

FOUNDATION REPAIR ASSOCIATION

EXPECTATIONS OF UNDERPINNING

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with help from
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Foundation repair/remediation contractors usually provide some form of underpinning as one of their services to repair a failed foundation. While underpinning is critical to the repair of foundations, it is also crucial that customers, engineers, remodeling contractors and the general public understand the purpose of underpinning, or foundation shoring, and the limitations of same.

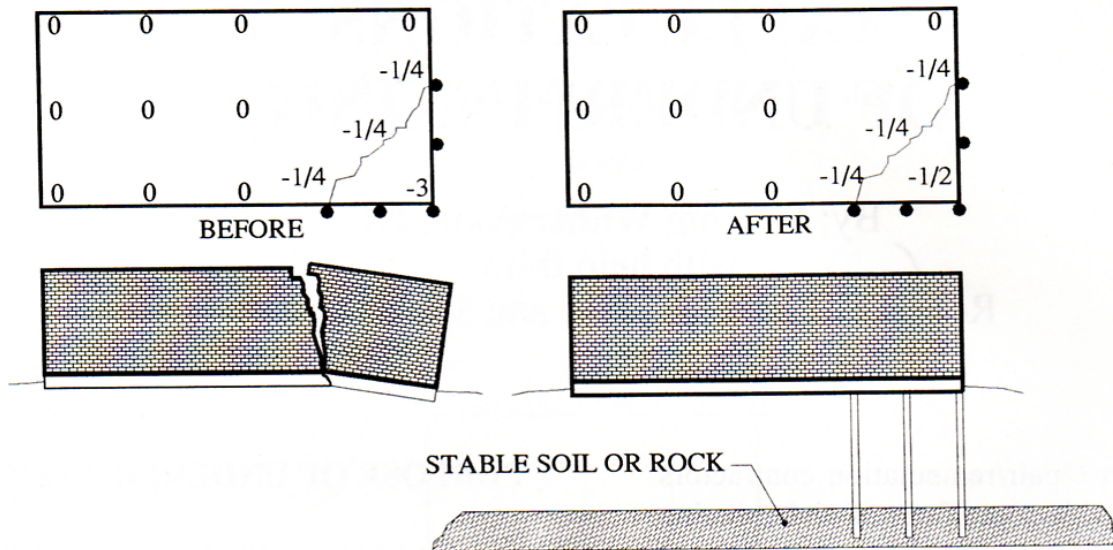
DEFINITION OF UNDERPINNING

Underpinning is the process of modifying an existing foundation system by extending it to or into subsurface strata that is deeper and more stable than the near surface soil that supports the existing foundation system. This is done to provide vertical support that is not present in the existing design. Methods of underpinning include the construction of footings, stem walls, driven piling or drilled piers.

PURPOSE OF UNDERPINNING

Many of the houses that forensic engineers and repair contractors are asked to evaluate were constructed with foundations that are inadequate for the conditions existing on site. Because of the lack of suitable land, homes are often built on marginal land that has insufficient bearing capacity to support the substantial weight of a structure. In addition, there are many areas of the country where the near surface soils consist predominantly of expansive clays that shrink and swell as their moisture content changes. As a result, underpinning is required to extend the foundation support to depths that provide greater bearing capacity and/or are less affected by climate, soil conditions and/or homeowner's actions. This underpinning, if properly designed and installed, provides the basis to lift the structure to a more acceptable elevation and provides vertical support to prevent the underpinned area from settling.

UNDERPINNING OF A LOW SEGMENT



SLAB-ON-GRADE FOUNDATIONS

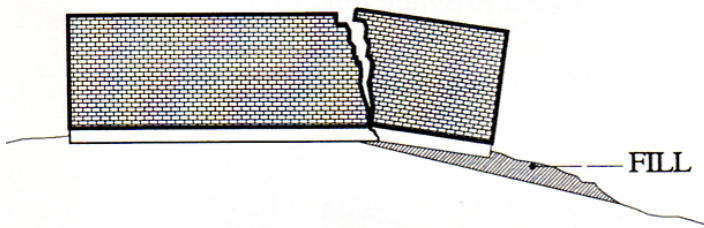
In many areas of the country, house foundations consist, wholly or in part, of concrete slabs supported directly by the soil. In some instances, the slab portion forms the ground or basement floor, which is structurally independent from the perimeter foundation. In other cases, a similar soil supported floor slab rests on top of, and is partially supported by, the perimeter foundation. In Texas, slabs are generally cast monolithically with perimeter as well as

interior beams that are designed to provide sufficient support for the entire structure as well as to provide stiffness to resist differential soil movement enough to limit cracking in the foundation and finishes. Texas slabs are typically reinforced with conventional reinforcing steel (re-bar) and/or post-tensioned cables that are installed throughout both the slab and beam portions of the foundation.

LIMITATIONS OF SLAB-ON-GRADE FOUNDATIONS

- Settlement As A Result Of Poor Pre-Construction Compaction.

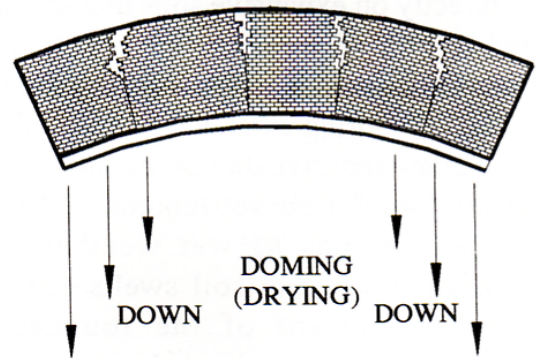
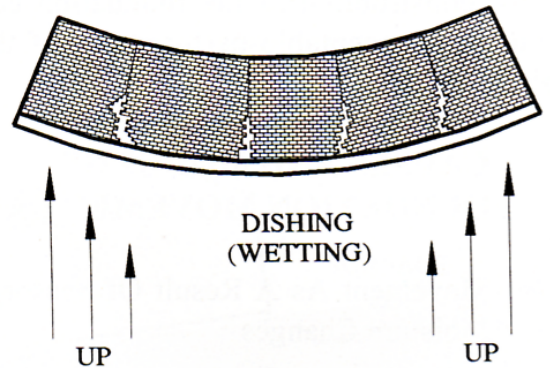
Slab-on-grade foundations depend upon the uppermost soil layer(s) to provide sufficient bearing capacity to support the structure and to keep the foundation stable. If the bearing soil was insufficiently compacted prior to construction, the foundation is subject to settlement as the supporting soil consolidates.



0	0	0	0	-2
0	0	0	-1/8	-1/2
0	0	0	-1/4	-3

Settlement As A Result Of Poor Pre-Construction Compaction

Foundation Movement Resulting From Seasonal Moisture Changes



- Foundation Movement Resulting From Soil Moisture Changes

Shallower soils are also generally the most affected by seasonal moisture changes. If the bearing soils consist of expansive clays that are subjected to changes in moisture content, differential foundation movement can occur if wetting and drying of the clays does not occur uniformly across the entire slab. This differential movement can result in "dishing" or "doming" of the foundation, and can become quite pronounced, especially in areas where the local climatic conditions include extended seasonal periods of both hot, dry weather and cooler, wetter weather.

In either case (consolidation or differential shrink/swell movement), inadequate design and/or construction of the foundation can result in unacceptable performance of the slab-on-grade.

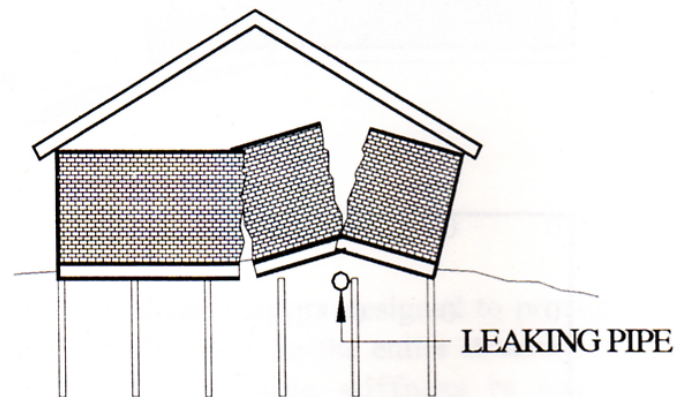
CAUSES AND MODES OF FOUNDATION MOVEMENT

- Movement As A Result Of Seasonal Moisture Changes

As mentioned above, foundations that are built directly on expansive soils that are subjected to non-uniform changes in the soil moisture content can suffer from differential movement. During extended periods of dry weather, the expansive supporting soil shrinks causing foundation settlement. During extended periods of wet weather, the expansive supporting soil swells causing upward movement of the foundation (upheaval). Localized site and environmental factors that promote or limit the flow of water into and out of the supporting soil as well as non-uniform distribution of the expansive soil under the foundation affect the magnitudes of the movement (either upward or downward) at different locations of the foundation. It is important to understand that it is *differential*, not the *total* movement of the foundation that causes damage to the structure. In other words, the performance of a foundation that moves up and down uniformly with the changing seasons is superior to a foundation where the movement is not uniform.

- Slab/Foundation Movement Caused By Plumbing Leaks

A slab-on-grade foundation acts as a vapor barrier by resisting soil moisture variations due to evaporative moisture loss and by shielding the under-slab soil from rainfall. Under optimum conditions, the soil moisture under the slab will achieve a degree of equilibrium. When a plumbing leak occurs under a slab, the moisture equilibrium is distorted. As moisture is added to the soil from the leak, soil and foundation movement often result. The type and degree of movement depends upon soil type and expansiveness, soil density, soil moisture content prior to the leak, the length of time over which the leak has occurred, the quantity of moisture being added to the soil over a given period of time and a few other factors.



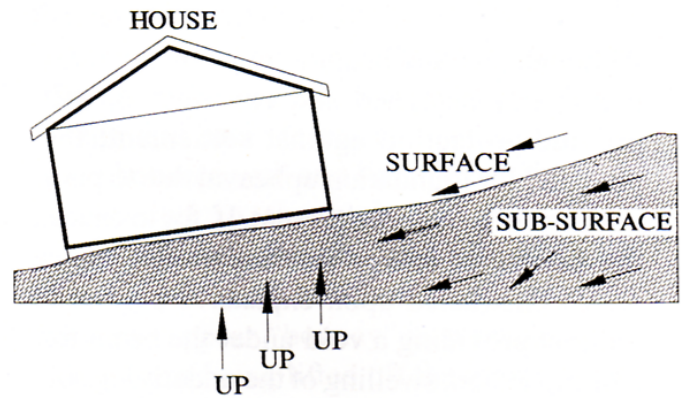
UPHEAVAL TO A SLAB-ON-GRADE CAUSED BY A PLUMBING LEAK

Typical examples:

1. If the soils are expansive and were dryer than optimum prior to the leak and have a high density, the foundation/slab will heave (move upward) in the vicinity of the leak and corresponding damages will be apparent in the structure. In this example, the soil will probably not contract significantly after the leak is repaired, which will result in a permanent dome in the slab.
2. If the soil is at optimum density and moisture prior to the leak, there is an opportunity for the soil to contract. It is possible, but not probable, that the slab will regain its original elevation profile because clay soil expansion/contraction generally does not follow a linear progression as moisture is added and then reduced. The slab could be permanently left above or below its initial elevation.
3. Should a leak occur under the slab where the soil is of very low density, the additional moisture often lubricates the solid clay particles and causes consolidation of the support soil prior to leak repair. After the leak is repaired under this example, the slab will often “dish” or settle (move downward) even more.

NOTE: Concrete and steel will often develop a “stress memory” after deformation that will not allow the slab to return to its original shape. This may be the result of soil or concrete chips filling cracks in the slab, which prevents the slab from “coming back together” completely. In a post-tensioned slab, stress in the post-tensioning cables may resist the tendency for the slab to move back into place.

UPHEAVAL TO A SLAB-ONGRADE CAUSED BY NEGATIVE DRAINAGE



In a conventionally reinforced slab, permanent deformation (yielding) of the steel reinforcing bars may prevent the slab from returning to its original shape.

- Foundation Upheaval Caused by Poor Drainage

Since additional moisture can cause expansive soils to swell, areas of poor drainage near the foundation can cause the soil under the foundation nearby to swell, resulting in upward movement of the foundation.

LIMITATIONS OF PIER AND BEAM FOUNDATIONS

- Foundation Upheaval Caused by Poor Drainage

Although pier and beam foundation systems, if properly designed and constructed, will provide protection against settlement; the potential for foundation upheaval due to poor drainage is sometimes present. If, for instance, the perimeter and/or interior grade beams were constructed upon expansive clay soil, without providing a void under the beam for soil expansion, swelling of the underlying soil may push the beam upward. Swelling soil can also push the supporting piles or piers upward, if they are not designed and constructed to adequately resist uplift. As a

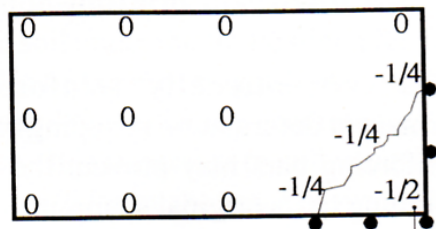
result, the grade beam will lift causing differential movement and subsequent cosmetic, and potentially structural, damage. It is, therefore, a good idea to maintain adequate drainage away from any type of foundation, especially where expansive soils are present.

- Foundation Settlement Caused by Inadequate Pier Depth

The piers supporting many older pier and beam foundations may not extend below the zone of expansive soil that is affected by the climate. During periods of dry weather, these shallow piers may not provide sufficient support to portions of the foundation, which may result in differential settlement.

