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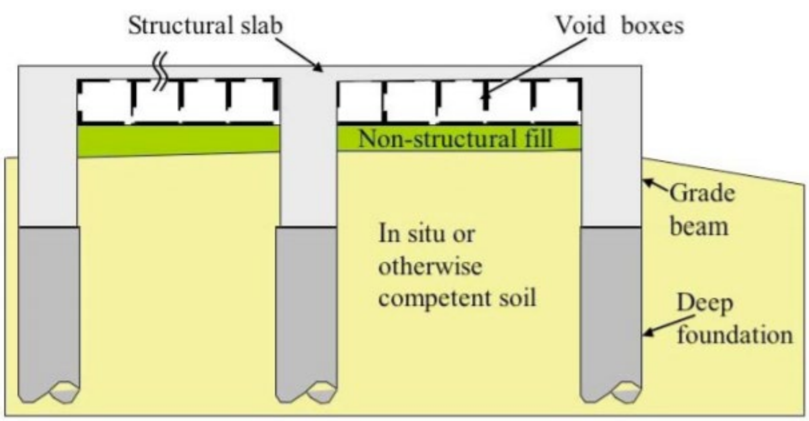
# Foundation Design Options for Residential and Other Low-Rise Buildings on Expansive Soils

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# FOUNDATION DESIGN OPTIONS FOR RESIDENTIAL AND OTHER LOW-RISE BUILDINGS ON EXPANSIVE SOILS

# 1.0 INTRODUCTION

The scope of this document is to provide guidance in the selection of design options for residential and other low-rise building foundations, typically called light foundations, which are founded on expansive soils. Low-rise buildings are defined as one to four stories in height. These buildings include houses, garages, apartment and condominium buildings, restaurants, schools, churches, and other similar structures. Design options for foundation systems, foundation components, and moisture and vegetation control methods are reviewed and compared. There are no absolute design rules for choosing a design. This document provides a list of advantages and disadvantages for each of the many commonly used foundation design options to assist the designer in selecting the most suitable option.

A brief overview of the design problems associated with expansive soils is provided in Section 2.0, and general design considerations are presented in Section 3.0. The foundation design options are categorized into three separate sections. Section 4.0 covers foundation system design options considering the structural foundation system as a whole. The foundation systems are subdivided into two groups: deep support systems and shallow support systems. Section 5.0 addresses design options for various individual structural components of the foundation systems that are discussed in Section 4.0. Section 6.0 discusses site design options for moisture and vegetation control systems.

Foundation design options for heavily loaded structures such as mid- to high-rise buildings or large industrial structures that usually require deep foundations or thick large mat foundations are not addressed, nor are design options for lightly loaded structures that are not susceptible to significant damage due to differential vertical movements from soil moisture changes, such as relatively flexible light gage metal buildings with exterior metal siding and roofing and wide open interior spaces with no interior partition walls.

# 2.0 PROBLEM DEFINITION

The challenge with designing building foundations on moderate to highly expansive clay soils is the potential detrimental effects of differential movements of the foundation structural elements due to volumetric changes of the underlying and surrounding soils. In simple terms, expansive clay soils swell and can cause heave with increasing soil moisture or can dry out and cause subsidence with decreasing soil moisture.

Movement of expansive soils is caused by fluctuations in the moisture content of soil particles. Because homogeneous expansive clay soils have very low permeability, fluctuations in the moisture content of the soils might normally be expected to occur over a very long period. However, permeability is increased with geotechnical phenomena such as ground faults, surface fractures due to desiccation of clays, and decomposition of tree roots which cause fissures and cracks that become widely disseminated over time.
Due to the repeated wetting, swelling, drying, and shrinking of the clay as it weathers, the fissures often fill with silt and sand, and create pathways for water that can exacerbate the infiltration process. Water can also easily move through naturally occurring sand strata, sand seams, and micro-cracks in clay soil caused by previous shrinkage. High negative pressures, also known as suction, in clay soils with low water content also increase the tendency for water to be absorbed into the clay.

Environmental factors other than climatic conditions can also affect expansive soils. Water extraction by trees and other vegetation, a process known as transpiration, can cause soil shrinkage. Swelling can be a result of water infiltration into the soil from lawn irrigation systems, broken water pipes, flooded and leaking utility trenches, poor drainage, or leaking swimming pools, or it can be a result of slow moisture replenishment and equalization after the removal of a tree. The combined effect and variability of all of these possibilities make it difficult to accurately predict expansive soil ground movements.

Foundation movements are considered problematic only if they result in negative phenomena that detrimentally affect the performance or appearance of the building. The negative phenomena are considered to be structural if the load carrying capacity of the superstructure or foundation elements are affected or are considered to be cosmetic if only the appearance of the exterior cladding or interior wall, floor, or ceiling finishes are affected. Negative phenomena can also affect the serviceability the building, such as the opening or closing of doors.

Negative phenomena due to foundation movement typically occur because of differential movements between various parts of the building. Differential movements often lead to high internal stresses in building components resulting as distress in the form of cracks, splitting, bending, buckling, or separations in the exterior cladding systems such as brick, cement-board panels, or in the interior finishes such as gypsum drywall panels, wood paneling, and flooring.

# 3.0 GENERAL DESIGN CONSIDERATIONS

Aside from supporting the building loads, the goal of structural foundation design in expansive soil areas should be to economically mitigate the detrimental effects of foundation movement. This can be done by either isolating elements of the foundation system from potential soil movements or by utilizing design methods and details that help to control the effects of the movement of the soil.

Movements of expansive clay soils are generally restricted to an upper zone of soils known as the active zone. The lower boundary of this zone is commonly defined as the line of zero movement. The depth of the active zone varies from site to site. In the Houston area, this depth is thought to range from 8 to 20 feet. The depth of the active zone is an important design parameter used in the engineering design of foundations on expansive soils, particularly when planning to use deep foundations.

Another general design consideration is the effect of the magnitude of surcharge pressure on the degree of swell that can occur. Lightly loaded foundation components, such as concrete flatwork, pavements, and building slab-on-grade floors, are impacted more by expansive soil volumetric changes than are heavily loaded foundation components such as heavily loaded bearing walls. Heavy loads reduce the amount of swell than can occur.

Numerous foundation system design options are available that meet these goals to varying degrees. Many options are also available in the design and selection of components that make up these foundation systems; however, choices should be based upon an engineered geotechnical investigation. Different options are also available in the design of the site around the foundation and the selection of landscaping components. Advantages and disadvantages of these options are discussed in the following sections.

# 4.0 FOUNDATION SYSTEM DESIGN OPTIONS

This section discusses the various types of foundation systems that are commonly used for residential and other low-rise buildings in the Houston area where expansive soils occur. In this document, the foundation system is considered to include the structural floor framing system at or near grade level and all other structural components beneath the building. The building superstructure consists of all structural elements above the grade level floor.

The foundation systems are subdivided into two groups: deep support systems and shallow support systems. Each of these systems has an associated level of risk of damage that can occur to the building superstructure and architectural components due to differential foundation movements. Each of these systems also has an associated relative cost of construction. When comparing the various foundation systems, the level of risk is typically found to be inversely proportional to the level of cost. Higher risks are often accepted due to economic considerations. For example, shallow support systems typically have a relatively higher level of risk than deep support systems but are often selected due to economics and affordability.

Because risk of damage and economic considerations are involved, building owners and/or developers need to be involved in the selection process of the foundation system. To assist in this selection, the foundation systems are generally listed in the order of increasing levels of associated risk and decreasing levels of construction cost.

## 4.1 DEEP SUPPORT SYSTEMS

Deep support systems are defined as foundations having deep components such as drilled piers or piles that extend well below the moisture active zone of the soils. They function to limit the vertical movements of the building by providing vertical support in a soil stratum that is not susceptible to downward movements caused by moisture fluctuations.

### 4.1.1 Isolated Structural Systems with Deep Foundations

Isolated structural systems are characterized as having a superstructure and a grade level structural floor system that are designed to be physically isolated from the effects of vertical movements of expansive soils. This is accomplished by providing sufficient space between the bottom of the floor system components and the top of the soil that will allow the underlying expansive soil to heave into the space or subside without causing movement of the floor system. The structural floor system usually consists of a reinforced concrete slab with a void forming system and series of grade beams. Other types of materials and framing systems can be used such as a crawl space, which is created by constructing the floor system above the ground.

#### 4.1.1.1 Structural Slab with Void Space and Deep Foundations

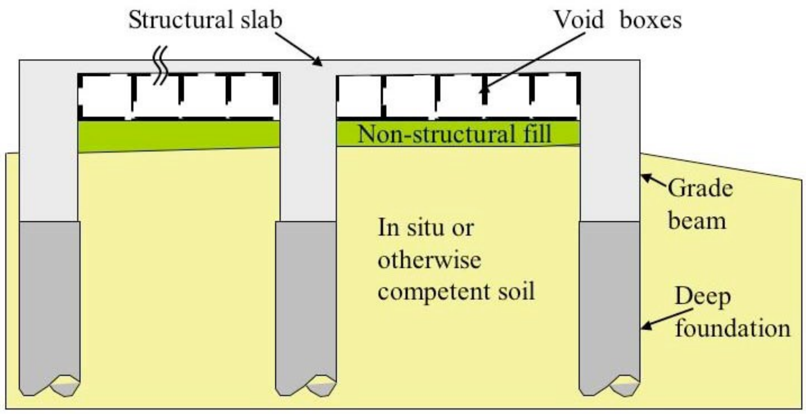



**Figure 4.1.1.1 Structural Slab with Void Space and Deep Foundations**

This foundation system typically consists of a structural reinforced concrete slab with cardboard carton forms that create a void space that separates the slab from the surface soils. The depth of the void forms ranges from four to eight inches and depends on the expansiveness of the soils. The more expansive the soil (i.e. the higher the plasticity index), the deeper the cardboard carton forms needed. The slab is called a “structural slab” because it spans between reinforced concrete grade beams that are supported entirely by deep foundations.

Because of the relatively small void space that is used with this system, the bottom portion of the grade beams are normally cast directly on the soil, even though they are designed to span between the deep foundations. The slabs typically range in thickness from four to eight inches. The reinforcement can consist of a single or double mat of rebar. The structural slab is designed in accordance with the American Concrete Institute (ACI) publication, Building Code Requirements for Structural Concrete, ACI 318.

