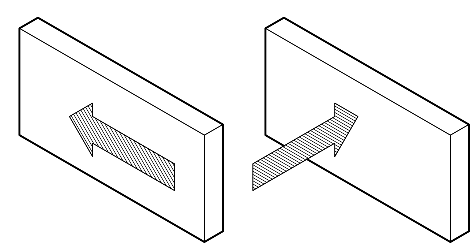
- *Base shear (static analysis)*: Calculated total shear force acting at the base of a structure, used in codes as a static representation of lateral earthquake forces. Also referred to as *equivalent lateral force*.

BASE SHEAR AND DRIFT
1.12



- *Design earthquake*: Earthquake ground motion for which a building is designed. This is typically about two-thirds of the maximum considered earthquake (MCE) (defined below) when designing per the IBC codes.
- *Drift and story drift*: Lateral deflection of a building or structure. Story drift is the relative movement between adjacent floors.
- *Ductility*: The ability of a structural frame to bend, but not break. Ductility is a major factor in establishing the ability of a building to withstand large earthquakes. Ductile materials (steel, in particular) fail only after permanent deformation has taken place. Good ductility requires special detailing of the joints.
- *Dynamic analysis*: A structural analysis based on the vibration motion of a building. Dynamic analysis is time-consuming, and normally reserved for complex projects.
- *Forces, in-plane*: Forces exerted parallel to a wall or frame.
- *Forces, out-of-plane*: Forces exerted perpendicular to a wall or frame.

FORCE DIAGRAMS
1.13



- *Maximum considered earthquake (MCE)*: The greatest ground-shaking expected to occur during an earthquake at a site. These values are somewhat higher than those of the design earthquake, particularly in areas where seismic events are very infrequent. The code maps are based on earthquakes of this magnitude.
- *Reentrant corner*: The inside building corner of an L-, H-, X-, or T-shaped plan.

ESTABLISHING SEISMIC FORCES

The equivalent lateral force procedure is the most common method used to determine seismic design forces. In it, the seismic load, V (base shear), is determined by multiplying the weight of the build-

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ing by a factor of Cs ($V = C_S W$). The value of C_S depends on the size of the design earthquake, the type of soil, the period of the building, the importance of the building, and the response-modification factor (a variable that accounts for different levels of ductility for different types of lateral force-resisting systems used). This force is applied at the base of the structure then is distributed vertically throughout the building according to the mass, and horizontally throughout the building according to the stiffness of the lateral elements of the structure (for a "rigid" diaphragm), or according to tributary width of the lateral elements of the structure (for a "flexible" diaphragm).

DESIGN FOR RESISTING SEISMIC FORCES AND FOUNDATION ISSUES

A design that resists seismic forces for a structure makes use of the lateral systems' ductility. Such ductile lateral systems are designed to deflect more under seismic loading than what would be expected from something such as wind loading. This allows for the use of smaller effective seismic design forces and more reasonably sized members. It is important, however, that the overall design still be capable of handling the expected deflections. Story drifts that are too large can result in secondary forces and stresses for which the structure was not designed, as well as increase the damage to the interior and exterior building components, and hinder the means of egress from the building.

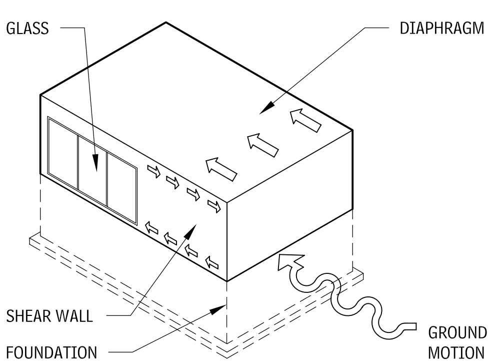
Typical means of resisting these forces include the use of moment frames, shear walls, and braced frames. Each of these types of lateral systems can be made up of one of the main structural materials (such as steel or reinforced concrete moment frames; masonry, wood, or reinforced concrete shear walls; or steel or reinforced concrete-braced frames). The building configuration and design parameters will have a major effect on which system to chose and, subsequently, the lateral system chosen will have a major impact on the foundations required to resist the loads.

Moment frames typically are distributed more evenly over the building footprint and have little or no uplift; they also generally have large base moments that can be difficult to resist. In addition, moment frames will tend to have greater lateral deflections than other stiffer systems (such as shear walls or braced frames). Concrete shear walls and steel-braced frames are more localized, not only concentrating lateral shear at the base but also having a high potential for net uplift forces to be resisted. These forces are difficult to resist with some foundation systems and should be reviewed extensively before selecting the lateral load-resisting system.