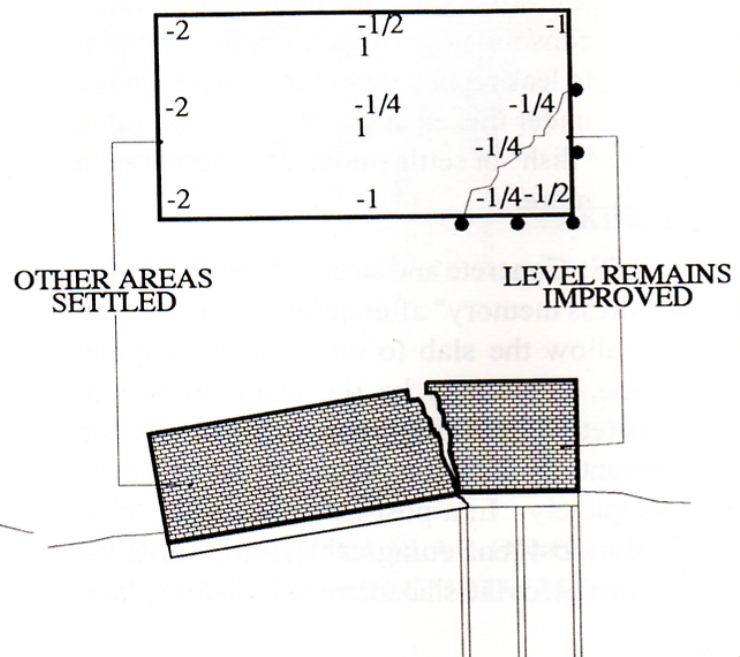
MOVEMENT OUTSIDE UNDERPINNED AREA

AFTER UNDERPINNING COMPLETION



LEVEL IMPROVED BY UNDERPINNING

POSSIBLE FUTURE MOVEMENT OUTSIDE UNDERPINNING AREA



OTHER AREAS SETTLED

LEVEL REMAINS IMPROVED

LIMITATIONS OF UNDERPINNING

- Movement Outside of the Underpinned Area

If a single area of a foundation is underpinned, only that area will resist downward movement. For example, if only one corner of the foundation is supported by piers, only that corner will resist settlement forces. The rest of the structure will be subject to seasonal settlement as clay soils shrink during dry periods. Therefore, an area that was originally the low portion of the foundation may now become the high point of the house during dry periods. It is also possible that cracking will occur at the last pier if the unsupported area settles and is resisted at this hinge point. It is, therefore, important to carefully evaluate and balance site risk factors against cost savings when electing to partially underpin a foundation.

- Upheaval

When underpinning is installed to a stratum that is competent and capable of supporting the structure, it will stop downward movement of the area of the foundation that is supported. Underpinning is generally not designed to keep the foundation from moving upward if the original support clays swell due to an increase in moisture. Plumbing leaks, negative drainage and/or acts of man or nature, can increase the moisture content of the bearing clays. Subsequent upward movement will often occur, which will result in a distorted foundation and cracking in the finishes.

- Interior Floor Instability As A Result Of Interior Settlement and/or Perimeter Upheaval

It is possible that cracks may occur at doors that are perpendicular to the perimeter walls as the interior slab settles from shrinking of clay soils. Where the wall is tied in to the ceiling and roof structure, a separation can occur between wall and floor. When the floor is secured to the slab, there may be separations between wall and ceiling. In the case of a pier and beam foundation, the wood floor can appear “bouncy” as a result of the floor beams being lifted off the interior piers in response to perimeter upheaval.

- Damage From Vegetation

Trees, bushes and other vegetation will draw moisture from under the foundation during times of drought. If the perimeter of a slab-on-grade foundation is underpinned and trees withdraw moisture from under the slab, the interior bearing soil will dry and shrink in volume. As a result, the interior slab may settle and cracking will likely occur in the interior of the home. It is also possible that tree roots under a slab will grow large enough to push the slab upward.

- Point Of Contact

Underpinning is only as good as the contact or connection point between pier/pile and the structure. If the grade beam, thickened slab, or steel beam support is faulty, pier support will not be fully transferred to the foundation and downward movement may occur.

Guidelines for the Evaluation and Repair of Residential Foundations

Version 2
(Adopted May 1, 2009)

**By the Texas Section
American Society of Civil Engineers**

Foreword to Version 2

The Texas Section of the American Society of Civil Engineers (ASCE) adopted Guidelines for the Evaluation and Repair of Residential Foundations on October 3, 2002, with an effective date of January 01, 2003. Version 2, presented herein, was adopted on May 1, 2009. For reference, the following pages present specific changes to Version 2.

The Section began this work in 1999. This effort grew out of the response of many Section members to the Policy Advisory issued by the Texas Board of Professional Engineers (TBPE) in 1998, which addressed residential foundation engineering. Many ASCE practitioners expressed the opinion that technical guidelines should more rightly be created by a technical society such as ASCE rather than by the TBPE. One goal of the guidelines has been to provide the TBPE with guidance in their evaluation of complaints brought against engineers practicing residential foundation engineering.

One committee and two subcommittees were formed to address the raised concerns. One subcommittee addressed Recommended Practice for the Design of Residential Foundations (with their work presented in a separate document). The Guidelines for the Evaluation and Repair of Residential Foundations Subcommittee developed the attached document (Recommended Practice for the Design of Residential Foundations). The Residential Foundation Oversight (“Oversight”) Committee provided review guidance to the two previously mentioned subcommittees.

The Oversight Committee and both subcommittees were composed entirely of ASCE members who were licensed engineers. Subcommittee membership was open to any Texas Section member who wished to participate. Subcommittee formation and periodic progress updates were publicized at the Texas Section meetings and in the “Texas Civil Engineer” magazine. Publicity included invitations to any interested member of the Texas Section to serve on the subcommittees. The procedure for adopting Version 1 of this document included review and comment by the Oversight Committee followed by a period of time for public review and comment. The procedure for adopting subsequent versions of the documents also includes review and comment by the Oversight Committee. The dollar value of the professional services donated to the effort is conservatively estimated to exceed \$1,000,000.

The Guidelines are not intended to be Standards, but are guidelines only, reflecting the engineering opinions and practices of the committee members. They in no way replace the basic need for good engineering judgment based on appropriate education, experience, wisdom, and ethics in any particular engineering application. Thus, they are primarily suited as an aid for and use by engineers.

Members of the Residential Foundation Evaluation and Repair Subcommittee (2008):

Marshall B. Addison, Ph.D., PE, Chair

Gardner D. Atkinson, Jr., Ph.D., PE	John T. Bryant, Ph.D., P.G., PE	Gary A. Osborne, PE
David A. Belcher, PE	John W. Dougherty, PE	Kenneth M. Struzyk, PE
Robert E. Bigham, PE	Philip G. King, PE	Daniel T. Williams, PE
Gary W. Boyd, PE	Kirby T. Meyer, PE	

Note: Robert F. Pierry, Jr., P.E. was Chair of the 2002 Subcommittee and Alberto Arroyo, Ph.D., PE, Laura Campa, PE, Jim W. Crawford, PE, Sarah Hancock-Gamez, PE, and Donald N. Garner, PE, were members of the 2002 Subcommittee

Members of the Residential Foundation Oversight Committee (2008):

Robert F. Pierry, Jr., PE, Chair

Marshall B. Addison, Ph.D., PE	Philip G. King, PE	Douglas S. Porter, Jr., PE
James G. Bierschwale, PE	Richard W. Kistner, PE	John T. Wall, PE
Dick Birdwell, PE	Jerald W. Kunkel, PE	William Witherspoon, Ph.D., PE
Edmundo R. Gonzalez, PE	William D. Lawson, Ph.D., P.E.	
Richard C. Hale, PE	Steven R. Neely, PE	

Note: Ottis Foster, PE was Chair of the 2002 Committee

The following lists the changes incorporated into Version 2:

Item 1. Section 3. LEVELS OF INVESTIGATION, 3.1.2 Level B

“1. A determination of relative foundation elevations in sufficient detail to represent the shape of the foundation or floor adequately.”

Changed to

“1. A determination of relative foundation elevations, considering floor finishes, in sufficient detail to represent the shape of the foundation or floor adequately.”

Item 2. Section 5. EVALUATION CRITERIA, 5.1 General

“The bases of these evaluation criteria are structural integrity (strength) and performance (serviceability). Both may be affected by foundation deformation and tilt.”

Changed to

“The bases of these evaluation criteria are structural integrity and performance. Both may be affected by foundation deflection and tilt.”

Item 3. Section 5. EVALUATION CRITERIA, 5.2 Structural Integrity

“In evaluating a foundation, structural integrity considers the capability of the foundation to support its design loads as well as results and effects on other load bearing members of the superstructure.”

Changed to

“Structural integrity considers the capability of the foundation to support its design loads as well as results and effects on other load bearing members of the superstructure.”

Item 4. Section 5. EVALUATION CRITERIA, 5.2 Structural Integrity

“1. Observed Cracks. Cracks may make concrete structural members weaker, although the majority of cracks do not compromise structural integrity.”

Changed to

“1. Cracks. Cracks may make concrete structural members weaker, although the majority of cracks do not compromise structural integrity.”

Item 5. Section 5. EVALUATION CRITERIA, 5.2 Structural Integrity

“3. Tilt, if any, of masonry veneer panels. Excessive tilt can lead to catastrophic panel collapse. Masonry veneer or infill is normally non load-bearing, and in some cases the veneer or infill may not be held in place except by its own weight. Wall tilt large enough to cause the weight vector (or center of gravity) to fall outside the middle third of bearing area is sufficient to cause tension in masonry veneer.”

Changed to

“3. Tilt of masonry walls or veneer panels. Excessive tilt can lead to masonry collapse. Masonry veneer or infill is normally non load-bearing, and in some cases the veneer or infill may not be held in place except by its own weight. Tilt large enough to cause the weight vector (or center of gravity) to fall outside the middle third of bearing area is sufficient to cause tension in masonry walls or veneer.”

Item 6. Section 5. EVALUATION CRITERIA, 5.2 Structural Integrity

“4. Observed material deterioration.”

Changed to

“4. Material deterioration.”

Item 7. Section 5. EVALUATION CRITERIA, 5.3 Foundation Performance

“5.3 Performance”

Changed to

“5.3 Foundation Performance”

Item 8. Section 5. EVALUATION CRITERIA, 5.3 Foundation Performance

“Performance considers the capability of the building to serve its intended purpose. Elements of concern are safety, function, durability, and habitability. Inadequate performance may result from inadequate strength or insufficient stiffness, and is shown in many ways.”

Changed to

“Foundation performance considers the capability of the building to serve its intended purpose. Elements of concern are safety, function, durability, and habitability. Inadequate foundation performance may result from inadequate strength or insufficient stiffness, and is shown in many ways.”

Item 9. Section 5. EVALUATION CRITERIA, 5.3 Foundation Performance

“11. Deflecting, deforming or tilting of structural elements”

Changed to

“11. Deflecting or tilting of structural elements”

Item 10. Section 5. EVALUATION CRITERIA, 5.3 Foundation Performance

“Observation of some of the listed conditions does not necessarily imply inadequate structural performance or insufficient stiffness.”

Changed to

“Observation of some of the listed conditions does not necessarily imply inadequate structural performance or insufficient stiffness. The importance of any of these indications may depend upon the age of the structure and any previous repairs.”

Item 11. Section 5. EVALUATION CRITERIA, 5.4 Deflection and Tilt

“Foundation deflection (bending or angular distortion) and tilt (planar rotation) may affect structural integrity and performance. Determining the deflection and tilt of a slab-on-ground foundation is an approximation without an as built or previous floor elevation survey, because the original surface configuration is unknown. Therefore, a floor elevation survey should not be the only basis for evaluating foundation deflection and tilt.”

Changed to

“Either foundation deflection (bending or angular distortion) or tilt (planar rotation) may affect structural integrity and performance. Determining the deflection and tilt of a slab-on-ground foundation is an approximation without an as built or previous floor elevation survey, because the original surface configuration is unknown. Therefore, a floor elevation survey can provide valuable information, but should not be the only basis for evaluating foundation deflection and tilt.”

Item 12. Section 5. EVALUATION CRITERIA, 5.4 Deflection and Tilt

Added Last Paragraph

“Foundation tilt is the planar variation from a level condition to one that slopes across the entire foundation. Tilt may be accompanied by deflection.”

Item 13. Section 5. EVALUATION CRITERIA, 5.5 Overall Deflection

“Overall deflection necessarily involves the overall foundation dimension in a given direction. When additions have been made to a foundation, the overall foundation dimension should be considered for each separate foundation element and for the entire foundation. The amount of overall deflection is measured by the deflection ratio.

Building codes specify that structural members shall be designed to have adequate stiffness to limit deflections. The *International Code Council International Residential CodeTM* for One- and Two-Family Dwellings (IRC) specifies a maximum allowable live load deflection of $L/360$. This deflection criterion may be appropriate for the analogous in-service deflection of a residential foundation due to loading from varying soil conditions. The maximum live load deflection of a floor is the in-service deflection that typically will not result in excessive damage to cosmetic finishes.”

Changed to

“Overall deflection necessarily involves the overall foundation dimension in a given direction. When additions have been made to a foundation, the overall foundation dimension should be considered for each separate foundation element and for the entire foundation. The amount of overall deflection is characterized by the deflection ratio.

Building codes specify that structural members shall be designed to have adequate stiffness to limit deflections. The *International Code Council International Residential CodeTM* for One- and Two-Family Dwellings (IRC) specifies a maximum allowable live load deflection of any structural floor member of $L/360$, where L is the unsupported length of the member. This requirement typically is sufficient, in that in-service deflection will not result in excessive damage to cosmetic finishes, racking of door frames, or vibration. This deflection criterion may be appropriate for the analogous in-service deflection of a residential foundation, where for simplicity the entire foundation is considered as though it was a single structural member and differential soil movement is considered analogous to live load.”

Item 14. Section 5. EVALUATION CRITERIA, 5.7 Tilt

“Floors may tilt enough to affect comfortable or convenient use of the building. A floor slope greater than 1 percent is usually noticeable. The Americans with Disabilities Act considers a 2 percent slope too large.”

Changed to

“Foundation tilt, deflection, or both may result in floor slopes that affect comfortable or convenient use of the building. A floor slope greater than 1 percent is usually noticeable. The Americans with Disabilities Act considers a 2 percent slope too large.”