Void forms serve as formwork for the placement of concrete by acting as a temporary platform that supports the weight of the wet concrete. Void forms typically are made of corrugated paper arranged in an open cell configuration. The exterior surface may be wax impregnated to temporarily resist moisture. The forms are specifically designed to gradually absorb ground moisture, lose strength, disintegrate over time, and leave a void between the expansive soils and the concrete slab. If the soil below the concrete heaves, it can expand into the space created by the void form without lifting the foundation.

| TABLE 4.1.1.1 | STRUCTURAL SLAB WITH VOID SPACE AND DEEP FOUNDATIONS | |
|---|---|---|
| ADVANTAGES * | DISADVANTAGES * | COMMENTS |
| 1. Reduces vertical movements of slab-at-grade due to expansive soils provided a sufficient void is maintained under slab and the supporting deep foundations are founded sufficiently below active zone.<br>2. Usually outperforms any other type of foundation system.<br>3. Reduces, but does not eliminate, need for a foundation maintenance program.<br>4. More rigid than a timber framed floor with crawl space and deep foundations, resulting in less differential movement of superstructure.<br>5. Allows a void under approximately 80–90% of foundation when void cartons are not used under grade beams.<br>6. No need for select structural fill. Fill can be comprised of expansive or non-expansive soil. Fill need only be compacted to a density sufficient to support slab during setup. | 1. Usually results in higher construction cost.<br>2. Can require additional engineering design effort than a slab-on-grade and can result in higher engineering fees.<br>3. Extra time required to construct structurally isolated floor can lengthen overall construction schedule.<br>4. Improper carton form installation can result in void that is insufficient to provide for anticipated soil expansion.<br>5. Termites can be attracted to moist cardboard of carton forms.<br>6. Grade beams that are in contact with soil can heave due to swelling of expansive soils.<br>7. Depending on slab elevation, can allow water to collect below slab. | 1. Slab is constructed about 4 to 8 inches above the soil using void carton forms.<br>2. Slab is designed to span between grade beams. Grade beams are designed to span between deep foundations.<br>3. Slab is more heavily reinforced than non-structural slab.<br>4. Vapor retarders such as polyethylene sheathing should not be placed below carton forms. Vapor retarders should be placed above carton forms in order to allow moisture to degrade void boxes.<br>5. Usually constructed with no carton forms below grade beams due to potential water infiltration into void and down shafts of deep foundations.<br>6. Installation of an expendable hard surface above carton forms such as Masonite sheeting will facilitate construction. |

* Compared to other foundation systems as described in Sections 4.1.1 to 4.2.3.

### 4.1.1.2 Structural Floor with Crawl Space and Deep Foundations

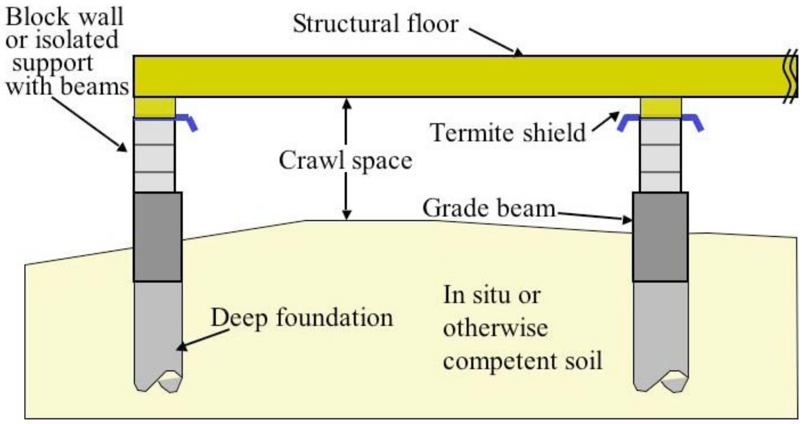



**Figure 4.1.1.2 Structural Floor with Crawl Space and Deep Foundations**

This foundation system is similar to the previous system, except that the vertical space used to isolate the floor system is much larger, usually at least 18 inches, which is sufficient to allow access underneath the floor, hence the name "crawl space". The structural floor system can be constructed utilizing any of the following common structural components: (a) wood subfloor and joists supported by wood, steel, or concrete beams; (b) concrete floor slab and joists supported by concrete beams; or (c) steel deck and open web bar joists or cold-formed sections supported by steel or concrete beams. Other combinations of these floor-framing components are possible, and other materials can be used such as precast concrete planks or T-sections.

| TABLE 4.1.1.2 | STRUCTURAL FLOOR WITH CRAWL SPACE AND DEEP FOUNDATIONS | |
|---|---|---|
| **ADVANTAGES *** | **DISADVANTAGES *** | **COMMENTS** |
| 1. Reduces vertical movement of slab-at-grade due to expansive soils, provided sufficient crawl space is maintained under slab and supporting deep foundations are founded sufficiently below active zone.<br>2. Usually outperforms any other type of foundation system.<br>3. Reduces, but does not eliminate, need for foundation maintenance program.<br>4. Void cartons are not required under the floor.<br>5. No need for select structural fill.<br>6. Accommodates certain architectural styles with raised first floors.<br>7. Exposed below-floor plumbing is accessible.<br>8. More suitable for flood-prone areas since ground floor is generally higher than for other foundation systems.<br>9. Floor is easier to level than a slab-on-grade or structural slab with void space.<br>10. Helps to preserve nearby existing trees by allowing oxygen to root zones.<br>11. Allows a void under approximately 95% of foundation when void cartons are not used under grade beams, or nearly 100% when all beams are raised completely above grade.<br>12. Reduces settlement from soil shrinkage. | 1. Usually results in highest construction cost.<br>2. Requires more extensive design effort and will result in higher engineering fees.<br>3. Takes longer to construct because it is labor intensive.<br>4. Void below floor can collect water if nearby grade or other surrounding sites are at a higher elevation.<br>5. Less rigid than a stiffened slab, which can allow more differential movement of superstructure, causing more cosmetic distress.<br>6. Crawl space can allow sufficient oxygen for roots to grow, which can cause soil shrinkage.<br>7. Proper drainage must be provided in crawl space.<br>8. Exposed below-floor plumbing can freeze. | 1. Ground floor is typically constructed 30 to 42 inches above grade but can be greater.<br>2. Floor beams typically consist of steel, concrete, or wood beams spanning between piers over a 12–30-inch high crawl space.<br>3. Also known as Post-and-Beam, Block-and-Beam, Block-and-Base, or Pier-and-Beam.<br>4. Flooring typically consists of wood framing, steel framing, precast concrete planks, or precast double tees.<br>5. Crawl space should be ventilated to evaporate moisture, which accumulates due to natural soil suction, drainage problems, and plumbing leaks.<br>6. Usually constructed with no carton forms below grade beams due to potential water infiltration into void and down shafts of deep foundations.<br>7. Vapor retarders, such as polyethylene sheathing, are not recommended to be used to cover soils within crawl space. |

* Compared to other foundation systems as described in Sections 4.1.1 to 4.2.3.

### 4.1.2 Stiffened Structural Slab with Deep Foundations

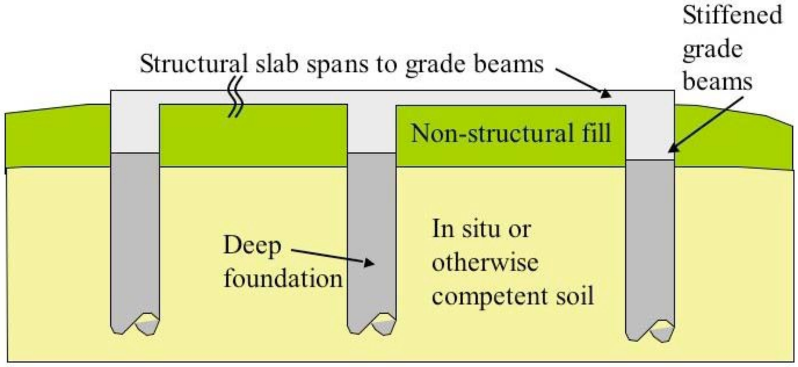



**Figure 4.1.2 Stiffened Structural Slab with Deep Foundations**

The stiffened structural slab with deep foundations is the same as the structural slab with void space and deep foundations with the following exception: the slab is placed, without a void, over the expansive soils and new fill, and the foundation must be designed to accommodate the pressures from the swelling soils. The foundation is designed as a "stiffened" slab. The grade beams form a grid-like or "waffle" pattern in order to increase the foundation stiffness and reduce the potential bending deflections due to upward movement of the foundation.

Using continuous grade beams in a grid-like fashion helps to reduce differential deflections. The deep foundations are used to minimize downward movement, or settlement, caused by shrinking soils. The stiffened structural slab with deep foundations should be designed to resist heave in accordance with the BRAB 33 (Building Research Advisory Board), Wire Reinforcement Institute (WRI) publication, Design of Slab-on-Ground Foundations; the ACI publication, Design of Slabs on Grade, ACI 360R, or the Post-Tensioning Institute (PTI) publication, Design and Construction of Post-Tensioned Slabs-on-Ground.

| TABLE 4.1.2 | STIFFENED STRUCTURAL SLAB WITH DEEP FOUNDATIONS | |
|---|---|---|
| ADVANTAGES * | DISADVANTAGES * | COMMENTS |
| 1. Compaction of new fill below slab not as critical and eliminates need for removing existing non-compacted fill.<br>2. Fill can be comprised of expansive or non-expansive soil. Fill need only be compacted to a density sufficient to support slab during setup.<br>3. Reduces settlement from soil shrinkage. | 1. Does not limit heave that can occur.<br>2. Requires additional design effort and higher design and construction cost. | 1. Slab is designed to span between grade beams. Grade beams are designed to span between deep foundations.<br>2. Slab is typically 4 to 8 inches thick, beam spacing is less, and slab is more heavily reinforced than for stiffened slab on fill.<br>3. Stiffening grade beams should be continuous across slab.<br>4. Slab is more heavily reinforced than non-structural slab.<br>5. Is not designed to prevent foundation tilt. |

* Compared to other foundation systems as described in Sections 4.1.1 to 4.2.3.

### 4.1.3 Stiffened Non-Structural Slab with Deep Foundations

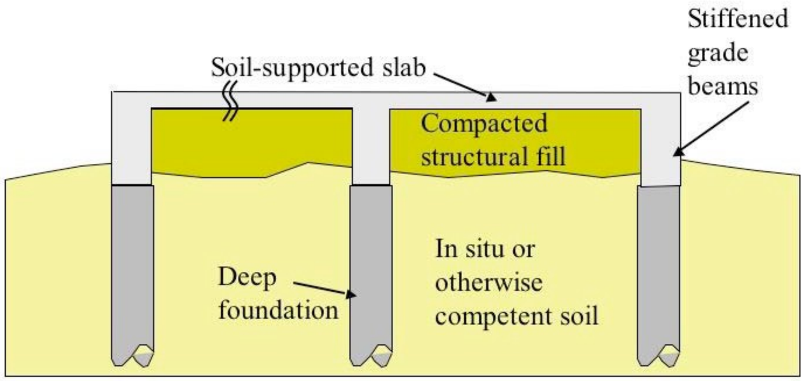



**Figure 4.1.3 Stiffened Non-Structural Slab on Fill with Deep Foundations**

This type of foundation system is a stiffened concrete slab that can bear on non-expansive select structural fill, with the stiffening grade beams spanning to deep foundations. Select structural fill can be defined as sandy clays with a plasticity index between 10 and 20, and a liquid limit less than 40. The fill acts as a buffer zone between the expansive soils and the slab, reducing the potential differential movement of the foundation. The foundation is designed as a ribbed mat that is "stiffened" with relatively deep and closely spaced grade beams. The grade beams are laid out in a grid-like or "waffle" pattern and are designed with sufficient stiffness to reduce the bending deflection caused by shrinking or swelling soils. See Section 4.1.2 for additional design information.

| TABLE 4.1.3 | STIFFENED NON-STRUCTURAL SLAB WITH DEEP FOUNDATIONS | |
|---|---|---|
| ADVANTAGES * | DISADVANTAGES * | COMMENTS |
| 1. Usually less expensive than structurally isolated systems with deep foundations.<br>2. Slab thickness and reinforcing is usually less than that of structurally isolated systems.<br>3. Settlement from soil shrinkage is usually less than that of shallow supported foundations. | 1. To resist potential uplift forces, grade beams may need to be deeper than those of a structurally isolated system. | 1. Stiffening grade beams should be continuous across slab.<br>2. Select structural fill can be used to reduce potential vertical rise.<br>3. Subgrade and fill, if used, should be field-verified for conformance to geotechnical specifications.<br>4. Is not designed to prevent foundation tilt. |

* Compared to other foundation systems as described in Sections 4.1.1 to 4.2.3.