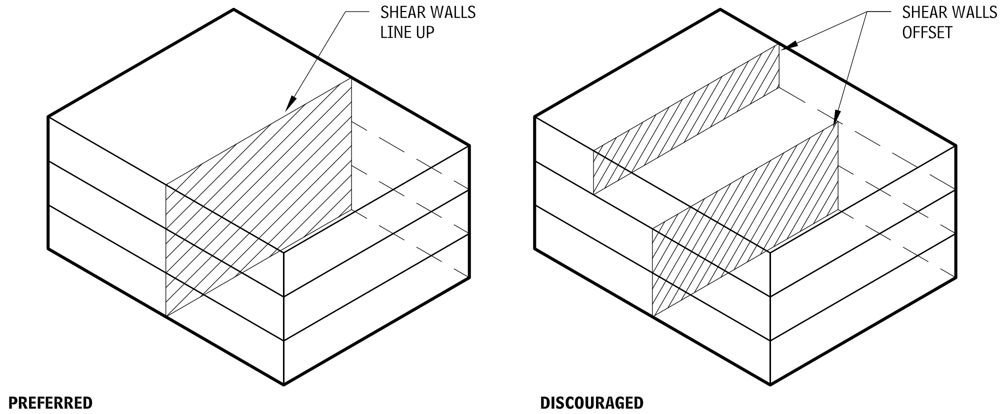
Tall, narrow structures tend to have overturning issues before they will face sliding issues, whereas short structures face sliding problems rather than overturning problems. Seismic motion rocks the building, increasing overturning loads, and can act in any direction. Thus, resistance to overturning is best achieved at a building's perimeter, rather than at its core.

Building foundations must be designed to resist the lateral forces transmitted through the earth and the forces transmitted from the lateral load-resisting system to the earth. In general, softer soils amplify seismic motion.

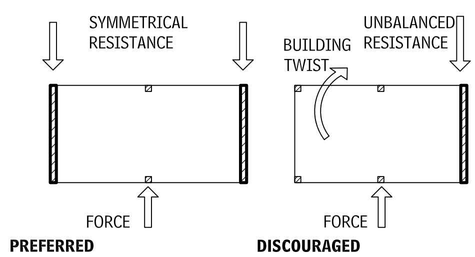
SHEAR WALLS AND DIAPHRAGMS
1.14



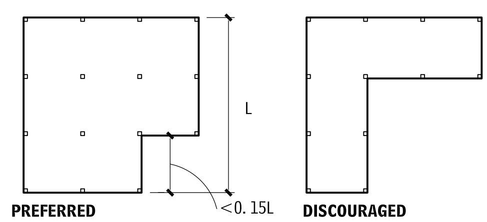
OUT-OF-PLANE VERTICAL OFFSETS
1.15



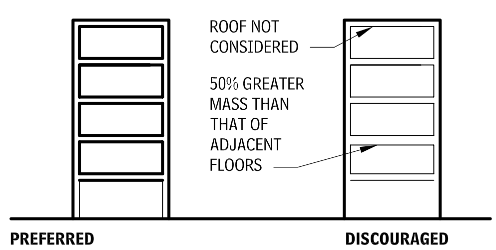
TORSION IN PLAN
1.16



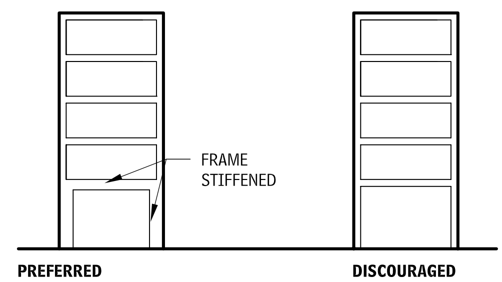
REENTRANT CORNERS
1.17



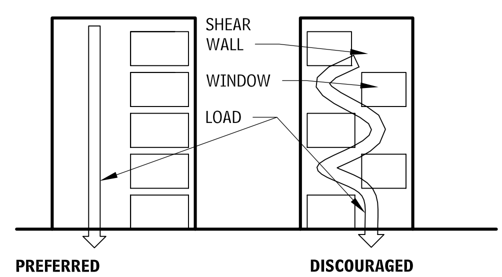
MASS IRREGULARITY
1.18



SOFT STORY
1.19



IN-PLANE DISCONTINUITY
1.20



NOTES

1.16 The lateral force-resisting system for a symmetrical building is much easier to design than that for an asymmetrical building. Because the source of an earthquake cannot be known, symmetry in both directions should be considered.
1.17 This is a variation of the symmetry issue. When the notch gets too big, the building tends to tear at the inside corner.
1.18 Not all floors have to be the same; nevertheless, it is important that no floor has much more mass than those adjacent.
1.19 When a taller (inherently softer) first floor is desired, anticipate using much heavier first-floor framing to equalize the stiffness with that of the floors above.
1.20 Although both drawings illustrate shear walls in the same plane, one arrangement is discouraged because the load path is not direct.

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