Table of Contents

Section 1. PURPOSE AND SCOPE	1
1.1 Introduction.....	1
1.2 Background	1
1.3 Objectives.....	1
1.4 Limitation	2
1.5 Adopted Changes.....	2
Section 2. QUALIFICATIONS OF THE ENGINEER	3
2.1 Professional Qualifications	3
2.2 Professional Ethics	3
Section 3. LEVELS OF INVESTIGATION.....	4
3.1 General.....	4
Section 4. EVALUATION METHODOLOGY.....	6
4.1 General.....	6
4.2 Analysis	6
Section 5. EVALUATION CRITERIA	7
5.1 General.....	7
5.2 Structural Integrity	7
5.3 Performance	8
5.4 Deflection and Tilt.....	8
5.5 Overall Deflection	9
5.6 Localized Deflection	10
5.7 Tilt.....	10
5.8 Remediation Criteria.....	10
Section 6. REPORTING	11
Section 7. REMEDIAL MEASURES	12
7.1 Objectives and Limitations of the Remedial Measures.....	12
7.2 Responsibility of the Engineer	12
7.3 Non-structural Remedial Measures	12
7.4 Structural Remedial Measures	14
7.5 Repair of Pier and Beam Foundations.....	16
7.6 Post Lift Plumbing Testing.....	17
7.7 Floor Elevations.....	17
7.8 Compliance Letter	17

Guidelines for the Evaluation and Repair of Residential Foundations

**By the Texas Section of the
American Society of Civil Engineers**

Section 1. PURPOSE AND SCOPE

1.1 Introduction

The purpose of this document is to provide guidance for engineers practicing in the field of residential foundation evaluation and repair within the State of Texas with the goal of protecting the public when obtaining these services. The principal items discussed in this document are as follows:

1. An introduction presenting the background leading to the need for this document
2. Qualifications of engineers performing evaluations or repair designs
3. Scope of services
4. Methodology
5. Information typically presented in the evaluation report
6. Performance criteria for residential foundations
7. Foundation repair and remedial alternatives
8. Anticipated structure performance after remedial measures

1.2 Background

Texas has large areas with clayey soils that shrink and swell with changes in soil moisture content. This shrinking and swelling may cause movement of residential foundations that adversely affects the residence. Other factors may influence foundation performance. Some of these factors are inadequate design or construction, unanticipated loads, deterioration of materials, compressibility of the supporting soils, landscaping practices, leaking plumbing, and slope instability. The American Society of Civil Engineers, Texas Section (ASCE, TX) developed this document as a guideline for evaluation and repair of residential foundations. A separate document, *Recommended Practice for the Design of Residential Foundations*, also developed by ASCE, TX, addresses residential foundation design.

1.3 Objectives

The most common purpose of an engineering evaluation of a residential foundation is to assess its performance. This involves observation and evaluation of cosmetic (non-structural) distress and structural damage. The evaluation may also provide opinions of probable causes of distress or damage, assessment of risk of further damage,

recommendations for remedial measures, and cost estimates. If the evaluation determines that remedial measures are appropriate, the engineer may be asked to provide the design and construction documents.

1.4 Limitation

These guidelines have been developed by experienced professional engineers and presents practices they commonly employ to help deal effectively with soil conditions that historically have created problems for residential foundations in Texas. These guidelines presume the existence of certain standard conditions when, in fact, the combination of variables associated with any given project always is unique. Experienced engineering judgment is required to develop and implement a scope of service best suited to the variables involved. For that reason, the developers of this document have made an effort to make the document flexible. Thus, successful application of this document requires experienced engineering judgment; merely following the guidelines may not achieve a satisfactory result. Unless adherence to this document is made mandatory through force of law or by contractual reference, adherence to it shall be deemed voluntary. This document does not, of itself, comprise the standard of care which engineers are required to uphold.

1.5 Adopted Changes

The Texas Section of the American Society of Civil Engineers (ASCE) has adopted procedures for changing the guidelines. In general, those interested in submitting changes for consideration by the Section should access the website at www.texasce.org, and follow the instructions for submitting changes. Changes may also be submitted in writing to the Texas Section-ASCE, 1524 S. IH-35 Suite 180, Austin, TX, 78704, phone 512.472.8905, (please call for faxing instructions). Anonymous changes will not be considered. Those submitting changes should include contact information, state why a change is proposed, include applicable calculations if appropriate, and provide alternative language to incorporate the change. The appropriate committee will consider the changes, and from time to time the Texas Section may adopt the changes and issue revised Guidelines.

Section 2. QUALIFICATIONS OF THE ENGINEER

2.1 Professional Qualifications

The evaluation and repair design shall be performed by a professional engineer licensed in the State of Texas. Engineers in responsible charge of this type of work must be competent to apply scientific and engineering education, training, knowledge, skill and experience to the investigation and analysis of constructed facilities. This determines the cause and extent of diminished performance and the means of remediation. Engineers should be competent in the related disciplines or should retain outside consultants as needed.

2.2 Professional Ethics

It is essential to avoid conflicts of interest to maintain the credibility of the evaluation investigation. The evaluating engineer must demonstrate qualities of character that will ensure impartiality. These qualities include objectivity, confidentiality, honesty and integrity.

ASCE members subscribe to the ASCE Code of Ethics, which includes the Fundamental Principles, Fundamental Canons, and Guidelines to Practice Under the Fundamental Canons of Ethics. Professional Conduct and Ethics comprise a sub chapter of the Texas Engineering Practice Act.

Section 3. LEVELS OF INVESTIGATION

3.1 General

The engineer should recommend an appropriate level of investigation to fulfill the objective of the evaluation. However, the scope of services shall be jointly established and agreed to by both the client and engineer. The engineer should personally visit the site and be in responsible charge of the investigative activities. If requested by the client, the engineer may only provide evaluation of reports by others, but this should be described as consultation, not investigation. For the purpose of aiding the client in determining the type of evaluation desired or actually performed, the following three levels of investigation are offered as guidelines.

3.1.1 Level A

This level of investigation shall be clearly identified as a report of first impressions and shall not imply that any higher level of investigation has been performed. This level of investigation will typically include, but is not restricted to:

1. Interview the occupant, owner and client if possible, regarding a history of the property and performance of the structure
2. Request from the client and review the provided documents regarding the foundation, such as construction drawings, geotechnical reports, previous testing and inspection reports, and previous repair information
3. Make visual observations during a physical walk-through
4. Observe factors influencing the performance of the foundation
5. If requested by the client, provide a written report, containing at least the following:
 - a. scope of services
 - b. observations, site characteristics, and data deemed pertinent by the engineer
 - c. discussion of major factors influencing foundation performance and rationale in reaching conclusions concerning the subject residence
 - d. conclusions and any recommendations for further investigation and remedial or preventative measures

3.1.2 Level B

This level of investigation should include a written report including the items listed above for a Level A inspection and also the following items:

1. A determination of relative foundation elevations, considering floor finishes, in sufficient detail to represent the shape of the foundation or floor adequately.
2. A drawing showing relative elevations

3.1.3 Level C

This level of investigation shall include the items listed above for Level A and Level B inspections and additional services, testing and related reports deemed appropriate by the Engineer. These may include, but are not limited to, the following:

1. Site specific soil sampling and testing
2. Plumbing testing
3. Material testing
4. Steel reinforcing survey
5. Post tensioning cable testing

This level of investigation should also include a more detailed level of reporting, which may include the following:

1. Scaled drawings
2. Description of factors that affect soil moisture
3. Observations of cut and fill
4. Tree survey
5. Photographs
6. Detailed distress survey

Section 4. EVALUATION METHODOLOGY

4.1 General

A rational method should be used to establish causes of distress or diminished performance, if any. A suggested method is summarized as follows:

1. Observe the structure, site conditions, other relevant phenomena, and collect pertinent data
2. Analyze the data
3. Formulate hypotheses
4. Test the hypotheses using analyses acceptable to the engineering profession along with engineering experience
5. Reach conclusions or reformulate the hypotheses

4.2 Analysis

Diminished performance of a structure may have several causes. The engineer should approach the analysis with an open mind. The analysis should follow a logical path to its conclusion. The evaluation should be quantitative to the extent practical, but should not assume greater accuracy or precision than warranted by the data.

Section 5. EVALUATION CRITERIA

5.1 General

Residential foundations are expected to remain reasonably flat and level to provide acceptable performance. The criteria herein are intended to lend rationality and reasonable uniformity, supported by a consensus of practitioners, to the evaluation of performance and the need for repair of residential foundations.

The bases of these evaluation criteria are structural integrity and performance. Both may be affected by foundation deflection and tilt. Evaluations may be interpreted from the body of evidence or demonstrated by calculations.

5.2 Structural Integrity

Structural integrity considers the capability of the foundation to support its design loads as well as results and effects on other load bearing members of the superstructure. Elements of concern are stability, component strength and condition, and material soundness. In evaluating structural integrity, it should be understood that in many instances portions of the foundation and other structural components may not be available for observation.

Lack of structural integrity may be indicated by excessive deflection, cracking, partial collapse, loss of section, material deterioration, or demonstrated by calculations. If loss of structural integrity is demonstrated by calculations, the conclusion must be consistent with the physical evidence. Examples of lack of structural integrity include loss of shear capacity in concrete through excessive cracking, excessive tilt of structural elements such as posts or piers, unstable conditions in non load-bearing masonry, and rotting of wood structural members. The engineer should evaluate the following, if they are observed:

1. Cracks. Cracks may make concrete structural members weaker, although the majority of cracks do not compromise structural integrity.
2. Tilting of posts or piers above grade. Tilting can affect structural integrity or stability, although posts or piers above grade designed for eccentricity of load can tolerate some tilting without overstress. However, ordinary construction tolerances may result in vertical members being built out of plumb.
3. Tilt of masonry walls or veneer panels. Excessive tilt can lead to masonry collapse. Masonry veneer or infill is normally non load-bearing, and in some cases the veneer or infill may not be held in place except by its own weight. Tilt large enough to cause the weight vector (or center of gravity) to fall outside the middle third of bearing area is sufficient to cause tension in masonry walls or veneer.

4. Material deterioration. The strength of deteriorated material may raise a structural integrity issue. Evaluation of material deterioration may be based on observation, material sampling and testing, or non-destructive methods.

5.3 Foundation Performance

Foundation performance considers the capability of the building to serve its intended purpose. Elements of concern are safety, function, durability, and habitability. Inadequate foundation performance may result from inadequate strength or insufficient stiffness, and is shown in many ways. Visible indications may include:

1. Cracking or separating of exterior walls
2. Rotating, buckling, or deflecting masonry veneer panels
3. Cracking of concrete foundation elements
4. Cracking of gypsum board walls and ceilings
5. Separating of walls from ceilings or floors
6. Separating of rafters from a ridge board
7. Racking of door and window frames
8. Separating or racking of other structural framing
9. Cracking, buckling, or separating of floor coverings
10. Separating of initially tight joints
11. Deflecting or tilting of structural elements
12. Deteriorating materials

Observation of some of the listed conditions does not necessarily imply inadequate structural performance or insufficient stiffness. The importance of any of these indications may depend upon the age of the structure and any previous repairs.

5.4 Deflection and Tilt

Either foundation deflection (bending or angular distortion) or tilt (planar rotation) may affect structural integrity and performance. Determining the deflection and tilt of a slab-on-ground foundation is an approximation without an as built or previous floor elevation survey, because the original surface configuration is unknown. Therefore, a floor elevation survey can provide valuable information, but should not be the only basis for evaluating foundation deflection and tilt.

Deflection may be more difficult to evaluate quantitatively than any other element of performance. Deflection is characterized by the deflection ratio, which is defined as the maximum deviation from a straight line between two points divided by the distance (L) between the two points. Overall deflection, as defined below, may be more easily interpreted and evaluated than localized deflection. Localized deflection may be a more common occurrence.

Foundation tilt is the planar variation from a level condition to one that slopes across the entire foundation. Tilt may be accompanied by deflection.

5.5 Overall Deflection

Overall deflection necessarily involves the overall foundation dimension in a given direction. When additions have been made to a foundation, the overall foundation dimension should be considered for each separate foundation element and for the entire foundation. The amount of overall deflection is characterized by the deflection ratio.

Building codes specify that structural members shall be designed to have adequate stiffness to limit deflections. The *International Code Council International Residential CodeTM* for One- and Two-Family Dwellings (IRC) specifies a maximum allowable live load deflection of any structural floor member of $L/360$, where L is the unsupported length of the member. This requirement typically is sufficient, in that in-service deflection will not result in excessive damage to cosmetic finishes, racking of door frames, or vibration. This deflection criterion may be appropriate for the analogous in-service deflection of a residential foundation, where for simplicity the entire foundation is considered as though it were a single structural member and differential soil movement is considered analogous to live load.

A single floor level survey yields the shape of the foundation at one instant, and may or may not furnish sufficient information to support a conclusion. An evaluation may include repeated floor level surveys performed over months or years. In such cases, the change in shape is measured between surveys. In addition, previous foundation repairs may change elevation shapes.

The engineer evaluating deflection must consider the floor level survey (Levels of Investigation B or C), and other indications of movement, such as:

1. Brick coursing not level.
2. Poor door alignment.
3. Levelness of built in horizontal surfaces, such as cabinets, countertops, sills and trim.
4. Cracking of exterior and interior wall finishes may indicate deflection, as do most items listed in 5.3 above.

If a foundation profile indicates the deflection is less than the analogous deflection limit of $L/360$, it is unlikely the foundation is deflected materially unless visible indications show otherwise.

If a foundation profile indicates the deflection is more than the analogous deflection limit of $L/360$ and minimal symptoms of deflection are present, then additional information is needed by the engineer to develop a conclusion. The additional information may allow the engineer to determine whether or not the foundation has deflected excessively.

If a foundation profile indicates the deflection is more than the analogous deflection limit of $L/360$ and sufficient symptoms of deflection are present, then the engineer generally will be justified in determining that the foundation has deflected excessively.

5.6 Localized Deflection

Localized deflection means a change from original profile or shape in an area smaller than the overall foundation. Localized deflection manifests itself in similar ways as overall deflection. It sometimes results in localized structural integrity or performance problems. The engineer should evaluate the significance of localized deflections and their consequences as in Section 5.5, but caution is advised when evaluating floor deviations over only a few feet because built-in unevenness can dominate.

5.7 Tilt

Foundation tilt can affect structural integrity and performance. Tilt of entire foundations may be evaluated for structural integrity using the criterion stated for veneer panels, as discussed in Section 5.2 of this document. This criterion may be found in the 1997 Uniform Code for Abatement of Dangerous Buildings.

Foundation tilt, deflection, or both may result in floor slopes that affect comfortable or convenient use of the building. A floor slope greater than 1 percent is usually noticeable. The Americans with Disabilities Act considers a 2 percent slope too large.

5.8 Remediation Criteria

If the residence is found to be unsafe due to structural inadequacies, the client and/or civil authorities should be informed immediately. The engineer should recommend repair, restoration, remediation, adjustment, or use alternatives if the structural integrity is inadequate. The engineer should provide alternatives for the client's consideration if performance is inadequate. Recommendations and alternatives should be commensurate with the nature and cause of the inadequacy, and the seriousness of its consequences.

The engineer should consider the cost effectiveness and practicality of the recommendations, the projected performance, and the needs of the client. For example, an owner may choose to perform periodic cosmetic repairs and door adjustments, rather than comprehensive foundation underpinning.