### 4.1.4 Non-Stiffened Slab-on-Grade with Deep Foundations

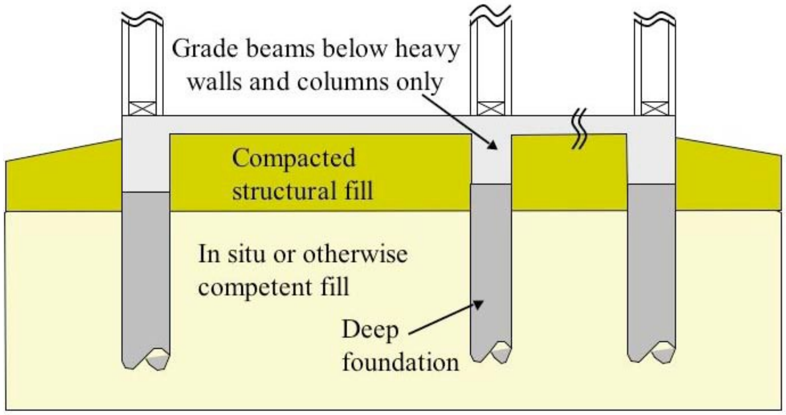



**Figure 4.1.4 Non-Stiffened Slab-on-Grade with Deep Foundations**

This system consists of a slab-on-grade with grade beams under load bearing walls supported by deep foundations. The foundation will move with the underlying soils. The foundation has little resistance to soil movement with this system. Perimeter grade beams are typically provided with this system to support the exterior wall system and to reduce undermining by erosion. They can also function as a root retarder or vertical moisture retarder. Interior grade beams are also usually provided under all interior load-bearing walls and shear walls. Interior columns are typically supported directly by deep foundations.

| TABLE 4.1.4 — NON-STIFFENED SLAB-ON-GRADE WITH DEEP FOUNDATIONS | | |
|---|---|---|
| **ADVANTAGES *** | **DISADVANTAGES *** | **COMMENTS** |
| 1. Comparatively easy and quick to construct.<br>2. Typically has fewer grade beams than stiffened slab foundation systems.<br>3. Construction joints and isolation joints can be used with this system to allow separate concrete placements. | 1. Does not significantly reduce amount of differential vertical movement that can occur.<br>2. More distress to the superstructure may occur with this system.<br>3. Lack of grade beams may not provide sufficient stiffness for jacking if future underpinning is required. | 1. Flat slab rests directly on underlying soil.<br>2. Warehouses, where interior slab movements can be tolerated, are often constructed using this method.<br>3. Select structural fill can be used to reduce potential vertical movements.<br>4. Subgrade and fill, if used, should be field-verified for conformance to geotechnical specifications.<br>5. Is not designed to prevent foundation tilt. |

* Compared to other foundation systems as described in Sections 4.1.1 to 4.2.3.

## 4.2 SHALLOW SUPPORT SYSTEMS

Shallow support foundation systems are defined as foundations having shallow foundation components that do not extend below the moisture active zone of the soils and are subject to vertical movements due to volumetric changes of the expansive soils.

### 4.2.1 Grade-Supported Stiffened Structural Slab

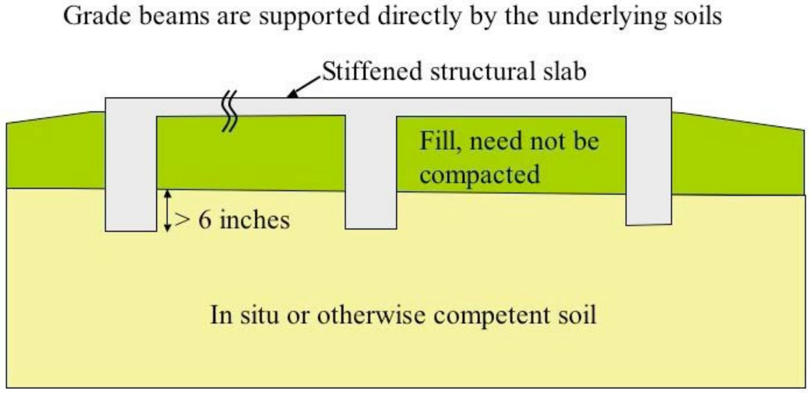



**Figure 4.2.1 Grade-Supported Stiffened Structural Slab**

This foundation system is similar to that discussed in Section 4.1.2, except that the grade beams are supported directly by the underlying soils instead of spanning to deep foundations. The key advantage of this system over that discussed in Section 4.2.2 is that the grade beams need only to penetrate a minimum of six inches into the competent natural soils or properly compacted fill. Fill placed between the grade beams is only required to be compacted enough to support the concrete during placement.

| TABLE 4.2.1 GRADE-SUPPORTED STIFFENED STRUCTURAL SLAB | | |
|---|---|---|
| ADVANTAGES * | DISADVANTAGES * | COMMENTS |
| 1. Compaction of new fill below slab not as critical and eliminates need for removing existing non-compacted fill.<br>2. Usually performs better than other grade-supported slabs.<br>3. If fill below slab is loosely compacted, potential vertical rise can be reduced as compared to other grade-supported foundations.<br>4. Faster to construct than slabs with deep foundations. | 1. May experience more vertical movement than stiffened slabs on deep foundations.<br>2. More expensive than slab-on-grade and non-structural systems due to more concrete and reinforcement.<br>3. Requires more design effort than non-structural slab systems. | 1. Also referred to as a ribbed mat or "super slab".<br>2. Grade beams must be supported by competent soils.<br>3. Slab is designed to structurally span between grade beams.<br>4. Slab is typically 4 to 6 inches thick, depending on beam spacing.<br>5. Grade beams can be wider or more closely spaced than other grade-supported slabs.<br>6. Stiffening grade beams should be continuous across slab.<br>7. Is not designed to prevent foundation tilt. |

* Compared to other foundation systems as described in Sections 4.1.1 to 4.2.3.

### 4.2.2 Grade-Supported Stiffened Non-Structural Slab

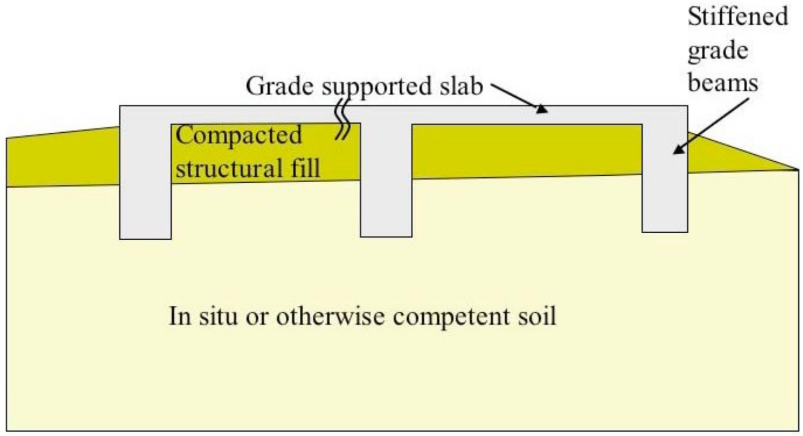



**Figure 4.2.2 Grade-Supported Stiffened Non-Structural Slab**

This foundation system is similar to that discussed in Section 4.1.3, except that the grade beams are supported directly by the underlying soils instead of spanning to deep foundations. It is also similar to Section 4.2.1 except that the entire stiffened slab is supported by the surface soils that are susceptible to the seasonal moisture fluctuations and movement. The foundation is designed utilizing continuous stiffening beams that form a grid like pattern.

Grade-supported stiffened slabs should be designed in accordance with the WRI publication, Design of Slab-on-Ground Foundations, the ACI publication, Design of Slabs on Grade, ACI 360R, or the PTI publication, Design and Construction of Post-Tensioned Slabs-on-Ground.

| TABLE 4.2.2 GRADE-SUPPORTED STIFFENED NON-STRUCTURAL SLAB | | |
|---|---|---|
| **ADVANTAGES *** | **DISADVANTAGES *** | **COMMENTS** |
| 1. Most economical system used where expansive soils are present.<br>2. Faster to construct than slabs with deep foundations. | 1. May experience more vertical movement than stiffened slabs supported on deep foundations. | 1. Stiffened slabs are sometimes called “waffle” or “floating” foundations.<br>2. Grade beams must be supported by competent soils.<br>3. Most commonly used foundation system in Houston area.<br>4. Stiffening grade beams should be continuous across slab.<br>5. Subgrade and fill, if used, should be field-verified for conformance to geotechnical specifications.<br>6. Is not designed to prevent foundation tilt. |

* Compared to other foundation systems as described in Sections 4.1.1 to 4.2.3.

### 4.2.3 Grade-Supported Non-Stiffened Slab of Uniform Thickness

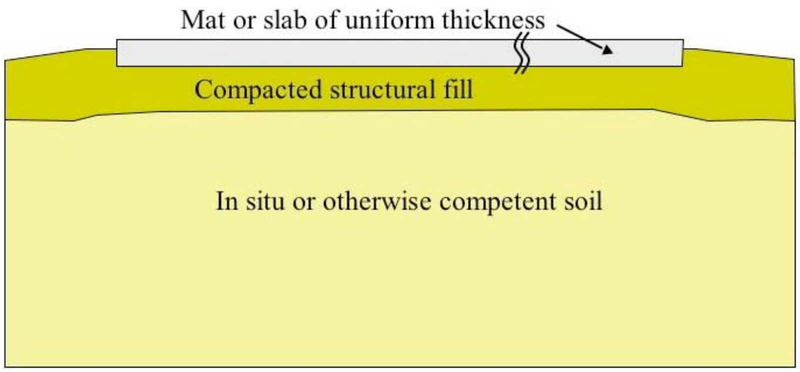



**Figure 4.2.3 Grade-Supported Non-Stiffened Slab of Uniform Thickness**

This system consists of a concrete slab-on-grade of uniform thickness with no deep support foundation components. The slab can be supported on in situ soils or compacted fill. This foundation system should be designed by the PTI method or other acceptable engineering methods to resist the potential bending moments induced by the differential deflections of the slab when subject to expansive soil movements.

| TABLE 4.2.3 | GRADE-SUPPORTED NON-STIFFENED SLAB OF UNIFORM THICKNESS | |
|---|---|---|
| ADVANTAGES * | DISADVANTAGES * | COMMENTS |
| 1. Faster to construct than stiffened slabs and deeply supported foundations.<br>2. Eliminates digging of grade beams.<br>3. Lack of grade beams makes it easier to jack against if underpinning is later required. | 1. May experience more vertical movement than stiffened slabs on deep foundations.<br>2. Potentially has more vertical differential displacement than stiffened slabs with the equivalent volume of concrete.<br>3. Allows roots to grow below foundation because there are no perimeter grade beams. | 1. Also called a "California Slab".<br>2. Behaves similar to a mat foundation.<br>3. Flat slab rests directly on underlying soil.<br>4. May include a perimeter grade beam as a root retarder or to prevent erosion.<br>5. Typically reinforced with conventional deformed bar reinforcing or post-tensioned cable.<br>6. Suitable for deep sandy soil or foundations having consistent subsoil formations with low propensity for volumetric movement.<br>7. Subgrade and fill, if used, should be field-verified for conformance to geotechnical specifications.<br>8. Is not designed to prevent foundation tilt. |

* Compared to other foundation systems as described in Sections 4.1.1 to 4.2.3.