Risks of continued diminished performance are involved in all remedial measures. The engineer can, however, provide recommendations for remedial measures that reduce risks. Not implementing the entire remedial plan may increase such risks.

Section 6. REPORTING

The report provides a record of the investigation, analysis and conclusions. Report formats may vary, but should contain pertinent information that was obtained or generated during the investigation. The following list includes items that may be included in a report:

1. Authorization and Scope
2. Property Location and Description
3. Sources of Information
4. Data
5. Assumptions
6. Analysis of Information and Data
7. Conclusions
8. Recommendations
9. Limiting Conditions

Section 7. REMEDIAL MEASURES

7.1 Objectives and Limitations of the Remedial Measures

The objective of the engineer should be to design and recommend cost effective remedial measures. Remedial measures should address diminished structural integrity and performance identified during the evaluation process. Recommendations for remedial measures should include a clear description of what the remedial measures are intended to accomplish.

Perfection is not attainable by remedial measures. Recommendations for remedial measures should identify important or significant limitations of the measures, and should comment on reasonable expectations of the remedial measures.

7.2 Responsibility of the Engineer

The engineer who provides sealed remediation documents or plans and specifications shall be the engineer of record and shall have approval authority over any changes. The Texas Engineering Practice Act and Rules adopted by the Texas Board of Professional Engineers prohibits the practice known as “plan stamping” by requiring that engineers seal only work done by them or under their direct supervision.

7.3 Non-structural Remedial Measures

Non-structural remedial measures may improve foundation performance and reduce future movement. Applying non-structural remedial measures and monitoring foundation performance prior to or in lieu of structural repairs may be a prudent approach. Typical recommendations for non-structural remedial measures may include, but are not limited to, the measures listed below.

7.3.1 Conscientious Watering Program

The client should be informed that maintaining near uniform soil moisture conditions near all sides of the foundation may be beneficial. Caution should be advised against excessive watering.

7.3.2 Vegetation Alteration

Trees or large shrubs near a foundation may cause soil shrinkage under the foundation. Removal of these trees or shrubs may stop shrinkage or lead to partial restoration of settled areas of the foundation. Removal may result in upheaval caused by soil moisture increase, especially if the tree predates construction. If trees are removed, a suitable waiting period may be recommended to allow for soil heave.

7.3.3 Root Barriers

Root barriers or periodic root pruning may mitigate the effects of vegetation. Root barriers are generally not as effective as tree removal.

7.3.4 Gutters and Downspouts

Uncontrolled roof runoff can cause erosion and ponding of water near the structure, which can be mitigated by addition of gutters and downspouts. Downspouts should be extended well past the edge of the foundation, past the edge of abutting planting beds, and into well-drained areas.

7.3.5 Drainage Improvements

Drainage improvements may be appropriate to address foundation movement. If drainage improvements are considered, the following guidelines may be appropriate.

7.3.5.1 Surface Grading

Where practicable, for adjacent ground exposed or vegetative areas, a minimum slope of 5 percent (i.e. 6 inches in 10 feet) away from the foundation should be provided for the first 5 feet all around. Swales should have longitudinal slopes of at least 2 percent (i.e. 6 inches in 25 feet), if practicable, and 1 percent (i.e. 3 inches in 25 feet) at a minimum.

7.3.5.2 Erosion Control

The remedial documents should indicate locations where fill, ground cover or retaining structures are to be added.

7.3.5.3 Surface Water Drainage

When surface drainage cannot be improved adequately by grading, or when otherwise appropriate, solid pipe drainage systems should be specified. The ground surface should be graded to slope to one or more drainage inlets. Cleanouts should be provided for maintenance. Downspouts may be connected to solid pipe drainage systems, if the pipe is large enough for the hydraulic load of roof drainage.

7.3.5.4 Subsurface Water Drainage

Subsurface water drains are appropriate to control subsurface water, and usually consist of perforated pipe, with or without filter fabric, in an aggregate-filled trench. Provide a continuous minimum slope of 0.5 percent to a surface outfall. Cleanouts should be provided for

maintenance. Downspouts should not be connected to perforated pipe subsurface drainage systems.

7.3.6 Moisture Barriers

Vertical or horizontal moisture barriers may be effective to mitigate moisture migration under the foundation. Moisture barriers may consist of durable impermeable plastic sheeting or other appropriate material attached to the foundation.

7.4 Structural Remedial Measures

Structural remedial measures may be necessary to improve foundation performance.

7.4.1 Structural Remedial Documents

The engineer should provide documents or plans and specifications that show specific details of the remedial measures. Plans should be specific for the project, and be based upon generally accepted engineering practice, including appropriate engineering calculations.

Remediation documents should include the following:

1. The site address
2. The engineer's name and the firm's name, address, and telephone number
3. The client's name and address
4. The purpose and limitations of the remedial measures
5. Available geotechnical information and source
6. A plan view of the foundation locating known relevant structural components
7. Details to show how to construct repair components
8. Specifications to identify appropriate materials and methods
9. Requirements for construction observation or testing by the engineer or others
10. Existing floor elevations or contours and elevation adjustment requirements, if appropriate
11. The requirement for performing a floor elevation survey after completion of the remedial measures
12. Site restoration requirements

7.4.2 Geotechnical Information

The engineer designing structural remedial measures will need geotechnical information. In some cases, geotechnical information may be derived from successful local practice, or other experience, verified during construction. For major or comprehensive remedial measures, geotechnical information should be derived from a site specific boring and testing program tailored to the project's needs.

7.4.3 Repair of Slab Foundations

Concrete slab-on-ground foundation repair methods include, but are not limited to: underpinning, grouting, mudjacking, crack injecting, tendon stressing, and partial demolition and reconstruction.

7.4.3.1 Underpinning

The plans should show or specify specific locations of underpinning elements and their sizes, depths, material types, and minimum required material strengths if appropriate. Underpinning design shall be based upon generally accepted engineering practice and appropriate engineering calculations. Performance of underpinning can be compromised by integrity of existing slab components, changes in soil moisture, skin friction, point load, and other factors.

Underpinning part of a structure may be specified if calculations, tests, or experience show that the unsupported structure can support its design loads. The construction documents should state that underpinning will not improve the performance of the foundation in non-underpinned areas.

Elevation adjustments by jacking or lifting atop underpinning elements may be applicable when floor slopes are excessive, or when the design requires that the foundation be lifted clear of expansive soil. Elevation adjustments should be governed by field judgment to limit damage to the foundation and finishes. It is unlikely that elevation adjustments will result in a level foundation.

7.4.3.2 Grouting and Mudjacking

In general, grouting provides continuous slab support without lifting appreciably. Mudjacking is done to adjust elevations of a foundation hydraulically with continuous uniform support. Grouting or mudjacking may be accomplished with temporary support atop shallow footings or long-term support atop deep piles or piers. Grouting or mudjacking should

not be performed beneath underpinned foundations if expected swelling of the soil in the injected area is sufficient to damage the structure.

7.4.3.3 Crack Injecting

Injecting slab cracks of about 1/32 inch and larger with epoxy repair cement is intended to restore stiffness across the injected crack. If the objective of the repair is solely to limit moisture intrusion or insect ingress, then alternative materials, such as sealants, may be appropriate.

7.4.3.4 Tendon Stressing

Stressing relaxed or inadequately stressed post-tensioned tendons may be applicable when tests show tendon forces below those specified in the original design or by applicable authority. Stressing may restore the residual prestress in the concrete, and should be performed after elevation adjustments and epoxy crack injecting, if any.

7.5 Repair of Pier and Beam Foundations

Pier and beam foundations consist of structurally supported floor systems atop piers, posts or footings. Repairs may include shimming the floor framing atop the existing supports, repairing or strengthening the floor framing, replacing or adding supports, and re-establishing void space.

7.5.1 Floor Shimming

Floor framing may be adjusted by addition of shims atop pier caps. Hardwood or steel shims may be used to fill gaps.

7.5.2 Framing Repairs

Structural members that are damaged or distressed should be replaced or reinforced. Treated lumber is recommended for general use in framing repairs.

7.5.3 Additional Supports

Additional supports can be installed when beam or floor framing spans are too great for the design loads, or when existing supports have deteriorated or are otherwise ineffective.

7.5.4 Void Space

Void spaces designed under foundation elements should be reestablished as necessary.

7.5.5 Under-Floor Crawl Space Moisture Control

Under-floor moisture control measures include crawl space cross ventilation, under-floor drainage, floor beam and floor joist ground clearance, and treated lumber.

7.6 Post Lift Plumbing Testing

Water supply and sanitary drain lines should be tested for leaks if jacking or lifting is included in the remedial measures. Gas service lines may require adjustment. Leaks found by such testing should be repaired.

7.7 Floor Elevations

Floor elevation measurements should be made after implementation of remedial measures. The engineer should keep a record of these elevation measurements and furnish a copy to the client.

7.8 Compliance Letter

Upon satisfactory completion of the remedial measures, the engineer, if retained to do so, should provide a letter of substantial completion to the client stating that to the best of the engineer's knowledge, the remedial measures generally conform to the remediation documents, including approved changes. Deviations from the remediation documents should be noted in the letter.

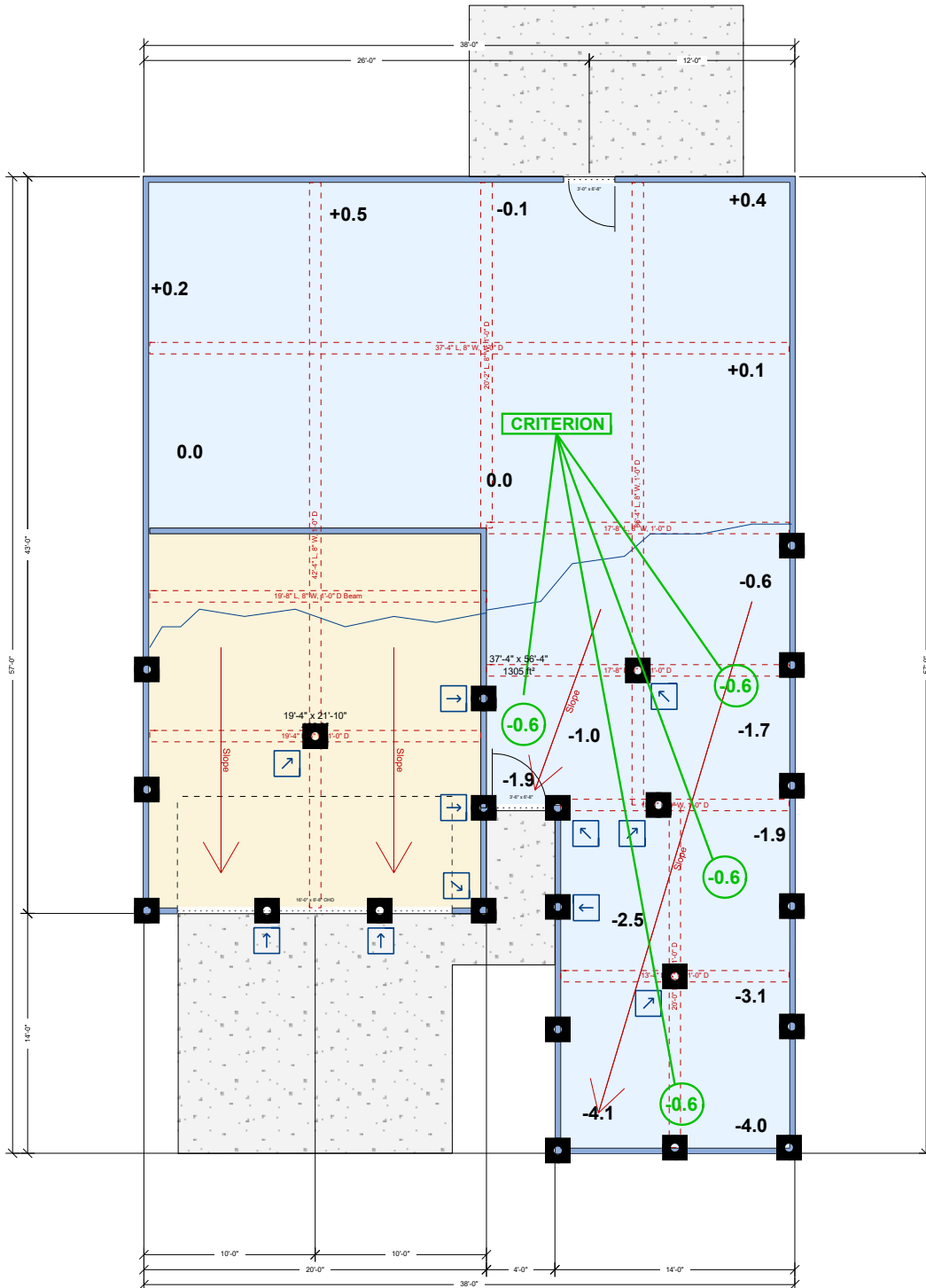
Liliana Henao
 17218 Valemist Ct.
 Houston, TX 77084.

346-689-2159
 manager@brandrealtyteam.com

General Notes:

- Condition: "Advancing"
- Single Family Home (Contiguous Post Tension Foundation).
- 4.0" overall elevation variance (not within 15ft)[with heaving].
- Load analysis calculation basis / load vs. soil composition (charted)[non-specific].
- ~0.5 Original workmanship variance
- <0.6" variance as tolerance + original workmanship variance.
- L/360 calculations observed.
- 18 Perimeter pier placement(s) (Repair)
- 5 Interior pier placement(s)
- Pressure and depth details required.
- Standard backfill and compaction.
- ASCE codes and standards.
- Lifetime Warranty

- Pier Installation
- Concrete Perforation / Re-Surface



Lifetime Foundation Warranty

Duratech Foundation Repair Company
Houston, TX

This Certifies that the homeowner(s) at

Sample

Have used the Duratech Foundation repair System.
Should any adjustment be required during the life of this home, due to settling, our company will re-raise all areas previously underpinned without cost to the owner. This warranty is transferable to one future homeowner located at the above stated address, provided that no major structural changes have been made.



Duratech Foundation Repair Co.

Company Officer Signature

Date

David Grissom, *P.E., Ph.D.*

Consulting Engineer

F - 1086

10802 Vickijohn Court / Houston, TX. 77071 / Ph. 713-974-7569

17 October 2011

To Those Seeking Information About Foundation Repair Methods:

The following pages contain an objective comparison of the two most widely used foundation repair methods available in the Houston area. These two methods are the Bell Bottom Pier method (also known as the Drilled and Poured Pier), and the Hydraulically Driven Piling method (also known as a Friction Piling, Pressed Piling, or Segmented Piling), the latter using pre-cast, high strength, reinforced concrete cylinders, 6 inches in diameter and 12 inches long.