## 4.3 MIXED DEPTH SYSTEMS

Mixed depth systems are foundations that extend to different bearing depths. They are sometimes used to support concentrated loads. Although their use is discouraged for certain applications, mixed depth foundation systems are sometimes used. They can be used for new buildings with large plan areas located on a site with widely varying soil conditions, for new buildings on sites with a substantial amount of deep fill, for new buildings on a sloping hillside, for new buildings located next to a waterway or slopes greater than 5%, for existing buildings when adding a new addition, etc. When a new addition is added onto an existing building, consideration must be given to the depths of the new and existing foundation systems.

### 4.3.1 Mixed Depth System for All-New Building Construction

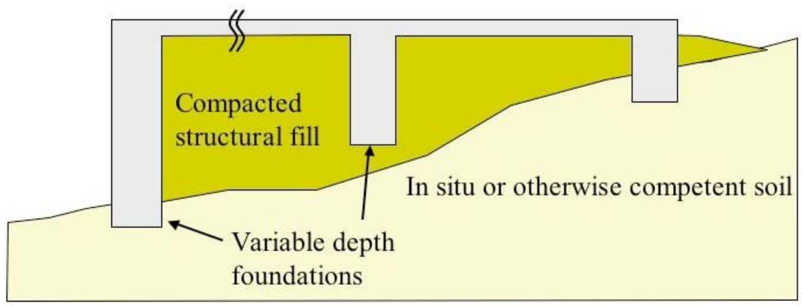



**Figure 4.3.1 Mixed Depth System for All New Building Construction**

Because of the increased possibility of differential movement, mixed depth systems are not often used for all-new construction except in areas of sloping grades and sloping strata.

| TABLE 4.3.1 | MIXED DEPTH SYSTEM FOR ALL-NEW BUILDING CONSTRUCTION | |
|---|---|---|
| ADVANTAGES * | DISADVANTAGES * | COMMENTS |
| 1. More economical than uniformly deep foundation system | 1. More likely to experience differential movement than foundations of uniform depth. | 1. Pier depth, if included, can vary to follow bearing stratum or to address slope instability issues.<br>2. Often used for perimeter and point loaded commercial buildings.<br>3. Is not designed to prevent foundation tilt. |

* Compared to other foundation systems as described in Sections 4.3.1 to 4.3.3.

### 4.3.2 Mixed Depth System for Building Additions with Deep Foundations

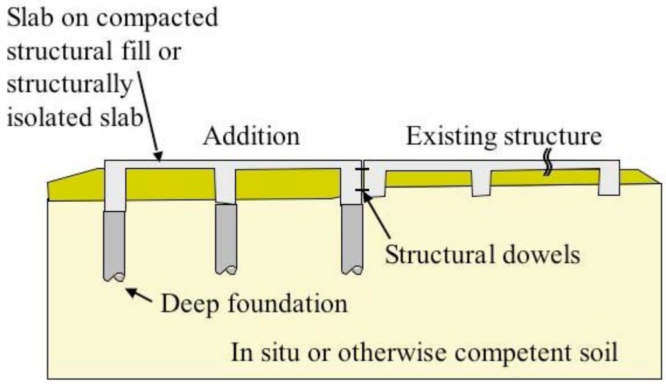


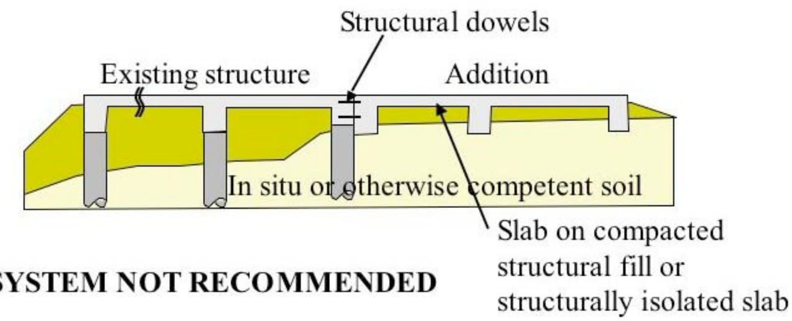

**Figure 4.3.2 Mixed Depth System for Building Addition with Deep Foundations**

Sometimes building additions are designed with deeper foundations than the original building in order to reduce movement of the addition. This is because the foundation of the older portion of the building has stabilized.

| TABLE 4.3.2 | MIXED DEPTH SYSTEM FOR BUILDING ADDITIONS WITH DEEP FOUNDATIONS | |
|---|---|---|
| ADVANTAGES * | DISADVANTAGES * | COMMENTS |
| 1. Addition is more stable than a new grade-supported foundation due to less seasonally active soils at increased foundation depth. | 1. More expensive than using a shallow foundation system for new addition. | 1. When used in conjunction with a new structurally isolated slab (i.e. isolated from soil movement, and structurally connected to existing building) minimizes risk of differential movement.<br>2. Is not designed to prevent foundation tilt. |

* Compared to other foundation systems as described in Sections 4.3.1 to 4.3.3.

### 4.3.3 Mixed Depth System for Building Addition with Shallow Foundations




**SYSTEM NOT RECOMMENDED**

**Figure 4.3.3 Mixed Depth System for Building Addition with Shallow Foundations**

Sometimes additions are built with shallower foundations than the original building in order to reduce the cost of construction.

| TABLE 4.3.3 | MIXED DEPTH SYSTEM FOR BUILDING ADDITION WITH SHALLOW FOUNDATIONS | |
|---|---|---|
| ADVANTAGES * | DISADVANTAGES * | COMMENTS |
| 1. More economical than uniformly deep foundation system. | 1. On expansive, compactable, or compressible soils, more shallowly supported addition is likely to move more than existing building. | 1. Not recommended due to high probability of differential movement. |

* Compared to other foundation systems as described in Sections 4.3.1 to 4.3.3.

# 5.0 FOUNDATION COMPONENT DESIGN OPTIONS

This section covers the advantages and disadvantages of common component design options for the systems that were discussed in Section 4.0. Components are referenced to other components in the same category.

## 5.1 DEEP SUPPORT COMPONENTS

This section discusses deep foundation support components that are commonly used in new construction for residential and other low-rise buildings. This includes drilled and under-reamed piers, drilled straight-shaft concrete piers, auger-cast concrete piles, displacement piles, and helical piers.

### 5.1.1 Drilled and Underreamed Concrete Piers

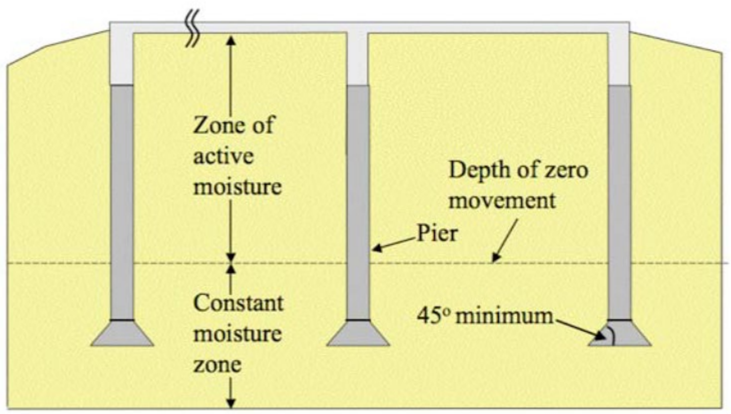



**Figure 5.1.1 Drilled and Underreamed Concrete Piers**

Drilled and underreamed piers are cast-in-place concrete foundation components with an enlarged bearing area extending downward to a soil stratum capable of supporting the loads. Drilled and underreamed concrete piers have also been referred to as drilled piers, drilled shafts, caissons, drilled caissons, belled caissons, belled piers, bell-bottom piers, foundation piers, bored piles, and or drilled-and-underreamed footings. The depth of the drilled pier should extend to a depth below the moisture active zone that is sufficient to anchor the pier against upward movements of swelling soils in the upper active zone.

| TABLE 5.1.1 | DRILLED AND UNDERREAMED CONCRETE PIERS | |
|---|---|---|
| **ADVANTAGES *** | **DISADVANTAGES *** | **COMMENTS** |
| 1. Has a long, successful track record, approaching a century of use.<br>2. Provides better lateral load resistance than other deep foundations with smaller projected surface areas.<br>3. Underreamed portion economically provides large end bearing capacity.<br>4. Most commonly used deep foundation component in Houston area.<br>5. Easier to install than displacement piles in very stiff sandy soils. | 1. Installation requires a minimum of four different procedures: shaft drilling, underreaming, reinforcing steel placement, and concrete placement.<br>2. Requires removing excavated soils off-site.<br>3. Sloughing of soils at pier shaft and bell can create installation problems.<br>4. Difficult to confirm integrity of concrete placed under groundwater or slurry conditions.<br>5. May be difficult for some contractors to install drilled piers below a depth of 15 feet because of equipment limitations.<br>6. Requires waiting until concrete sufficiently cures before applying load.<br>7. Drilling piers below soil active moisture zone in Houston area often results in encountering water or sands. | 1. Many contractors falsely believe underreams should be founded in certain color or stiffness clay rather than at depth shown on foundation engineering drawings.<br>2. Slump should be greater than 5 inches to prevent honeycombing.<br>3. Vertical reinforcement should be used to resist tensile forces due to friction on shaft from swelling soils.<br>4. Can be constructed in areas with high groundwater table by using slurry displacement method.<br>5. Can be installed through sandy layers by using retrievable casing. |

* Compared to other deep supporting elements as described in Sections 5.1.2 to 5.1.5.

### 5.1.2 Drilled Straight-Shaft Concrete Piers

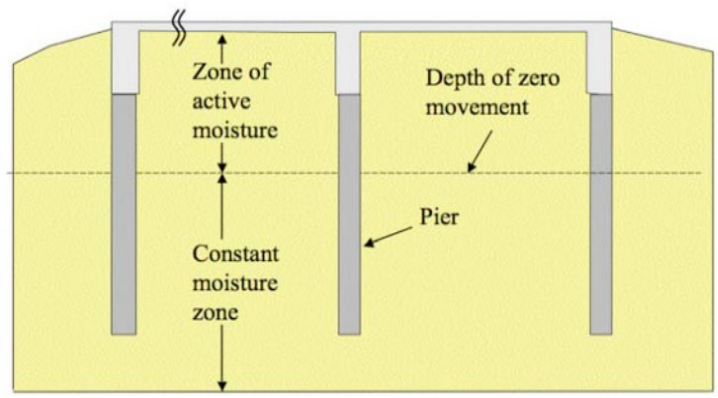



**Figure 5.1.2 Drilled Straight-Shaft Concrete Piers**

Drilled piers are cast-in-place concrete foundation components extending downward to a soil stratum capable of supporting the loads. Drilled straight-shaft concrete piers are not underreamed.

| **TABLE 5.1.2** | **DRILLED STRAIGHT-SHAFT CONCRETE PIERS** | |
|---|---|---|
| **ADVANTAGES *** | **DISADVANTAGES *** | **COMMENTS** |
| 1. Quality control is simpler than for drilled and underreamed piers.<br>2. Shafts are typically larger diameter than drilled and underreamed piers and provide better lateral load resistance.<br>3. Easier to inspect than underreamed piers.<br>4. Has a long, successful track record, more than a century of use.<br>5. Easier to install than displacement piles in very stiff sandy soils. | 1. Soil borings are required to be deeper than underreamed piers, which adds to cost.<br>2. Geotechnical reports do not routinely provide shaft allowable skin friction capacity values.<br>3. Requires removing excavated soils off-site.<br>4. Can require steel casing to drill through sandy soils.<br>5. Can require slurry or concrete to be pumped to bottom of hole when groundwater is encountered.<br>6. Requires waiting until concrete sufficiently cures before applying load.<br>7. Sloughing of soils can create installation problems.<br>8. Difficult to confirm integrity of concrete placed under groundwater or slurry conditions.<br>9. May be difficult for some contractors to install drilled piers below a depth of 15 feet because of equipment limitations.<br>10. Drilling straight-shaft piers often results in encountering water or sands.<br>11. Drilling piers below soil active moisture zone in Houston area often results in encountering water or sands. | 1. Many contractors falsely believe underreams should be founded in certain color or stiffness clay rather than at depth shown on foundation engineering drawings.<br>2. Only recently used as an alternative to drilled and underreamed footings in light foundation industry.<br>3. Slump should be greater than 5 inches to prevent honeycombing.<br>4. Vertical reinforcement should be used to resist tensile forces due to friction on shaft from swelling soils.<br>5. Can be constructed in areas with high groundwater table by using slurry displacement method.<br>6. Can be installed through sandy layers by using retrievable casing. |

* Compared to other deep supporting elements as described in Sections 5.1.1 and 5.1.3 to 5.1.5.

### 5.1.3 Auger-Cast Concrete Piles

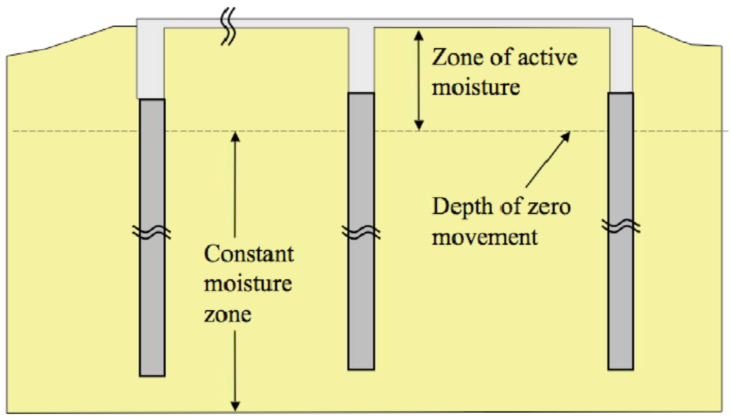



**Figure 5.1.3 Auger-Cast Concrete Piles**

Auger cast piles are installed by rotating a continuously-flighted hollow shaft auger into the soil to a specified depth. Cement grout is pumped under pressure through the hollow shaft as the auger is slowly withdrawn.

| TABLE 5.1.3 | AUGER-CAST CONCRETE PILES | |
|---|---|---|
| ADVANTAGES * | DISADVANTAGES * | COMMENTS |

| | | |
|---|---|---|
| 1. Can be readily installed through sand strata and below the water table.<br>2. Can be easily installed at angles other than vertical. | 1. Reinforcing cage must be installed after auger is removed, which limits depth of reinforcing cage that can be installed and may result in inadequate concrete cover due to cage misalignment.<br>2. If singly reinforced, auger-cast piles do not provide significant bending resistance.<br>3. Higher mobilization costs than for other systems.<br>4. Fewer contractors are available that offer this system, making construction pricing less competitive.<br>5. Soil borings are required to be deeper than underreamed piers, which adds to cost.<br>6. Geotechnical reports do not routinely provide shaft allowable skin friction capacity values.<br>7. Requires removing excavated soils off-site.<br>8. Requires waiting until concrete sufficiently cures before applying load.<br>9. Difficult to confirm integrity of concrete. | 1. Commonly utilized in situations drilling through collapsing soils and emerging free water.<br>2. Vertical reinforcement should be used to resist tensile forces due to friction on shaft from swelling soils.<br>3. Only recently used as an alternative to drilled and underreamed footings in light foundation industry.<br>4. Slump should be greater than 5 inches to prevent honeycombing. |

* Compared to other deep supporting elements as described in Sections 5.1.1, 5.1.2, 5.1.4 and 5.1.5.

### 5.1.4 Displacement Piles

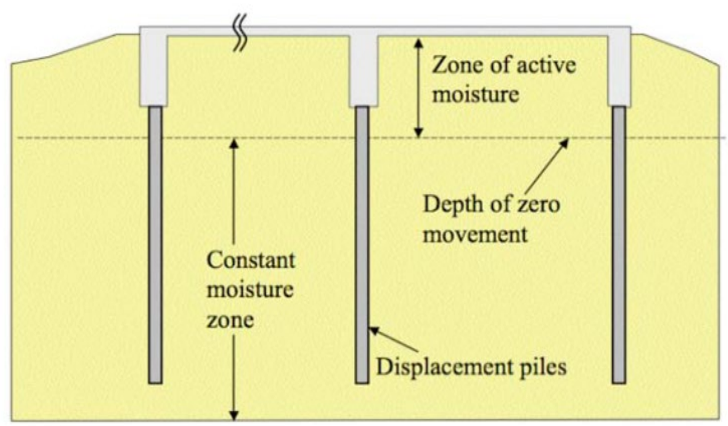



**Figure 5.1.4 Displacement Piles**

For the purpose of this document, displacement piles are defined as relatively long slender members driven, vibrated, or pressed into the soil while displacing soil at the pile tip.

| TABLE 5.1.4 | DISPLACEMENT PILES | |
|---|---|---|
| ADVANTAGES * | DISADVANTAGES * | COMMENTS |
| 1. No excavated soils to remove.<br>2. Only one trade typically involved during installation.<br>3. Easier to remove than drilled piers if future demolition is required.<br>4. Can be installed through soft soils and water-bearing strata. | 1. Vibrations and noise that occur during installation can be a problem.<br>2. Difficult to install through stiff sand strata.<br>3. Because of relatively small diameters, grouping or clustering can be required, which can lead to other potential problems. | 1. Typically used at shoreline locations, swamps, marshes, or other soft soil areas. |

* Compared to other deep supporting elements as described in Sections 5.1.1 to5.1.3, and 5.1.5.

### 5.1.5 Helical Piers

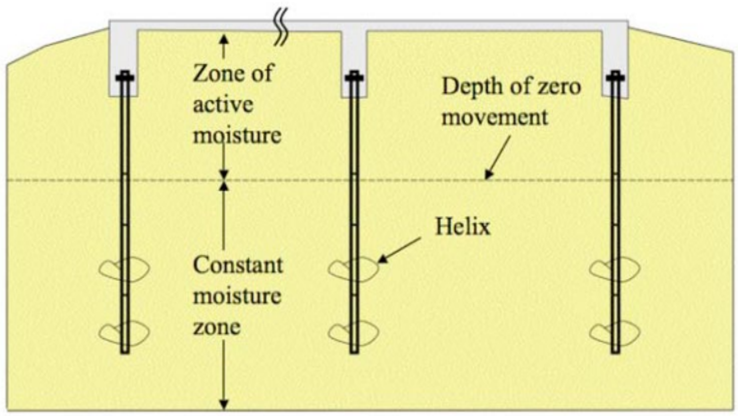



**Figure 5.1.5 Helical Piers**

Steel helical piers, also known as screw anchors or screw-in piles, have been used since the early 1950s as tie back anchors for retaining walls and as foundations for lighthouses, substations, towers, heavy equipment, and other similar applications. They are now gaining popularity for use in supporting heavier foundations such as residential and other low-rise buildings.

The anchor consists of a plate or series of steel plates formed into the shape of a helix to create one pitch of a screw thread. The shape of the plate permits easy installation, which is accomplished by applying torque to the shaft of the anchor and screwing it into the ground using rotary motors. The anchors can be used to resist a tensile or compressive load, which is accomplished by means of bearing pressure resistance on the area of each helix, and not by skin friction along the shaft. The plate helices of helical pier foundations are attached to a central high-strength steel shaft that can be segmented to facilitate construction and to allow various combinations of the number and diameter of helices used. The pier is screwed into the soils until the applied torque readings indicate that the necessary load capacity has been achieved or until the desired depth below the moisture active zone of the expansive soils is obtained. In new construction, the pier shafts are typically anchored to the grade beams by using fabricated brackets that are tied to the grade beam reinforcing before placing the concrete and bolted to the top of the pier shafts. The bracket consists of a flat horizontal plate welded to a vertical square tube that slips over the shaft of the pier. The plate is embedded into the grade beam concrete.

| TABLE 5.1.5 | HELICAL PIERS | |
|---|---|---|
| ADVANTAGES * | DISADVANTAGES * | COMMENTS |
| 1. Can be installed in low headroom applications in limited access areas.<br>2. Shaft of helical pier has small surface area, which limits amount of uplift or drag-down frictional forces that can occur due to vertical movements of expansive soils.<br>3. Only licensed contractors may install helical piers, which provide some means of assuring that contractors are tested and trained in all facets of helical pier construction.<br>4. Does not require excavation of soil for installation, thus providing minimal disturbance to site.<br>5. Can be installed in less time than drilled piers or auger-cast concrete piles.<br>6. Can be installed at a batter to resist lateral loads on foundation.<br>7. Shaft extensions can easily be added to install helices deep below soil moisture active zone.<br>8. Loads can be applied immediately after installation.<br>9. Only one trade typically involved during installation. | 1. Fewer contractors are available that offer this system, and construction pricing is less competitive.<br>2. Usually requires on-site test pier to verify instability and load bearing capacity.<br>3. Although steel is often galvanized, corrosion can limit life expectancy.<br>4. In very soft soils with low lateral restraint, external concrete jacket is required to prevent buckling of small shaft under large loads.<br>5. Square shafts of helical piers disturb soil around shaft during installation to some extent and can result in gaps occurring between soil and shaft along full length of pier. This gap can become a pathway for water to flow down around shaft and activate swelling of dry expansive soils in non-active zone and can also allow air and moisture to speed up rate of steel corrosion.<br>6. Vertically installed helical piers provide little resistance to lateral forces because of their small shaft diameter. | 1. Additional protective coatings (e.g., coal-tar epoxy) or cathodic protection can be used to control corrosion. |

* Compared to other deep supporting elements as described in Sections 5.1.1 to 5.1.4.