Other methods, such as helical piers, square block pilings, foundation watering and lawn drain systems, root barriers, and others, are not within the scope of this comparison. These are specialty techniques which only have very limited usage parameters, and are not part of the main line of foundation repair techniques, and are not typically FHA, VA, or Conventional Loan approved repair methods.

This comparison is based upon this Professional Engineer's years of experience, encompassing thousands of foundation repair projects, in all of the more than 30 types of soils in the Houston area and surrounding counties. It is the intention of this comparison to clearly and concisely state the relevant facts, in a purely objective manner, leaving it to the reader to draw their own conclusions based upon the facts. My hope is that the reader will gain a better understanding of these two foundation repair methods, thereby having enough information to make the right choice for their own situation.



17 October 2011

Sincerely:

David Grissom

David Grissom
P.E. #24560

OBJECTIVE COMPARISON OF FOUNDATION REPAIR METHODS

Bell Bottom Piers Vs. Hydraulically Driven Pilings

1. HISTORY:

BELLS: Developed over 50 years ago to temporarily stabilize residential foundation movement in most soils and for most loads. Mainly used today in new home construction.

PILINGS: Pile driving technology was developed over a thousand years ago in Europe to build, level, and stabilize any number of structures, from bridges to the great cathedrals and castles.

About 25 years ago, Structural Engineers at The University of Houston, among others, thoroughly tested and secured FHA and VA approval for a residential foundation repair piling application.

Today, reinforced, aligned, and connected cylindrical concrete pilings are the industry standard.

2. REGULATION:

Both methods are approved by FHA, VA, and Conventional Lenders, and by all City Codes. Most Lending Requirements, City Codes, and Accepted Building Practices specify a

Maximum Spacing of no more than 8 Feet-On-Center, Interior or Exterior, Pier or Piling.

3. WARRANTY:

BELLS: Lifetime Service Agreement - Free adjustments for the first 4 to 10 years, followed by charges of about \$55. Per Pier, Per Adjustment. Usually transferable only once and with restrictions.

PILINGS: Lifetime Transferable Warranty - Free adjustments for the lifetime of the structure. Usually no cost or time restrictions on transferability. Beware of possible voiding clauses.

4. ENGINEERING REQUIREMENTS:

BELLS: Pier Depth and Bell Diameter are **CRITICAL** to performance. Extensive soil testing and load evaluation **MUST** be performed by a Registered Professional Engineer, **PRIOR** to calculating the exact pier size. Before pouring concrete, pier holes **MUST** be inspected by the Engineer of Record to ensure that specifications for Depth, Shaft and Bell Size, and Steel Reinforcement have been strictly adhered to. Approximate cost for soil tests, inspections, and final certification: \$ 1,500.

PILINGS: No soil test is required as pilings are Pre-engineered to test soil capacity and load requirements as the properly aligned and reinforced piling is hydraulically driven into the ground, creating a **3:1 or 4:1 Safety Factor**. Piling depths and final hydraulic pressure readings should be logged on final completion drawing, and then certified by a Registered Professional Engineer.

5. LIFE EXPECTANCY:

BELLS: Properly Engineered, Designed, Inspected, and Installed Piers will have an adjustment rate of approximately **90%** within the First 10 years; (Industry Average).

The Industry average failure rate is approximately **8%**; (8% not re-useable after first 10 years).

PILINGS: Properly driven, Aligned, and Reinforced Standard Cylinders (6 inch diameter by 12 inch height), will have an adjustment rate of approximately 3% within the first 10 years.

There is **NO FAILURE RATE** for Correctly Installed, Aligned, and Reinforced Cylindrical Pilings

6. JOB TIME:

BELLS: Usually about **4 to 6 weeks** due to piers being made on-site. Requirement for curing **3000 P.S.I.** concrete, of 28 days, as per A.C.I. Standards, is sometimes ignored by contractor's on-site foreman to expedite job, at sacrifice of quality. Additionally, rain can cause un-poured pier shafts to fill with water and collapse, causing major time delays. Calculating clean-up and weather delays, some jobs can take over 60 days to complete.

PILINGS: Usually **1 to 5 days**, depending upon the number of pilings. Requirement for curing **6000 P.S.I.** concrete of 28 days, as per A.C.I. Standards, exceeded, as all blocks and cylinders are pre-made and batch stress tested and certified at the factory before shipping. Speed with which piles are driven precludes any rain delay problems, except for "actual raining time" delays.

7. COST COMPARISON:

BELLS: Aside from previously mentioned up-front soil analysis charges, small, Exterior, **Type A** piers (9/24 -9 inch shaft, 24 inch bell) cost about \$450. to \$550. each. Larger, more stable **Type B** piers (12/30 or 12/36) cost around \$650.; and **Type C** piers (14/42) cost at least \$950. The cost increases dramatically if hand drilling is required. For interior piers, add at least \$100. per pier.

PILINGS: No soil analysis required. Exterior, **Steel Aligned and Reinforced Pilings** cost between \$375. to \$450. each. For interior pilings, add about \$100. per piling.

8. MUD PUMPING:

BELLS: Mandatory in all situations to minimize "initial settlement" load transfer problems during the first four to six months after job completion. Frequently leads to additional problems such as swelling and interior heaving, and can occasionally cause sewer problems.

PILINGS: Variable applications. Due to the minimum 3:1 or 4:1 safety factor inherent in correct piling installations, "initial settlement" problems are negligible. Usage and scope determined by the contractor on a case-by-case basis at the time of the job. No heaving problems.

9. LANDSCAPING:

BELLS: Longer job time and heavy equipment required usually destroys lawns / shrubs.

PILINGS: Shorter job time and no heavy equipment required, drastically reduces re-landscaping problems and costs. Also, fewer plants have to be removed. Grass rarely dies.

10. REMEDIAL REPAIRS:

BELLS: Recommended **MINIMUM** wait of **4 to 6 months** after job completion before any repairs or remodeling, (doors, sheetrock, painting, wallpaper, tile, brick/mortar, etc.); due to initial settlement after load transfer, and possible heaving. Cracks can reappear for about 2 years.

Tunneling is not available for interior pier installation.

PILINGS: Usually, a **MAXIMUM** wait of **30 to 45 days** after job completion, to allow structural members to absorb the stresses of leveling. No initial settlement or heaving problems. Doors, brick and mortar cracks, plumbing and sewer lines, and other items not affected by re-alignment can be repaired immediately, often simultaneously. This can further reduce the actual total job time.

Interior pilings can be installed via tunnels, eliminating family displacement, health concerns, costly floor replacements and / or repairs, and to minimize interior packing / clean-up requirements.

BUYER'S GUIDE TO SLAB-ON-GROUND FOUNDATIONS

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TREC 895

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Table of Contents

FREQUENTLY ASKED QUESTIONS ABOUT EXPANSIVE SOILS

(page 6)

What are expansive soils?

Why do so many houses in the Greater Houston Area show signs of damage due to foundation movement?

What areas of the Greater Houston Area are affected?

FREQUENTLY ASKED QUESTIONS ABOUT SLAB-ON-GROUND FOUNDATIONS

(page 8)

What are post-tensioned slab-on-ground foundations?

What are conventionally reinforced slab-on-ground foundations?

What are the significant differences between conventionally reinforced and post-tensioned slab-on-ground foundations?

Should it make any difference to a buyer what kind of slab-on-ground foundation a house has?

How do slab-on-ground foundations work?

What are active and dormant areas of slab-on-grade foundations?

FREQUENTLY ASKED QUESTIONS ABOUT FOUNDATION PERFORMANCE EVALUATIONS

(page 12)

How do engineers identify damage caused by foundation movement?

What are foundation inspections and foundation performance evaluations?

Are there different types of foundation engineering evaluations?

How reliable are foundation performance evaluations?

How much damage should a homebuyer be willing to tolerate?

How far out-of-level is acceptable?

Will my house fall down?

FREQUENTLY ASKED QUESTIONS ABOUT FOUNDATION CRACKS

(page 17)

What is a cracked slab?

If my floor tile has cracks, is my slab cracked?

What is a corner or wedge crack?

When does a crack become a problem?

If my floor tile pops loose, do I have a foundation problem?

FREQUENTLY ASKED QUESTIONS ABOUT BUILDING CODES
(page 21)

What does the code say about foundation performance?

What do the code-approved design protocols say about foundation performance?

FREQUENTLY ASKED QUESTIONS ABOUT MITIGATION AND REPAIR
(page 23)

What options are available for addressing foundation performance issues?

What options are available for mitigating moisture changes in the soil supporting the foundation?

Are there any practical limitations on our ability to mitigate moisture changes in the soil?

How is the need for structural foundation repair established?

How are foundations structurally repaired?

How much improvement in performance can reasonably be expected from foundation repair?

If I buy a house that shows signs of foundation-movement-related damage, will I be able to sell the house?

What are some examples of foundations in need of concrete repair?

What is your philosophy of foundation mitigation and repair?

FREQUENTLY ASKED QUESTIONS ABOUT RETAINING ENGINEERS

(page 33)

What is the difference between a real estate inspection report and an engineering performance evaluation?

What should a homebuyer look for when retaining a Professional Engineer?

What is the most important criteria for selecting a Professional Engineer?

HOUSTON AREAS AND SOILS

(page 36)

OTHER SOURCES OF INFORMATION

(page 42)

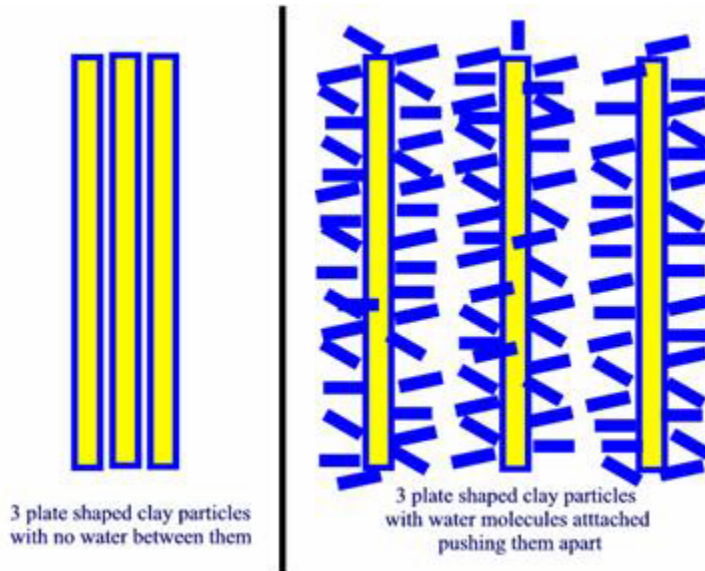
Websites

Books for Homeowners

FREQUENTLY ASKED QUESTIONS ABOUT EXPANSIVE SOILS

What are expansive soils?

Expansive soils contain clay soil. Clay soil particles are very small and are shaped like very thin plates; due to the thin plate shape, clay particles have a lot of surface area for their size. The clay particles are electrically charged and bond to each other like small magnets. The electrical bonding force is relatively weak and can be easily broken by water molecules that become inserted between the clay particles. As the soil becomes wetter, more and more water molecules attach themselves to the plate-shaped clay particles and the water molecules push the clay particles further and further apart. (Think of the plate-shaped clay particles being like a deck of cards where the cards are being pushed apart making the card deck appear thicker.) This results in the apparent volume of the soil mass growing so that there is soil heave or expansion. As the soil dries out, the process reverses; as the water molecules evaporate and become detached from the clay particles, the clay particles move closer and closer together. This results in soil shrinkage. In a sense, expansive soils act like a sponge; the apparent volume of the sponge increases as it takes on water and shrinks as the water evaporates.



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Why do so many houses in the Greater Houston Area show signs of damage due to foundation movement?

There are several reasons why the Greater Houston Area includes large numbers of houses that show signs of damage due to foundation movement:

- **Expansive Soils:** Expansive soils swell when they get wet and shrink when they become dry.
- **Climate:** The Houston climate is characterized by weather that alternates between very wet to very dry. This area experiences occasional periods of little or no rain that may last as long as 2-years or more.
- **Flexible Slab-on-Ground Foundations:** The large majority of houses in the Greater Houston Area are founded on thin, flexible slab-on-ground foundations that are designed to distort as the supporting soils distort by shrinking and swelling.

When you put the above facts together, it is surprising that there are not even more residential foundation problems than what we see.

What areas of the Greater Houston Area are affected by expansive soils?

Most of our soil consists of various types of clay with some sand mixed in. The South, Southwest, East and Central areas of Houston are characterized by what is known as the Beaumont formation. This soil formation contains significant amounts of moderately to highly expansive clays. The north and some parts of west Houston are underlain by the Bentley and Lissie formations. The Bentley and Lissie formations consist of sands and sandy clays; these soils generally have a low to moderate shrink/swell potential.

Some of the sandy soils in the north and west parts of the Greater Houston Area also contain silt and can become very weak when they are wet. In many cases, the silty, sandy soils on the surface are underlain by an impermeable clay strata that can hold water creating what engineers call a perched water table. The perched water table can hold water allowing the underlying clay soil to soften which can result in the clay soil losing much of its bearing capacity resulting in foundation problems. In some situations, the underlying clays are expansive making a bad situation even worse.

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The section of this book titled **Houston Areas and Soils** provides more specific information concerning the variety of soil types and risks of damage due to foundation movement found in the Greater Houston Area.

The bottom line is this: although some areas may not be as bad as others, or may have a different mix of problems than other areas, there are very few subdivisions in the Greater Houston Area that do not have the potential for foundation movement that can cause damage to a conventionally constructed house.

FREQUENTLY ASKED QUESTIONS ABOUT SLAB-ON-GROUND FOUNDATIONS

What are post-tensioned slab-on-ground foundations?

A post-tensioned slab-on-ground foundation is simply a ground-supported concrete slab foundation that is reinforced with flexible cables that are tensioned after the concrete hardens. When the cables are tensioned, the concrete is placed in compression. The cables are not normally tensioned until at least 7-days (and sometimes not until 30-days) after concrete placement. Since the cables cannot provide any crack control until after the cables are tensioned, every post-tensioned slab experiences anywhere from 7 to 30-days during which there is no crack control at all. This allows for the development of large, visible curing cracks called restraint-to-shrinkage (RTS) cracks.

In spite of this, post-tensioning is generally considered to be a superior method of bending crack control as compared to conventional reinforcing.



this is a bundle of post-tensioning cables as they are delivered to the site



an overview of a post-tensioned slab-on-ground foundation ready for concrete



this is a close-up of the post-tensioned cables after installation – notice the conventional reinforcing steel at the left side; it is not unusual to mix post-tensioned and conventional reinforcing



close-up showing a live-end anchor; notice the use of duct tape – this shows poor workmanship

What are conventionally reinforced slab-on-ground foundations?

A conventionally reinforced slab-on-ground foundation is simply a ground-supported concrete slab foundation that is reinforced with what are called deformed steel bars. Unlike post-tensioning cables in post-tensioned slabs, the concrete bonds to the conventional reinforcement as the concrete cures. The conventional reinforcement provides crack control almost immediately.



reinforcing steel in field area of a slab-on-ground foundation



reinforcing steel in field area of a slab-on-ground foundation

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reinforcing steel in a perimeter stiffening beam of a slab-on-ground foundation



reinforcing steel in a stiffening beam intersection of a slab-on-ground foundation

What are the significant differences between conventionally reinforced and post-tensioned slab-on-ground foundations?

The most important differences between post-tensioned slabs-on-ground and conventionally reinforced slabs are listed below:

- **Post-tensioned slabs-on-ground are usually thinner than conventionally reinforced slabs-on-ground.** This fact alone makes the post-tensioned slab potentially more flexible than a conventionally reinforced slab. There are other aspects, however, that, in practice, mitigate this difference.
- **Post-tensioned slabs are less likely to develop cracks due to bending.** Since the concrete in a post-tensioned slab is placed in compression, cracks due to bending are less likely than in conventionally reinforced slabs.
- **Post-tensioned slabs are more likely to develop cracks due to restraint-to-shrinkage.** Since the cables cannot be tensioned for at least 7-days after the concrete is placed, visible RTS cracks are almost inevitable in a post-tensioned slab. These cracks will tighten when the cables are tensioned. However, certain conditions, including debris lodging in a crack, may prevent an RTS crack from fully closing. These cracks are not significant structurally to the performance of the foundation whether they close or remain open.

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- **Post-tensioned slabs-on-ground can be less expensive.** If several foundations are to be constructed using the same design, a post-tension design will almost always be less costly to the builder. This situation is common with large builders; constructing post-tensioned slabs can bring significant cost savings for such builders.

Should it make any difference to me what kind of slab-on-ground foundation a house has?

The reality is that the large majority of house foundations constructed in the Greater Houston Area in the last 25-years have been post-tensioned foundations. In addition, if you are looking for a house within a specific price range in a particular subdivision or area of town, every house that fits your criteria may be either post-tensioned or conventionally reinforced. From a practical perspective, what is important is how well or how poorly a specific foundation has performed in the past rather than how it is reinforced.

One of the authors grew up in a house founded on a conventionally reinforced foundation and has lived in a house founded on a post-tensioned foundation for the almost 30-years. Neither house has ever shown any significant distress due to foundation movement with the exception of the house the author grew up in; and that house displayed problems only after it was rented and the occupants did not water the soil adjacent to the foundation during dry periods.

The bottom line is that, in our opinion, the question of whether a resale house has a conventionally reinforced foundation or a post-tensioned foundation should be a non-issue.

How do slab-on-ground foundations work?

The structural function of a slab-on-ground foundation is to act as a buffer that mitigates the differential distortions between the supporting soil and house supported on the foundation. Slab-on-ground foundations do this by resisting the moisture-induced distortion of the supporting soil and by spanning over moisture-induced distortions in the supporting soil.

The foundation is intended to do this while maintaining the surface levelness within

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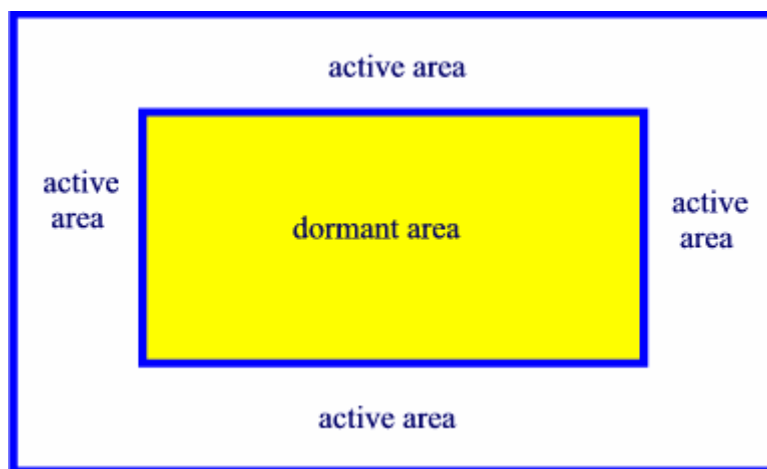
permissible levelness tolerances. The levelness tolerances are dependent on the as-constructed levelness of the foundation surface and construction of the house. The intent of the design protocol is for the foundation surface to distort within a range that:

- **Does not result in significant structural damage to the house frame.**
- **Does not distort the frame structure so that numerous doors and windows cannot function.**

It is extremely important to understand that slab-on-ground foundations are not designed to eliminate the possibility of cosmetic damage or minor door problems.

What are active and dormant areas of slab-on-grade foundations?

When a slab-on-ground foundation is placed in the ground, the presence of the slab inhibits the ground under the foundation from wetting up or drying due to wet and dry weather, respectively. This is most pronounced in the central area of the foundation. Since this area is protected from seasonal weather-related changes in the soil moisture, the ground supporting the central area of the foundation does not shrink and swell very much compared to the area of the foundation near the perimeter or edge of the foundation. Most of the soil shrinkage and swelling occurs in the area of the foundation within 8 to 10-feet of the foundation edge. This area near the edge of the foundation is called the active area since this is where most of the soil distortion due seasonal weather changes occurs. The following sketch shows the relative locations of the active and dormant areas of a rectangular slab-on-ground foundation.



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How do engineers identify damage caused by foundation movement?

Professional Engineers usually make judgments concerning whether cracks and other forms of damage or distress are due to foundation movement using their knowledge of structural mechanics, the engineering characteristics of building materials and their experience inspecting hundreds and sometimes tens of thousands of homes.

There are two points that should be recognized at the outset. If the damage is minor, such as a few hairline cracks, it is very difficult to say definitively what caused the damage. On the other hand, if the damage is severe, such as, say, $\frac{1}{4}$ th inch wide cracks in the drywall, the damage is almost certainly due to structural distortion. The problem is with the houses in between. The following are some rules of thumb published by the Institution of Civil Engineers and the Building Research Department in the United Kingdom.

- **Foundation movement usually tends to produce a few large cracks, usually at least $\frac{1}{16}$ th inch wide, rather than a lot of small cracks.**
- **Cracks in brick veneer due to foundation movement will normally extend from the top of the wall to the bottom of the wall.**
- **The cracking usually will be tapered if caused by foundation movement. By tapered I mean that the crack will be wider at the top or the bottom. If a crack is due to foundation movement, it will almost never be the same width at the top and bottom; such a crack is more likely to be due to thermal stresses than to foundation movement.**
- **Considered as a whole, the pattern (meaning the location and taper) of the cracking should be consistent with a possible known mode of foundation distortion. For instance, if a brick veneer wall shows cracks that were close to each other and one was wide at the top while the other was narrow at the top, it would usually be unreasonable to consider both cracks to be due to foundation movement since they are not both consistent with a known mode of**

foundation distortion.

- **Foundation movement usually results in cracks in drywall and brick veneer at weak points such as at the corners of windows and doors.**
- **Cracks that show up after a long period of dry weather and tend to close when the weather turns wetter are usually due to foundation movement.**
- **Foundation movement can distort door openings, causing doors and windows to stick and bind. Wallpaper can exhibit rucking at the inside corners of walls and at the intersection of walls and ceilings.**
- **In some situations, finished floors can become perceptibly out-of-level. Unfortunately, floors are constructed out-of-level and foundations that undergo a normal range of movement can also become more or less out-of-level over time. Relating floor levelness to foundation movement is always based to a great degree on the engineering judgment of the inspecting engineer; that judgment is always subjective and interpretative.**
- **Brick courses, countertops and sills can become noticeably out-of-level due to foundation distortion. These items are normally constructed to a tighter level of tolerance than floors.**

What are foundation inspections and foundation performance evaluations?

A foundation inspection consists of observing the interior and exterior of the house for signs of structural distortion that might be related to foundation movement. An engineering evaluation of the performance of a foundation consists of taking the data from the inspection and using it, in conjunction with the engineer's knowledge of structural mechanics, the structural behavior of houses (including the structural behavior of brick veneer walls, stucco walls, drywall walls and door frames) and the engineering properties of building materials to make engineering judgments about the performance of the foundation.

Are there different types of foundation engineering evaluations?

The Texas Section of the American Society of Civil Engineers (TSASCE) has recognized different levels of residential foundation evaluations including a Level A and a Level B evaluation. The Level A evaluation is usually referred to as a visual evaluation or a report of “first impressions.” I prefer to describe it as a visible damage evaluation. The Level B evaluation is built on a Level A evaluation but also includes a finished floor elevation survey. Some engineers claim to be able to use an elevation survey to confirm or deny whether the observed damage from the Level A evaluation is due to foundation movement.

How reliable are foundation performance evaluations?

This is a very interesting question, but the answer is not clear. In fact it is not clear that it is even possible to answer the question. We really do not know how reliable foundation performance evaluations are and, I would argue, it is not possible to know how reliable they are. It is not possible to know, at least in any verifiable, quantitative sense. Foundation performance evaluations are always subjective opinions. The subjectivity makes many engineers and some real estate inspectors uncomfortable; but there is no way around the fact that these evaluations are full of subjective assessments and opinions. For instance, any recommendation to underpin or not to underpin a foundation rests, at least in part, on a subjective assessment of the likely effectiveness of underpinning and its associated risks for a specific foundation. For a specific foundation, there is simply no way to know how effective foundation underpinning will be and what the costs (in terms of damage to the foundation and the house) of the underpinning process are until after the foundation is underpinned. In fact, it will normally be some time after the repair work is completed before a reliable assessment can be made of how effective the foundation repair was. And, if the foundation is underpinned, we will never know how the foundation would have performed without the repair.

In a sense deciding to repair or not to repair a foundation is like a fork in Robert Frost's road in his famous poem *The Road Not Taken*. There is simply no way to ever know for sure if you made the best decision or not. For precisely that reason it is important to gather as much information as possible and come to the best understanding you can before making a decision as to how to address expansive soil foundation problems. One essential element is to seek the council of an unbiased structural engineer who specializes in this area.

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How much damage should a homebuyer be willing to tolerate?

Structural safety problems that result from foundation movement are clearly intolerable. But beyond that, the correct answer is that there is no answer that is correct for everyone. Different people have a different tolerance for cracks in wall coverings and sticking doors. It is important in searching for a home to purchase that you be realistic. Demanding a house that shows no signs of foundation movement, has never shown any sign of foundation movement and never will show damage that could be attributed to foundation movement is not realistic. You should not buy any home that you are not comfortable with, especially without having a structural engineer make a damage evaluation. But the ultimate decision as to how much damage you are willing to tolerate is one only you can make.

How far out-of-level is acceptable?

There is no answer to this question that is universally accepted. The Post-Tensioning Institute has published a peer-reviewed paper in which it is stated that a diagnosis of excessive expansive soil movement cannot be made unless the slab surface is out of level substantially in excess of published American Concrete Institute (ACI) standardized construction levelness tolerances for slab-on-ground foundation construction. The ACI publishes several different construction tolerances but recommends the use of what are called F-numbers. The F-number system allows the elevation of two points 10-feet apart to be different by as much as 1.25 inches. If a foundation were to deflect $L/360$ in both directions (which most engineers would consider acceptable), the resulting slope (adding an as-constructed slope to the slope caused by foundation distortion) could result in a foundation surface slope of 1.65 inches or more over 10-feet. A slope greater than 1% (1.2 inches over 10-feet) is noticeable by most people. Thus, a noticeable floor slope may or may not indicate excessive foundation movement. You should also understand that the as-constructed slope and the slope due to foundation movement may not add together; the foundation may distort in a way that makes the slab surface more level, not less level.

Some engineers prefer to judge the levelness of the foundation due to distortion by looking, not at the levelness of the slab surface, but at the levelness of first floor counter-tops and sills since these elements are normally constructed to much tighter levelness tolerances than slab-on-ground foundation surface tolerances. If the countertops and sills are reasonably level within normal construction tolerances, then it is reasonable that any floor out-of-levelness is probably due to original construction.

Will my house fall down?

It is important to understand that it is extremely unlikely for expansive soil foundation movement to cause a house to collapse. First, very few houses collapse for any reason. The most common reason for this type of failure is fire. It is conceivable for a house that has extremely severe moisture and termite damage to collapse, especially if it is abandoned. Houses under construction have been known to collapse when subjected to high winds. Houses under construction are subject to this risk before key structural elements have yet been installed. Of course, extreme weather events such as hurricanes and tornadoes can also cause a house to collapse. But I do not know of a single case in which expansive soil movement caused a house to collapse.

What seasonal weather-related expansive soil movement can do is cause cosmetic damage to the house in various forms, usually drywall cracking and brick veneer cracking. Door frames can become distorted so that doors no longer fit properly in their frame; also, doors may not latch and could stick and bind. It is also possible for foundation movement to cause framing members to pull apart to some degree. In most cases, the damage is restricted to cosmetic damage that can be repaired using normal decorative repair techniques or minor functional problems such as sticking doors that can be corrected by adjusting or reinstalling the door.

The fear of a house falling down due to expansive soil movement is not based on reality.

FREQUENTLY ASKED QUESTIONS ABOUT FOUNDATION CRACKS

What is a cracked slab?

The term “cracked slab” is not a technical term. You will not find it in any engineering text we are familiar with. The term “cracked slab” is used by lay people and foundation repair contractors. We frankly do not like the term and believe it should not be used. Language can be used in a way that helps us understand and solve problems and language can be used to obscure and confuse. In my opinion, the term “cracked slab” serves no legitimate purpose.

The term “cracked slab” can be understood literally to mean a slab that has cracks. But if this is what term is taken to mean, then it conveys no useful information at all. All concrete exhibits cracking. It is a characteristic of the material that it cracks. There is, in fact, no difference between a “cracked slab” and a “concrete slab” since all concrete slabs have cracks.