## 5.2 SLAB AND GRADE BEAM REINFORCING

Since concrete is weak in tension, concrete slabs and grade beams are almost always reinforced with some type of steel reinforcing. The most common design options include post-tensioned reinforcing, deformed bar reinforcing, welded wire fabric reinforcing, and fiber reinforcing. Under special circumstances, unreinforced plain concrete can also be used. Advantages and disadvantages of these types of reinforcement for slab-on-grade and grade beam applications are discussed below.

### 5.2.1 Post-Tensioned Reinforcing

Post-tensioned concrete is a type of prestressed concrete in which the cables are tensioned after partial curing of the concrete has occurred. Pretensioned prestressed concrete, in which the cables are tensioned before placement of concrete around them, is not commonly used for slabs and grade beams in residential and other low-rise buildings. Post-tensioned reinforcing has become the norm for residential slabs in most Texas metropolitan areas.

Post-tensioned reinforcing consists of high-strength steel wire strands, typically referred to as tendons or cables, which are encased in plastic sheathing or ducts. When also used near the bottom of grade beams, the tendons are usually located near the top of the grade beam at the ends of the span and draped into the bottom portion of the grade beam near mid-span.

Tendons typically consist of 1/2-inch diameter high-strength seven-wire strands having yield strength of 270 ksi. The tendons are elongated by hydraulic jacks and held in place at the edges of the foundation by wedge-type anchoring devices. The type of tendons typically used in residential slabs and grade beams are unbonded tendons, in which the prestressing steel is not actually bonded to the concrete that surrounds it except at the anchored ends. Coating the steel strands with corrosion-inhibiting grease and encasing them in extruded plastic protective sheathing that acts as a bond-breaker will accomplish this. The tendons are typically fully stressed and anchored 3 to 10 days after concrete placement.

| TABLE 5.2.1 | POST-TENSIONED REINFORCING | |
|---|---|---|
| ADVANTAGES * | DISADVANTAGES * | COMMENTS |
| 1. Costs less than conventional steel rebar reinforcing.<br>2. Speeds up construction because there are fewer pieces to install than conventionally reinforced.<br>3. Controls the size of curing and shrinkage surface cracks in concrete slabs after tendons are stressed.<br>4. Can reduce required amount of control joints in slab.<br>5. Slab is designed as an uncracked section, therefore should require less concrete. | 1. Requires specialized knowledge and expertise to design, fabricate, assemble, and install.<br>2. Geotechnical design parameters, such as $y_m$ and $e_m$, are not consistently defined among geotechnical engineers.<br>3. Slab design can be compromised if cracks open before stressing and fill with debris.<br>4. Making penetrations into slab can be hazardous due to presence of tensioned cables.<br>5. Additional operations such as stressing, cutting, and grouting are required after concrete placement.<br>6. Cannot prevent cracks prior to stressing caused by plastic shrinkage, plastic settlement, and crazing at slab surface.<br>7. Tendon end anchorages, which are highly stressed critical elements of system, are located at exterior face of foundation where exposed strand ends, and anchors can be susceptible to corrosion.<br>8. Post-tensioned reinforced foundations are susceptible to blowouts, in which sudden concrete bursting failure occurs during or after stressing. If a tendon or anchorage fails or a blowout occurs, additional operations are required for repair. | 1. Normally used locally to reinforce stiffened slabs-on-grade but can be used for other configurations as well.<br>2. Post-tensioned foundations are typically designed using Post Tensioning Institute (PTI) publication *Design and Construction of Post-Tensioned Slabs-on-Ground.*<br>3. Compared to other types of post-tensioned construction, residential slabs are lightly reinforced with average concrete compression levels ranging only between 50 psi and 100 psi. |

* Compared to other types of slab and grade beam reinforcing described in Sections 5.2.2 to 5.2.5.

### 5.2.2 Deformed Bar Reinforcing

Deformed bar reinforcing, commonly call rebar, typically consists of ASTM 615 steel having yield strength of either 40 or 60 ksi. Grade 40 rebar was more common in pre-1970 construction, and Grade 75 rebar is expected to become more common in the future.

Deformed bar reinforcing is categorized as “passive” reinforcement since it does not carry any force until the concrete member deflects and cracks under applied loads. On the other hand, post-tensioned tendons are considered “active” reinforcing because they are prestressed and carry tensile force even when loads are not applied to the concrete member.

| TABLE 5.2.2 | DEFORMED BAR REINFORCING | |
|---|---|---|
| **ADVANTAGES *** | **DISADVANTAGES *** | **COMMENTS** |
| 1. Less technical installation operations than for a post-tensioned foundation system.<br>2. Post-construction slab penetrations are less hazardous to install than in slabs with post-tensioned reinforcing.<br>3. Field splices are easier to implement. | 1. Requires specialized knowledge and expertise to design, fabricate, assemble, and install.<br>2. Costs more than post-tensioned reinforcing.<br>3. Slower to construct than post-tensioned reinforced slabs<br>4. Foundation performance is more sensitive to correct placement of slab reinforcement. | 1. Some local building officials do not require deformed bar reinforced foundations to be engineered, even though design has similar difficulty as does post-tensioned foundations.<br>2. Deformed bar reinforced slab foundations are typically designed per American Concrete Institute (ACI) publication ACI 360R, *Design of Slabs on Grade*, charts from Portland Cement Association (PCA) publications *Concrete Floors on Ground* and *Slab Thickness Design for Industrial Concrete Floors on Grade*, Wire Reinforcement Institute (WRI) publication *Design of Slabs on Grade*, Building Research Advisory Board (BRAB) publication *Criteria for Selection and Design of Residential Slabs-on-Grade*, Post Tensioning Institute (PTI) publication *Design and Construction of Post-Tensioned Slabs-on-Ground,* or finite element methodology.<br>3. Local building officials may not require construction certification by engineers of foundations using only deformed bar reinforcing. |

* Compared to other types of slab and grade beam reinforcing described in Sections 5.2.1 and 5.2.3 to5.2.5.

### 5.2.3 Welded Wire Fabric Reinforcing

Welded wire fabric concrete reinforcing consists of cold-drawn wire in orthogonal patterns, square or rectangular, that is welded at all intersections, and is typically used in slab construction. Welded wire fabric (WWF) is commonly called "wire mesh", but mesh is a much broader term that is not limited to concrete reinforcement. Welded wire fabric can be made of smooth wire (ASTM A185) or deformed wire (ASTM A497) and can be manufactured in sheets (usually wire sizes larger than W4) or rolls (usually wire sizes smaller than W1.4).

| TABLE 5.2.3 | WELDED WIRE FABRIC REINFORCING | |
|---|---|---|
| **ADVANTAGES *** | **DISADVANTAGES *** | **COMMENTS** |
| 1. Welded wire fabric rolls can be manufactured in any lengths, up to maximum weight per roll that is convenient for handling (100-200 ft).<br>2. Has greater yield strength than conventional deformed bar reinforcing, which can result in reducing required cross-sectional area of steel.<br>3. Development lengths are typically much smaller than for deformed bar reinforcing.<br>4. Concrete shrinkage cracks can be kept smaller due to confinement offered by welded cross wires, and microcracking is better distributed.<br>5. Labor costs to install welded wire fabric are less than to install conventional deformed bar reinforcing through elimination of tying reinforcing rods and faster placement of large sheets. | 1. Welded wire fabric is difficult to position and hold in place within thickness of slab. Slab crack performance is more sensitive to correct placement of reinforcement.<br>2. Shipping restrictions as well as manufacturing limitations can limit maximum sheet size.<br>3. Application is generally limited to slabs only.<br>4. Heavy welded wire fabric reinforcement may not be readily available and can require special order and/or long lead-time.<br>5. Practice of placing wire mesh on subgrade and using hooks to lift it, as workers walk on mesh, invariably results in large areas of mesh remaining at bottom of slab. | 1. Welded wire fabric reinforced residential foundations are typically designed per Wire Reinforcement Institute (WRI) methodology.<br>2. Local building officials may not require engineering certification of foundations using only welded wire fabric. |

* Compared to other types of slab and grade beam reinforcing described in Sections 5.2.1, 5.2.2, 5.2.4, and 5.2.5.

### 5.2.4 Fiber Reinforced Concrete

Fiber reinforced concrete consists of synthetic or steel fibers that help to control plastic shrinkage cracking, and plastic settlement cracks. Helps reduce bleeding and water migration to slab surface, which helps to control water-cement ratio and produce concrete with less permeability and improved toughness. Fiber reinforced concrete helps increase impact resistance and surface abrasion resistance of concrete.

Fiber reinforced concrete is not a substitute for structural reinforcing per ACI 544R-88. Therefore, advantages and disadvantages are not given.

### 5.2.5 Unreinforced Concrete

Unreinforced concrete, also known as "plain" concrete, is concrete without any reinforcing. Soil-supported concrete slabs can be designed as plain concrete, as well as continuously supported grade beams. Unreinforced concrete should not be used for structural foundations on expansive soils and is not recommended for use in slabs subject to movement unless cracking is not objectionable. Therefore, advantages and disadvantages are not given.

## 5.3 VOID SYSTEMS UNDER GRADE BEAMS AND PIER CAPS

Voids used by some engineers under grade beams and concrete caps for deep foundations are commonly created by using the same type of wax-impregnated corrugated cardboard forms described in Section 4.1.1.1. If the grade beams are constructed by using the trenching method in which concrete is cast directly against the soil in the excavated trenches, self-disintegrating void forms must be used.

An alternate method of grade beam construction is to form the sides of the concrete grade beams, particularly for foundation designs that use non-expansive backfill that elevate the slab above the surrounding grade for drainage purposes. In this case, it is possible to use removable forms to create the voids under the grade beams, and to install strip forms along the bottom edges of the grade beams to keep the soil from filling the voids when backfilling against the sides of the grade beams.

Carton forms are not typically used below grade beams due to potential water infiltration into void and down shafts of deep foundations.

## 5.4 VAPOR RETARDERS

A vapor retarder (sometimes misleadingly called a vapor barrier) is sheeting material, usually polyethylene film, which is placed under a ground level concrete slab in order to reduce the transmission of water vapor from the soils below the foundation up through the concrete slab. Vapor retarders are commonly used where moisture can migrate upward from below the slab and cause damage to floor coverings, household goods, or stored materials. Vapor retarders should be overlapped at least 6" at the joints and should be carefully fitted around pipes and other service penetrations through the slab.