The other meaning of the term “cracked slab” is a slab that has failed. But this usage, in our opinion, is illegitimate. Slab-on-ground foundations do not fail in any normal sense. These are ground-supported structures. They are not elevated structures that can collapse and fall down like, say, an elevated structure such as a bridge. Slab-on-ground foundations are most realistically understood and evaluated, not in terms of “failed” or “not failed,” but in terms of performance and specifically in terms of degrees of performance. To quote Donald P. Coduto, P.E.:

“A common misconception, even among some engineers, is that foundations are either perfectly rigid and unyielding, or they are completely incapable of supporting the necessary loads and fail catastrophically. This ‘it’s either black or white’ perspective is easy to comprehend, but it is not correct. All...foundations have varying degrees of performance that we might think of as various shades of gray.” (*Foundation Design - Principles and Practices*, by Donald P. Coduto, P.E., page 10).

The term “cracked slab” presumes that slab-on-ground foundations are best understood and evaluated in terms of “failed” and “not failed.” We consider this perspective to be wrong and misleading.

If my floor tile has cracks, is my slab cracked?

We take this question to mean that if there are cracks in the floor tile are there corresponding cracks in the slab surface? The answer is that it depends. There are usually one of two situations that present themselves for evaluation. We discuss each of these below:

- **There are one or more individual tiles that are cracked but no cracks that run from tile to tile:** In this situation, the most reasonable explanation is that there are probably no cracks in the slab surface under the cracked tile. If there is such a crack, it is almost certainly not an active crack.
- **There is at least one crack in the tile that runs from tile to tile:** When this is the case, there is almost always a crack in the slab surface that mirrors the crack or cracks in the floor tile. The cracks in the slab are usually restraint-to-shrinkage (RTS) cracks and are not considered a major structural defect.

What is a corner or wedge crack?

The large majority of slab-on-ground foundations will develop what are called corner cracks or wedge cracks. The name comes from the fact that these cracks develop at or very close to the outside corners of the foundation frequently in the shape of a wedge.

These cracks develop as a result of the expansion of the brick veneer when it is warmed by the sun. When the temperature of the brick veneer rises, the brick veneer wall expands in length and pushes or slides against the slab surface. At the end of a brick veneer wall at an outside corner of the slab, there is nothing to push back and the concrete cracks at each side of the corner forming a wedge. Builders will usually place a piece of plastic between the bottom of the first course of brick and the slab; this reduces the friction force when the brick expands and slides against the slab. This has the practical effect of reducing the cracking on the slab at the corners but it by no means eliminates the corner cracking.

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These cracks do not indicate anything unusual about the foundation. If the cracking at a corner becomes very bad, the concrete wedge may become loose and even fall off. In extreme cases, the wedge will no longer adequately support the brick veneer; when this happens, the corner will need to be repaired. This is a concrete repair and not a foundation repair.



corner or wedge crack

When does a crack become a problem?

We can divide this question into two separate questions:

- **When does a foundation crack become a concern?** The Shallow Foundation Committee of the American Society of Civil Engineers has published some guidelines for evaluating cracks in slab-on-ground foundations based on the width of the crack. Their recommendation is that if a crack is 1/16th inch wide, it should probably be looked at by an engineer. They also state that cracks that are 1/8th inch or less do not typically indicate that the foundation is not capable of performing as intended. Also, the Shallow Foundation Committee points out that the presence of cracks in slab-on-ground foundations "does not indicate a life-threatening, dangerous condition."
- **When does a foundation crack become a serious problem?** Cracks due to foundation bending can result in significantly more flexibility in the slab. This means that the foundation will not do as good a job as it was intended to do to mitigate the amount of damage the soil distortion causes the house. If the flexibility caused by foundation cracking results in structural damage to the house frame so that the frame structure can no longer safely carry normally imposed loads, then the foundation crack is a serious problem. Also, if a crack increases the flexibility of the house so that doors necessary for an emergency exit cannot be opened and closed by a small child, that too is a serious issue that must be

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resolved. Barring either of these two situations, a foundation crack may be a legitimate concern but it is not a serious problem from a structural engineering perspective.



this is a very wide crack that has faulted severely; notice the business card

If my floor tile pops loose, do I have a foundation problem?

Foundation movement, even foundation movement that is well within a normal, expected range, can crack floor tile. But it is virtually impossible for foundation movement to cause well-bonded floor tile to pop loose. Floor tile is bonded to the slab surface with what is called thin-set. This material does an excellent job of binding the tile to the slab surface if it is properly applied. The key is for the concrete slab surface to be clean and free of any contaminants. The underside of the tile must also be clean but this is usually not hard to achieve. The slab surface is another matter. It is easy, during normal construction operations, for the slab surface to get material on it that prevents a good, permanent bond. When this is the case, the tile may eventually come loose.

In summary, this problem is almost always a bonding issue and not a foundation movement issue.

FREQUENTLY ASKED QUESTIONS ABOUT BUILDING CODES

What does the code say about foundation performance?

The Texas State Legislature recently adopted the **International Residential Code for One and Two Family Dwellings** as the state building code. The following is a summary of some key issues from this code:

- There is no stated requirement that foundation deflection not be allowed to exceed some specified amount such as $L/360$.
- The Building Official has the discretion to permit the construction of a slab-on-ground foundation without an engineered design if past experience has shown that the proposed slab-on-ground foundation has performed adequately.
- For a non-engineered slab-on-ground foundation to be judged to be performing adequately, it must meet three stated criteria.

1. The foundation must be able to resist differential volume changes:

While this would eliminate some minimal foundation designs, almost all foundation designs typically used in the metropolitan areas of Texas could be said to provide some degree of resistance to differential soil volume changes.

2. The foundation must be able to prevent structural damage to the supported structure. In this context, it is clear that structural damage means damage to the supported structure that reduces the ability of the supported structure to carry the imposed loads in a safe manner. Most foundations would be able to pass this test.

3. Deflection and racking of the supported structure shall be limited to that which will not interfere with the usability and serviceability of the structure. This would imply that the foundation deflection should not result in functional problems such as doors or windows that bind and stick. This is clearly a problem with some homes.

What do the code-approved design protocols say about foundation performance?

For engineered slab-on-ground foundations on expansive soils, there are two code-approved design protocols that may be used, one published by the Post-Tensioning Institute (PTI) and the other published by the Wire Reinforcement Institute (WRI). The 1996 edition of the PTI book *Design and Construction of Post-Tensioned Slabs-On-Ground* includes the following wording:

Application of these recommendations results in slab designs similar to those that have exhibited satisfactory performance.

The WRI publication, *Design of Slab-on-Ground Foundations – An Update*, includes similar wording. Neither code-approved design protocol promises that the actual deflection of engineered slab-on-ground foundations will be less than some stated amount. They do promise that actual foundation performance in terms of superstructure distress will be “satisfactory” and the distress “minimal.” I think it is fair to say that slab-on-ground foundations designed and constructed in accordance with either design protocol will not deflect enough to cause structural (load-bearing) damage to the superstructure. There is likely to be some degree of cosmetic distress and some minor door problems. The levelness of the slab surface is not addressed by either design protocol.

FREQUENTLY ASKED QUESTIONS ABOUT MITIGATION AND REPAIR

What options are available for addressing foundation performance issues?

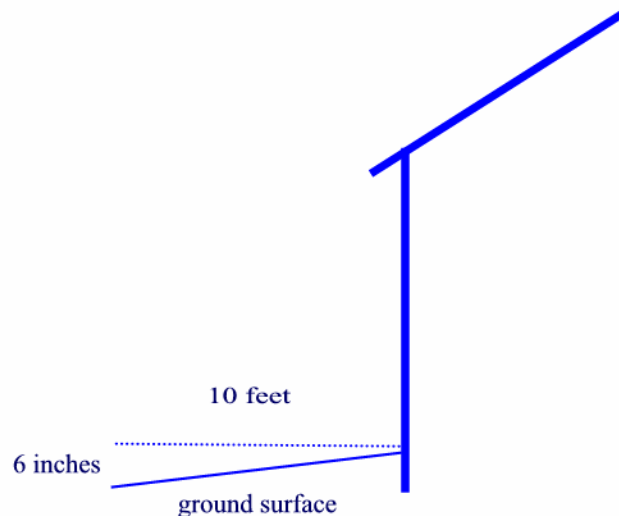
Many houses in the Greater Houston Area will experience foundation performance issues during their useful life. The foundation performance issues experienced can range from hairline cracking that is difficult, if not impossible, to reliably attribute to foundation movement (or any other specific cause) to severe cracking in drywall and brick veneer accompanied by wood framing members being pulled apart. Such a wide range of performance problems dictate a wide range of options to address the issue. The options available include the following:

- **Taking no action at all.** This is a perfectly acceptable option so long as there is no structural damage. In our experience, this is also the most common response when the damage due to foundation movement is minor.
- **Non-structural remediation measures.** Non-structural remediation measures include vigilantly watering the foundation during dry periods, making occasional cosmetic repairs, improving and maintaining drainage around the foundation, removing trees and/or large shrubs and making changes in the finishing of the house such as changes in wall coverings.
- **Structural remediation measures.** Structural remediation measures applicable to slab-on-ground foundations usually include what engineers refer to as structural underpinning, grouting and mudjacking, crack injection and tendon stressing.

What options are available for mitigating moisture changes in the soil supporting the foundation?

There are a number of potentially applicable options for mitigating changes in the moisture in the soil supporting a foundation. These options include soil surface grading, subsurface drains, watering the soil adjacent to the foundation, removing and pruning trees, controlling roof water, maintaining ground covers, and controlling lawn irrigation. Each of these is briefly discussed below:

- **Soil Surface Grading:** This is your first and primary line of defense against excessive moisture in the supporting soils. It is very important that the ground adjacent to the foundation be graded so that it falls 6-inches in 10-feet or to the property line.



- **Subsurface Drains:** Underground drains are appropriate for playing a supplemental role in preventing the supporting soils from absorbing too much water. I say supplemental because it is usually a mistake to rely on an underground drain system when the ground adjacent to the foundation is not properly graded. Grading the soil properly to an underground drain around 10-

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feet away from the foundation is acceptable. Leaving the ground surface flat and placing the subsurface drain close to the foundation is asking for trouble. Underground drains can clog and they can develop leaks.

- **Managing Trees and Large Shrubs:** Trees and large shrubs extract large amounts of water from the soil every day. When they are close to the foundation, they can significantly exacerbate the shrinkage of soil when there is a drought. It is during extended dry periods that we see most of the damage due to foundation movement; the houses that exhibit damage during a drought almost always have trees close to the foundation that are clearly making the situation much worse than it would be otherwise. Trees and large shrubs can be managed for improved moisture control and foundation performance. Large shrubs can be removed. Trees can also be removed. In many cases, the roots of trees can be pruned between the tree and the foundation.
- **Controlling Roof Water:** Large quantities of water come off the roof of a house. The flow of water off the roof will always be uneven except for the case of a hip roof. The best way to control water flow off a roof is with a roof gutter system. It is important that all eave areas be guttered. Guttering some of the eaves while leaving other eaves without gutters makes the problem worse, not better. It is also important that the water not be discharged onto the ground within 5-feet of the foundation. Discharging roof water close to the foundation increases the potential of causing significant foundation movement. Water discharged close to the foundation can easily percolate through the backfill to the supporting soil under the perimeter of the foundation if the backfill is not properly compacted. Unfortunately, the backfill is usually clay and clay can be difficult to properly compact.
- **Maintaining Ground Covers:** There are many homes that have areas around the foundation where it is difficult to get grass to grow. The grass simply cannot compete with the trees for moisture and soil nutrients. The best thing to do, in many cases, is to turn these areas into gardens and mulch them heavily. The mulch can be very effective in preventing the soil from losing excessive moisture. What happens in many cases is that the area is not turned into a garden, but is left as an area that is bare and exposed. During a dry period, these areas can easily become desiccated resulting in more settlement and damage than would otherwise occur.
- **Maintaining Lawn Sprinkler Systems:** There is nothing wrong with having a lawn sprinkler system. Having stated that point, I must also point out that most of them are installed in a way that presents a (potential) problem to the future

performance of the foundation. The two most important problems with these systems are the following:

- **The supply lines are usually placed to close to the foundation.** These lines are prone to leakage which can cause swelling of the soil near the areas that are leaking.
- **The control valves are prone to leakage.** Since these valves are usually very close to the foundation, they should be checked frequently for leakage. Ideally, they should also be located at least 5-feet from the foundation.

Are there any practical limitations on our ability to mitigate moisture changes in the soil?

It should be understood that, from a practical perspective, there are several fundamental reasons why a homeowner, or an engineer for that matter, has only a limited ability to mitigate moisture changes in the soil supporting a foundation. One limiting factor is clearly the weather. Houston weather varies from very wet to extended periods of dry weather and even drought. While this can be compensated for by watering the ground adjacent to the foundation, the reality is that it is impossible to insure uniform wetting of the soil to a sufficient depth to be effective.

Also, there is virtually nothing a homeowner can do about the movement of moisture from lower soil strata to the soil near the surface supporting a foundation. The fact is that engineers have a limited, even inadequate, understanding, of how moisture moves through the soil.

From our experience, most engineers practicing in this area believe that aggressive moisture stabilization measures can cut foundation movement by around 50%. That is a significant reduction, but it may take 6-months to 3-years to obtain that result. It is important to realize that aggressive moisture stabilization results in a wide range of reduction of foundation movement. Some houses may get a much greater reduction and some may get a much lower reduction.

How is the need for structural foundation repair established?

Unless foundation movement results in a structural safety issue that can only be corrected by underpinning the foundation, repairing the foundation structurally should be viewed as an option, not a need. In the large majority of situations where there is impaired foundation performance, structural foundation repair should be viewed as an option that may or may not be appropriate for a given situation. Deciding to make structural repairs to a foundation should be made with a clear understanding of the likely benefits and risks of the proposed repair.

For instance, there is a series of questions that should be asked and answered before deciding to underpin a foundation:

- **What improvement in foundation performance can realistically be expected from underpinning?** If the damage is not severe, it may be better to make cosmetic repairs to the house and take other appropriate non-structural

remediation measures. Underpinning is not normally effective or cost efficient unless the foundation-related damage to the house is severe. No honest foundation repair contractor will guarantee that underpinning will result in a level foundation. In fact, studies have shown that the typical foundation repair job, where the perimeter of the foundation is underpinned, can actually result in a less level foundation surface as the central non-underpinned area settles during dry periods while the perimeter is not allowed to settle due to the presence of piers or pilings. Foundation repair contractors also cannot guarantee that the underpinning will prevent future damage to the house. There is always some residual risk of damage due to foundation movement after the foundation is underpinned.