In typical southeast Texas area slab-on-grade construction, the vapor retarder is normally placed directly on top of the finish-graded in situ clay or sandy clay soil, or when fill is added, on top of the non-expansive select fill. If cardboard void cartons are used, the vapor retarder should be placed above the void forms in order to allow moisture to degrade the void boxes.

For residential construction in areas having expansive soils, concrete is most commonly placed directly on the vapor retarder. At grade beam locations, the vapor retarder may be draped down into the excavated trench and be continuous around the exterior surface of the grade beam.

## 5.5 GRADE-BEAM-TO-PIER CONNECTIONS

Traditionally, drilled pier shafts in new construction have been tied to the grade beams with hooked or long straight rebar anchorage to create a connection. The recent trend over the last decade in the Houston area residential construction market is to allow the grade beams to float on top of the deep foundation components with no vertical restraints. This eliminates stresses due to fixed pier-to-beam connections.

### 5.5.1 Grade-Beam-to-Pier Connections with No Restraints

Grade-beam-to-pier connections with no restraints implies that the foundation grade beams are cast atop the already cured drilled piers, which are flat and allow the grade beam to translate relative to the pier in all directions except vertically downward.

| TABLE 5.5.1 | GRADE-BEAM-TO-PIER CONNECTIONS WITH NO RESTRAINTS | |
|---|---|---|
| **ADVANTAGES *** | **DISADVANTAGES *** | **COMMENTS** |
| 1. Allows foundation to rise more uniformly if underlying soils swell.<br>2. Easier to clean mud from top of pier caps.<br>3. Pier steel does not interfere with trencher during grade beam excavation. | 1. Foundation can move laterally due to swelling soils or sloping sites.<br>2. After concrete is placed, cannot easily verify if reinforcing steel was installed in piers. | |

* Compared to other types of grade-beam-to-pier connections described in Sections 5.5.1 to 5.5.3.

### 5.5.2 Grade-Beam-to-Pier Connections with Horizontal-Only Restraints

Grade-beam-to-pier connections with horizontal-only restraints implies that the foundation grade beams have a positive connection to the piers in any lateral direction, but the grade beams are allowed to translate vertically upward, relative to the piers.

| TABLE 5.5.2 | GRADE-BEAM-TO-PIER CONNECTIONS WITH HORIZONTAL-ONLY RESTRAINTS | |
|---|---|---|
| **ADVANTAGES *** | **DISADVANTAGES *** | **COMMENTS** |
| 1. Horizontal foundation movement is limited.<br>2. Allows foundation to rise more uniformly if underlying soils swell. | 1. Requires additional labor and material. | 1. Bond-breakers, such as sleeved deform bars, non-deformed bar dowels, and shear keys can be used.<br>2. Recommended at sloping sites where lateral resistance is required. |

* Compared to other types of grade-beam-to-pier connections described in Sections 5.5.1 to 5.5.3.

### 5.5.3 Grade-Beam-to-Pier Connections with Horizontal and Vertical Restraints

Grade-beam-to-pier connections with horizontal and vertical restraints implies that the foundation grade beams are connected to the top of the piers in such a way that there can be no relative translation in any direction.

| TABLE 5.5.3 | GRADE-BEAM-TO-PIER CONNECTIONS WITH HORIZONTAL AND VERTICAL RESTRAINTS | |
|---|---|---|
| **ADVANTAGES *** | **DISADVANTAGES *** | **COMMENTS** |
| 1. May provide uplift resistance from swelling soils if piers are adequately anchored.<br>2. Horizontal foundation movement is limited. | 1. Impedes or prevents jacking of a foundation that must be lifted. Pier reinforcing must be severed before lifting.<br>2. Does not allow grade beams to freely lift off piers if upper strata heave occurs. This can cause distress in slab because it is more flexible than grade beams.<br>3. Beams, beam-to-pier connections, and slab must be designed for uplift forces due to swelling soils. | 1. Connection typically is an extension of pier shaft vertical deformed reinforcement.<br>2. Recommended at sloping sites where lateral resistance is required. |

* Compared to other types of grade-beam-to-pier connections described in Sections 5.5.1 to 5.5.3.

# 6.0 FOUNDATION SITE DESIGN OPTIONS

The various types of mitigation options to reduce the damaging effects of soil movement due to improper drainage and transpiration of trees and shrubbery that are discussed in this guide can be categorized into two basic groups: (1) moisture control systems, and (2) vegetation control systems.

## 6.1 MOISTURE CONTROL SYSTEMS

Moisture control systems mitigate damage by controlling the amount of water and moisture that enter into the site soils. This includes methods to control stormwater runoff and methods of providing irrigation to site vegetation.

### 6.1.1 Site Drainage Systems

Three methods of controlling site drainage include site grading, French drains, and area drains. These systems reduce vertical movements of building foundations by moderating the effects of seasonal moisture changes.

#### 6.1.1.1 Site Grading

Site grading causes excess water to flow away from the foundation via surface sloping and drainage swales. Adequate surface drainage slopes are essential to minimize foundation movement and damage. Current International Residential Code requires 6" minimum fall the first 10' out from and perpendicular to building walls, and 2% minimum elsewhere to drain off lot. Because current building practices sometimes have homes built closer than 10’ to the adjacent structure or lot line, it is necessary to have greater slopes so that the 6” minimum is maintained.

| TABLE 6.1.1 SITE GRADING | | |
|---|---|---|
| ADVANTAGES * | DISADVANTAGES * | COMMENTS |
| 1. Fill materials are readily available.<br>2. Less maintenance required afterwards.<br>3. Inadequate drainage is easier to detect.<br>4. Most economical. | 1. Improper grading can cause water to shed to adjacent properties.<br>2. Fill materials require proper compaction and material. | 1. Materials should consist primarily of clay. Do not use bank sand or clayey sand or silts.<br>2. Can require excavation in addition to fill. |

* Compared to other types of site drainage systems described in Sections 6.1.1.2 and 6.1.1.3.

#### 6.1.1.2 French Drains

French drains are subsurface drainage systems that are used around the perimeter of a foundation to remove free water in the subsoil.

| TABLE 6.1.1.2 | SUBSURFACE DRAINAGE SYSTEMS (FRENCH DRAINS) | |
|---|---|---|
| **ADVANTAGES *** | **DISADVANTAGES *** | **COMMENTS** |
| 1. Helps reduce moisture infiltration from underground water sources.<br>2. Suitable when site grading is not an available option. | 1. If not draining effectively, can recharge the surrounding soil with moisture, causing damage to the foundation.<br>2. Not very effective in expansive clay soils because soil suction is high when soil permeability is very low.<br>3. Can cause erosion of surrounding soil, causing settlement of foundation if too close.<br>4. Requires some maintenance but is difficult to monitor.<br>5. French drain fabric membranes can tear or be punctured.<br>6. If used in conjunction with a vertical moisture retarder on one side, sufficient geotechnical or geophysical testing is required to determine natural flow direction and source of groundwater.<br>7. Most expensive system. | 1. Must have functioning outfall to storm drain system.<br>2. Commonly used when site is too flat to accommodate proper grade slopes.<br>3. Usually consists of a 4" or larger PVC perforated pipe, covered with sand and gravel and sloped to a positive outlet, but must comply with International Residential Code.<br>4. Utilized in removing moisture behind retaining and basement walls. |

* Compared to other types of drainage systems described in Sections 6.1.1.1 and 6.1.1.3.

### 6.1.1.3 Area Drains

Area drains (catch basins) with non-perforated pipe are surface collection systems used around the perimeter of a foundation to remove surface water by gravity flow or mechanical lifting.

| TABLE 6.1.1.3 | AREA DRAINS | |
|---|---|---|
| **ADVANTAGES *** | **DISADVANTAGES *** | **COMMENTS** |
| 1. Suitable when site grading is not an available option.<br>2. Water from downspouts can be discharged into area drainage system. | 1. A clogged drain can cause localized flooding.<br>2. If used in conjunction with a vertical moisture retarder on one side, sufficient geotechnical or geophysical testing is required to determine to natural flow direction and source of surface water.<br>3. A leaking pipe can cause soils to erode or swell. | 1. Commonly used in back yards when site is too flat to accommodate proper grade slopes.<br>2. Usually consists of a 4" or larger PVC non-perforated pipe.<br>3. When used, sump failure can cause flooding and can require periodic maintenance.<br>4. Can be used in conjunction with site grading.<br>5. A mechanical lift should be used if gravity outfall is not possible. |

* Compared to other types of drainage systems described in Sections 6.1.1.1 and 6.1.1.2.

### 6.1.2 Moisture Retarder Systems

Moisture retarder systems are used to reduce moisture transfer to the soils underneath foundations. Such systems include horizontal moisture retarders and vertical moisture retarders. These systems help moderate effects of seasonal changes on foundation movements.

### 6.1.2.1 Horizontal Moisture Retarders

Horizontal moisture retarders usually consist of materials of low permeability. These systems extend outward around the edges of the foundation. Sidewalks, driveways, or parking lots can be multifunctional, also serving as moisture retarders.

| **TABLE 6.1.2.1** | **HORIZONTAL MOISTURE RETARDERS** | |
|---|---|---|
| **ADVANTAGES *** | **DISADVANTAGES *** | **COMMENTS** |
| 1. Readily inspected and maintained<br>2. Requires less slope than green space (e.g., only 1/8” / ft.) to achieve positive drainage away from foundation.<br>3. Can double as pavement for parking or sidewalk. | 1. Requires larger area to be effective.<br>2. Heaving of retarder can occur due to soil hydration.<br>3. Fabric membrane retarders more prone to tear or puncture.<br>4. Unsecured rigid retarders can "walk-away" from building and allow water infiltration through gap created at edge of building if seal is not maintained.<br>5. Owner or future owner can remove it, not realizing it serves a design purpose, and inadvertently eliminate benefit it provides.<br>6. Only retards surface moisture.<br>7. May not be aesthetically acceptable. | 1. Usually concrete or asphalt pavement.<br>2. Horizontal moisture retarders slow root growth by reducing oxygen transmission to roots.<br>3. Doubles as root retarder. |

* Compared to other type of moisture retarder system described in Section 6.1.2.2.

### 6.1.2.2 Vertical Moisture Retarders

Vertical moisture retarders usually consist of materials of low permeability that extend downward from grade level around the perimeter of the foundation.

| **TABLE 6.1.2.2** | **VERTICAL MOISTURE RETARDERS** | |
|---|---|---|
| **ADVANTAGES *** | **DISADVANTAGES *** | **COMMENTS** |
| 1. More effective in retarding lateral moisture migration.<br>2. Controls vertical movements better.<br>3. Also functions as a root retarder. | 1. Higher cost.<br>2. Requires severing tree roots and can compromise tree health.<br>3. Is difficult to inspect and to know when to repair or replace.<br>4. Fabric membrane retarders more prone to tear or puncture.<br>5. Can retain moisture from under slab leaks and exacerbate heaving. | 1. Usually consists of concrete, steel, polyethylene or fabric sheets, or bentonite clay. |

* Compared to other type of moisture retarder system described in Section 6.1.2.1.

### 6.1.3 Watering Systems

Watering systems are usually used to induce moisture into the soils and to water vegetation around the foundation, thereby attempting to provide a constant and uniform moisture condition. During droughts, water can be rationed, preventing use of these systems. A soil moisture sensor with automatic controls is recommended with these watering systems.

#### 6.1.3.1 Sprinkler Systems

An irrigation system consists of below grade piping and above grade sprinkler heads.

| TABLE 6.1.3.1 SPRINKLER SYSTEMS | | |
|---|---|---|
| ADVANTAGES * | DISADVANTAGES * | COMMENTS |
| 1. Can attract tree roots away from foundations if system is properly drained, zoned, and set.<br>2. Provides moisture during dry periods, thereby reducing movement due to soil shrinkage.<br>3. Can provide more uniform moisture content to site. | 1. Can cause uneven soil moisture, moving and damaging the foundation.<br>2. If not properly monitored, can result in excess watering, resulting in heave or loss of soil bearing.<br>3. Leaks may not be detected thereby causing localized foundation movement.<br>4. Requires more maintenance than other watering systems.<br>5. Overspray onto superstructures can occur.<br>6. Results in more waste of water by runoff and evaporation. | 1. Only enough irrigation should be applied to sustain vegetation, so that there is no ponding or algae buildup.<br>2. It is essential that drainage slopes comply with International Residential Code. |

* Compared to other types of watering systems described in Sections 6.1.3.2, 6.1.3.3 and 6.1.3.4.

#### 6.1.3.2 Soaker Hose Systems

Soaker hoses are permeable water conduits resembling garden hoses normally used to water localized areas.

| TABLE 6.1.3.2 SOAKER HOSE SYSTEMS | | |
|---|---|---|
| ADVANTAGES * | DISADVANTAGES * | COMMENTS |
| 1. Properly maintained soaker hoses apply water more slowly to soil than sprinkler systems.<br>2. Can be used to provide moisture to vegetation.<br>3. Easiest to install. | 1. Can cause excessive and uneven soil moisture, moving, and damaging the foundation.<br>2. Hoses can be subject to premature deterioration.<br>3. Sensitive to damage from freezing.<br>4. Can attract roots toward foundation if used around perimeter of foundation. | 1. Normally limited to garden and foundation applications.<br>2. Can be buried to reduce evaporation and avoid damage from lawn equipment. |

* Compared to other types of watering systems described in Sections 6.1.3.1, 6.1.3.3 and 6.1.3.4.

### 6.1.3.3 Under-Slab Watering Systems

Under-slab watering systems are installed under slabs to provide moisture directly below the foundation. These systems typically consist of a network of piping, wells, and moisture sensors, which are intended to function together to maintain a uniform level of moisture in the soil beneath the structure.

| TABLE 6.1.3.3 | UNDER-SLAB WATERING SYSTEMS | |
|---|---|---|
| **ADVANTAGES *** | **DISADVANTAGES *** | **COMMENTS** |
| 1. Low to medium cost although high-cost systems are also available.<br>2. Minimizes evaporation. | 1. Can cause excessive and uneven soil moisture, moving and damaging the foundation.<br>2. Requires strict monitoring and maintenance.<br>3. Can take a long time to stabilize vertical building movements.<br>4. Difficult to install underneath existing buildings. High-cost system requires cutting holes through slab-at-grade to install system.<br>5. Soil irregularities and discontinuities can limit effectiveness of system.<br>6. Dramatic subsidence could occur if system is disabled.<br>7. Attracts roots toward foundation, which can increase dependency on this system.<br>8. Monitoring program should be included that entails regular geotechnical testing and foundation level distortion surveys.<br>9. During droughts, water can be rationed, preventing its use.<br>10. Moisture sensors are subject to frequent replacement and performance can be unreliable.<br>11. Desired moisture content under slab is difficult to determine. | 1. Low cost foundation watering systems that do not include a continual soil moisture content monitoring system that is connected to moisture release valves is considered an unacceptable system.<br>2. It is essential that drainage slopes comply with International Residential Code. |

* Compared to other types of watering systems described in Sections 6.1.3.1, 6.1.3.2 and 6.1.3.4.

### 6.1.3.4 Drip Watering Systems

Drip irrigation slowly applies water to soil under low pressure through emitters, bubblers, or spray heads placed at each plant.

| TABLE 6.1.3.4 | DRIP WATERING SYSTEMS | |
|---|---|---|
| **ADVANTAGES *** | **DISADVANTAGES *** | **COMMENTS** |
| 1. Offers increased watering efficiency and plant performance when compared to sprinkler irrigation.<br>2. Can be installed without excavation. | 1. Can cause excessive and uneven soil moisture, moving and damaging the foundation.<br>2. Requires strict monitoring and maintenance.<br>3. Not permanent.<br>4. Frost sensitive.<br>5. Can attract roots toward foundation if irrigation is excessive near building. | 1. Drip irrigation slowly applies water to soil under low pressure through emitters, bubblers, or spray heads placed at each plant.<br>2. Normally limited to garden and foundation applications.<br>3. A moisture meter is recommended with this type of system. |

* Compared to other types of watering systems described in Sections 6.1.3.1, 6.1.3.2 and 6.1.3.3.

## 6.2 VEGETATION CONTROL SYSTEMS

Vegetation control systems mitigate damage by providing some control over the growth of roots that can penetrate into unwanted areas and cause shrinkage of foundation soils by means of water withdrawal through the transpiration process.

### 6.2.1 Root Retarder Systems

Root retarder systems are typically physical or chemically induced barriers that limit the growth direction of the roots of trees, shrubbery, and other large plants.

#### 6.2.1.1 Vertical Root Retarders

Vertical root retarders are vertical barriers that are installed in the ground adjacent to the perimeter of a foundation or around a tree or other large plant.

| TABLE 6.2.1.1 | VERTICAL ROOT RETARDERS | |
|---|---|---|
| ADVANTAGES * | DISADVANTAGES * | COMMENTS |
| 1. Minimal disturbance of landscaping.<br>2. Impervious type root retarder also doubles as moisture retarder, which can prevent excess moisture resulting from drainage problems from reaching foundation. | 1. Requires severing tree roots, necessitating tree pruning or other treatment when using near existing trees.<br>2. Can compromise tree health.<br>3. Can compromise tree stability.<br>4. Will only help to control vertical foundation movements, not stop it.<br>5. Limited warranty and limited period of effectiveness (for biocide systems).<br>6. Requires special details for penetration of building utility lines.<br>7. Very difficult to inspect and to know when to repair or replace.<br>8. Sometimes difficult or impractical to install below deepest lateral tree roots.<br>9. Usually aesthetically required to be installed completely below grade, which can allow roots to grow over retarder.<br>10. Impervious type of root retarder also acts as a moisture retarder, which can interrupt existing natural below-grade moisture movement due to soil suction or gradients.<br>11. Extensive geotechnical and geophysical testing can be required to ensure that installation of impervious retarders is not detrimental to foundation.<br>12. For cases where retarder is installed adjacent to structure, foundation support can be compromised in order to install retarder deep enough to be useful. | 1. Can be an impervious type (e.g., plastic, concrete or sheet metal piling) or a biocide type.<br>2. Vertical root retarders slow root growth below a foundation by forcing roots to grow to a greater depth.<br>3. Should be professional installed to minimize root damage.<br>4. Non-impermeable retarders require more maintenance. |

* Compared to other types of vegetation control systems described in Sections 6.2.1.2 and 6.2.2.

### 6.2.1.2 Horizontal Root Retarders

Horizontal root retarders are horizontal barriers that are installed on top of the ground adjacent to the perimeter of a foundation or around a tree or other large plant.

| TABLE 6.2.1.2 | HORIZONTAL ROOT RETARDERS | |
|---|---|---|
| ADVANTAGES * | DISADVANTAGES * | COMMENTS |
| 1. Doubles as pavement for parking or sidewalks.<br>2. Its presence prevents planting of trees near foundation.<br>3. Doubles as a horizontal moisture retarder.<br>4. Quick to install.<br>5. Relative low cost. | 1. Not as architecturally pleasing, especially for residences.<br>2. Needs steel reinforcement and expansion joints to prevent cracking due to ground movement.<br>3. Expansion joints and cracks must be sealed to retard oxygen transfer to soil.<br>4. Joint seals require maintenance, which is easily forgotten by Owner.<br>5. Owner or future owner can remove it, not realizing it serves a design purpose.<br>6. Tree roots can lift and break retarder causing vertical offsets. | 1. Normally concrete pavement. Horizontal root retarders slow root growth by minimizing oxygen flow to roots.<br>2. May not be effective in preventing root growth. |

* Compared to other types of vegetation control systems described in Sections 6.2.1.1 and 6.2.2.

### 6.2.2 Root Watering Wells

Root watering wells are installed near trees to provide moisture below grade. These systems typically consist of a drilled hole filled with coarse material. Piping can be inserted in the holes in order to maintain a clear path for water access.

| TABLE 6.2.2 | ROOT WATERING WELLS | |
|---|---|---|
| ADVANTAGES * | DISADVANTAGES * | COMMENTS |
| 1. Minimal excavated material.<br>2. Minimal disturbance of landscaping.<br>3. Can be beneficial to health of trees by helping them establish roots at a greater depth.<br>4. Can help keep new tree roots from growing under buildings provided wells are installed away from foundation.<br>5. Less likely to damage existing tree roots during installation process. | 1. Effectiveness of reducing moisture withdrawal from under building is questionable.<br>2. Beneficial effects can take a long time to materialize.<br>3. Require maintenance.<br>4. Require ongoing operating costs and water usage.<br>5. Can hit utility line or tree root when drilling.<br>6. Movement of water through unfractured clays is extremely slow.<br>7. Chlorinated water directly applied to deep roots can be detrimental to tree health. | 1. If used, root watering wells should be installed on side of tree opposite foundation. |

* Compared to other types of vegetation control systems described in Sections 6.2.1.1 and 6.2.1.2.

## 6.3 TREE AND PLANT SELECTION

When doing the initial site landscaping design, the proper selection of site vegetation with regard to tree and plant moisture requirements can directly affect future foundation performance. Vegetation selection can also be a deciding factor in the selection of other moisture and vegetation control system design options.

| TABLE 6.3 | TREE AND PLANT SELECTION | |
|---|---|---|
| **ADVANTAGES** | **DISADVANTAGES** | **COMMENTS** |
| 1. Proper tree and plant selection can also be aesthetically pleasing.<br>2. Proper tree and plant selection can increase property value. | 1. Limits available vegetation for landscaping design.<br>2. Owner or future owner can remove trees and shrubbery with low-water-requirements, not realizing they serve a design purpose. | 1. An example of site vegetation control is Xeriscape landscaping, defined as quality landscaping that conserves water and protects environment, by using plants and trees with low-water requirements.<br>2. Selecting plants and trees with low-water requirements can reduce potential for problems caused by vegetation water demands.<br>3. Using vegetation with low water requirements means less run-off of irrigation water that can carry polluting fertilizers and pesticides to nearby streams or lakes, and less permeation of irrigation water into ground that can leach nutrients deep into soil away from vegetation and increase chances of polluting groundwater. |