- **What means are available to mitigate soil moisture changes?**

Foundation movement in expansive soil areas is normally driven by changes in the moisture regime in the supporting soil. Even if the foundation-related damage to the house is severe, underpinning is not likely to be effective in the long-run unless the causes of the changes in the moisture regime are removed. There are several ways to mitigate the changes in the soil moisture. They include maintaining positive drainage away from the foundation. The normal recommendation is to shape the surface of the ground adjacent to the foundation so that it falls 6-inches in 10-feet as you move away from the foundation. No water should be allowed to discharge within 5-feet of the foundation. This includes plumbing leaks, air conditioning condensate discharges, and discharges of water from roof gutters. Trees, especially hardwoods such as oaks, and large shrubs can remove large amounts of water from the soil leading to excessive foundation settlement, especially at the outside corners of the foundation. All ground within 5-feet of the foundation should have some sort of ground cover to prevent excessive drying. Last, but not least, the ground adjacent to the foundation should be watered when the weather is dry.

Unfortunately, the migration of moisture through the soil is one of the least understood aspects of expansive soils. We know that, in at least some situations, soil moisture migrates from lower soil strata to the soils supporting the foundation. This moisture can become trapped under the slab-on-ground foundation resulting in a center lift distortion mode.

- **What damage to the house is the repair process likely to cause?**

Underpinning and grouting and mudjacking can result in unintended damage the foundation and the house. The damage is usually minor, but it can be significant. One of the authors has personally seen drywall cracks as wide as 1.25 inches that were caused by underpinning. Underpinning can result in portions of the foundation being forced to act as an elevated structure instead of a ground-

supported structure. This can result in significantly higher bending moments in the slab structure than it was intended to experience. True structural failure can result.

- **Is the foundation movement excessive and progressive?** Foundation movement is usually considered excessive if the foundation is deflecting more than an inch for every 360 inches of span. Thus, a 60-foot (720-inches) wall could deflect 2-inches at each end; a 30-foot (360-inches) wall could deflect 1-inch at each end. Foundation movement is considered progressive if it is clearly growing over time. This can be determined only by monitoring foundation movement over a period of time, usually at least 6-months but possibly lasting as long as 2-years.

In summary, the decision to underpin or not to underpin a foundation is a judgment based on an understanding of the type and extent of damage judged to be caused by foundation movement, the probable benefits and risks of foundation repair and the monetary costs involved.

How are foundations structurally repaired?

In most cases, foundations that are structurally repaired are underpinned. This is an engineering term that, in this context, refers to the process of providing structural support under the existing slab-on-ground foundation. Underpinning a slab-on-ground foundation is usually done with the intent to lift some foundation areas to attempt to bring the slab surface to a closer approximation to the as-constructed condition. The underpinning is also intended to make the foundation perimeter less susceptible to future settlement. The traditional way to underpin a slab-on-ground foundation is to place reinforced concrete piers under the perimeter of the foundation. The bottoms of the piers are belled out. This spreads the load transferred to the soil and prevents the pier from being pushed up when the soil swells.

~~TO GET THE FULL TEXT OF THIS DOCUMENT, PLEASE VISIT OUR WEBSITE AT: www.foundationrepair.com~~

How much improvement in performance can reasonably be expected from foundation repair?

This is a question that is difficult answer. Most people are surprised that no reputable foundation repair contractor actually promises to make their foundation work better than it did prior to the repair work. All they warrant is that after the foundation repair work the underpinned area will not settle more than a specified amount, usually an inch of settlement for every 30-feet of underpinned span. The repair work is almost always done without any definitive evidence that the foundation has settled more than an inch for every 30-feet of span. Most homeowners who underpin their foundation have no way of knowing if their foundation has settled more than one inch for every 30-feet of span. Nor do they normally have a rational basis for believing that the foundation will or will not settle more than the warranted amount in the future absent any underpinning.

In our experience, foundation underpinning will usually reduce the future settlement by about half. In terms that the lay person can relate to, that generally means that the number of drywall and stucco cracks will be cut in about half. The number of brick veneer cracks will usually not change but the average width of the brick veneer cracks will usually be cut in half. The number of sticking doors may also be cut in half.

If I buy a house that shows signs of foundation-movement-related damage, will I be able to sell the house?

Engineers and real estate inspectors are in the business of informing potential buyers as to the condition of the house, not its marketability. However, there are a couple of points that bear on this question that can best be made by an engineer or inspector:

- **It is unreasonable to not expect some degree of damage due to foundation movement in resale houses in the Greater Houston Area.** The combination of expansive soils, thin flexible slab-on-ground foundations and wooded lots virtually guarantees that many houses will experience some damage due to seasonal foundation movement. This type of movement rarely affects the structural stability of the frame structure of the house.
- **There is a wide range of opinions concerning how much cosmetic damage is acceptable or not acceptable.** Some people find even hairline cracks unacceptable; others find almost any crack width acceptable so long as there are no structural safety or stability issues. If the degree-of-damage shown by a house you are considering buying makes you uncomfortable, you should

probably not buy the house.

What are some examples of foundations in need of concrete repair?

The following are two examples of concrete repair that are sometimes required:

- **Wedge or Corner Cracks:** These are cracks that are frequently formed within 12-inches of the outside corners of the foundation. They result when the brick veneer expands when it is heated by the sun. As the brick veneer expands it pushes outward on the foundation. The frictional forces on the concrete surface cause the foundation to crack at the corner. Wedge cracks or corner cracks are not indicative of a structural performance issue. They may, however, require concrete repair if the cracking is so bad that the brick veneer begins to fail.



- **Exposed Cable Ends:** In post-tensioned slabs-on-ground, the ends of the post-tensioning cables may become exposed. When this happens, the anchors that hold the cables in place can become damaged due to corrosion. To prevent the damaging corrosion, a concrete repair should be executed that will protect the anchors.



What is your philosophy of foundation mitigation and repair?

Our philosophy of foundation evaluation can be summarized in the following statements:

- **Most houses that show distress due to foundation movement do not warrant foundation repair.** The reason is that most damage due to foundation movement is cosmetic. Making cosmetic repair is more economical than underpinning the foundation; furthermore, underpinning the foundation is not likely to be effective in preventing future cosmetic damage. In our opinion, foundation repair should be reserved for houses that show true structural damage or *severe* cosmetic and/or functional damage.
- **The cause of the soil moisture changes causing the damaging foundation movement should isolated.** This is the key to mitigating the damage to the house caused by the moisture changes in the soil. The US Army Corps of Engineers recommends that no underpinning be done until the causes of the soil moisture changes have been corrected and some period of time is allowed to pass so the effect of the corrections can be evaluated.
- **The work may have to be repeated because of a failure to isolate the cause of the moisture changes in the foundation soil.** It is not always obvious what the source of the moisture changes in the supporting soil is. One should be prepared for the possibility that the search for the source or sources of the moisture changes may result in a time consuming trial and error process awhile.

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- **Only one remedial measure at a time should be attempted at a time so that its effect on the structure can be evaluated.** The best approach is usually to attempt one remedial measure at a time. It is important to allow some time to pass before attempting another remedial measure so the effect of the first remedial measure can be evaluated.
- **The structure is seldom rebuilt to its original condition.** It is unrealistic to expect that non-structural remedial measures or foundation underpinning can make the house like new. Once a house is damaged by foundation movement, it will always show some evidence of distortion.
- **Remedial measures may not be successful.** Many people naively believe that foundation underpinning will "fix" the foundation. Nothing could be further from the truth. The fact is that some houses cannot be "fixed" regardless of any structural repairs or non-structural remedial measures that are taken.
- **Be prepared to live with what you are buying.** Since it is possible that remedial measures may not be successful, understand that if you buy the house it will be yours and you will have to live with it. Do not purchase a house that shows a level of foundation performance that you are not comfortable with or are not willing to tolerate.

We believe the above approach is consistent with the Texas Section ASCE publication *Guidelines for the Evaluation and Repair of Residential Foundations* and with the US Army Corps of Engineers publication *Foundations in Expansive Soils*.

FREQUENTLY ASKED QUESTIONS ABOUT RETAINING ENGINEERS

What is the difference between a real estate inspection report and an engineering performance evaluation?

From a practical perspective, the difference between a real estate inspection report and an engineering evaluation comes down to what they report if the foundation performance is judged to be inadequate.

- **The Real Estate Inspection Approach:** Under the rules licensed real estate inspectors are required to follow, if they judge the performance of a foundation to be inadequate, the inspector is required to report the foundation as in “need of repair.”
- **The Engineering Approach:** An example of an engineering approach can be found in a publication of the Texas Section of the American Society of Civil Engineers. The guidelines state that if the foundation performance is judged to be inadequate, the engineer should report to his client the options that are available to improve the performance. Those options do include structural foundation repair but also can include non-structural options such as landscaping changes, more or less aggressive watering of the foundation, making cosmetic repairs and/or changes to the house and, if appropriate, doing nothing.
- **Why the Engineering Approach is a More Comprehensive Approach:** According to the US Army Corps of Engineers publication *Foundations in Expansive Soils*, the fact that a foundation is not performing "adequately" does not mean that foundation repair is either necessary or desirable. Nor does it mean that foundation repair will actually improve the performance of the foundation. An engineer has both the training and duty to exercise his engineering and analytical judgment in judging both the adequacy of the performance of the foundation and in reporting what options are applicable for improving inadequate foundation performance. The real estate inspection approach frequently results in a repair recommendation that is both unnecessary and counterproductive. Many real estate inspectors know this. They usually follow the rules by reporting a house that shows signs of damage due to foundation movement as in need of foundation repair but then also recommend a second opinion from a structural

engineer.

What should a homebuyer look for when retaining a Professional Engineer?

When engaging an engineer, your first choice should be an engineer who specializes in foundation performance evaluations for purposes of a real estate transaction. These engineers will usually have an advertisement in the Greater Houston Area Yellow pages under “real estate inspectors.” There is a very limited number of engineers who specialize in this area of practice.

- **Select an engineer who uses an engineering approach that you can understand and are comfortable with.** Some engineers use a damage evaluation approach based mainly on visible cracks, especially on how many there are and how wide they are. Another approach is what I call a levelness evaluation which focuses on how level the finished floor surface is. Either approach, if done by a skilled and experienced engineer who exercises good engineering judgment, is acceptable. But the approach should make sense to you.
- **Obtain a sample report.** Most engineers will provide you with a sample report if you ask for one. It can be E-mailed to you in a few hours. Most engineers do not maintain websites but that is likely to change soon. If an engineer has a website, visit it and you may find you can download a sample report.
- **Select an engineer who has no relation to any foundation repair company.** Do not assume that an engineer has no relation to a foundation repair company. If you want an unbiased report, make sure the engineer you retain is not related in any way to a foundation repair contractor. Be especially wary of any engineer who has a relation to CableLock.

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What is the most important criteria for selecting a Professional Engineer?

When you retain an engineer, you are paying for his judgment. That is true of any professional you retain whether it is an engineer, a doctor or an accountant. When you talk to the engineer on the phone, ask yourself the following questions:

- **Does the engineer sound as if he or she knows what they are talking about?**
- **Does the engineer answer your questions in a manner that you find understandable?**
- **Does the engineer sound as if he or she is a reasonable person?**

HOUSTON AREAS AND SOILS

Below we have provided a list of many subdivisions, developments and areas in the Greater Houston Area with descriptions of the type of soils and foundation problems found in each. Unfortunately, we cannot list every subdivision, but we have listed representative subdivisions in every area of the Greater Houston Area.

Atascocita Area	Loose sandy soils and sandy clays on the surface underlain by impermeable clays with low to high shrink/swell potential. Perched water tables can cause upper soils to loose bearing capacity resulting in foundation distress. There are pockets of the Atascocita Area that have experience severe problems with foundation movement in the past.
Bellaire	The Bellaire area is underlain with clay soils that are highly expansive. High risk that slab-on-grade foundation will be underpinned at some point in the life of the structure. The City of Bellaire no longer permits the use of slab-on-ground foundations although the use of pier-supported slab-on-ground foundations are permitted in some areas of Bellaire.
Brightwater	Highly expansive clays and sandy clays are typical. The shrink/swell potential is high with high risk of foundation distress.
Bunker Hill	Sandy clays, sands and clay soils. The clays are generally moderately expansive. Some faults. Ravines can pose special foundation problems.
Champions Forest	This area is characterized by a number of different soil formations. The soils are generally sandy clays ranging from low to moderate shrink/swell potential. The soils are poorly drained and some formations have perched water tables after heavy rains, especially during the cool months of the year.

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Cinco Ranch	Parts of Cinco Ranch have surficial soils that are clay and some parts have surficial soils that are sand. The clays are highly expansive with a high shrink/swell potential. The areas with surficial sand soils may suffer loss of bearing capacity with a perched water table condition.
Clear Lake Area	Highly expansive clays and sandy clays are typical. The shrink/swell potential is high with high risk of foundation distress.
Copperfield	Loose sandy soils and sandy clays on the surface underlain by impermeable clays with low to high shrink/swell potential. Perched water tables can cause upper soils to lose some bearing capacity resulting in foundation distress.
Cypresswood	Loose sandy soils and sandy clays on the surface underlain by impermeable clays with low to high shrink/swell potential. Perched water tables can cause upper soils to lose some bearing capacity resulting in foundation distress.
Fairfield	Loose sandy soils and sandy clays on the surface underlain by impermeable clays with low to high shrink/swell potential. Perched water tables can cause upper soils to lose some bearing capacity resulting in foundation distress.
First Colony	Highly expansive clays and sandy clays are typical. The shrink/swell potential is high with high risk of foundation distress.
Greatwood	Highly expansive clays and sandy clays are typical. The shrink/swell potential is high with high risk of foundation distress.
Hedwig Village	Sandy clays, sands and clay soils. The clays are generally moderately expansive. Some faults. Ravines can pose special foundation problems.
Heights	Sandy clays, sands and clay soils. The clays are generally stable to moderately expansive.
Hunter's Creek	Sandy clays, sands and clay soils. The clays are generally

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moderately expansive. There are some faults in the Hunter's Creek area. Ravines can pose special foundation problems.

Kelliwood Gardens	Highly expansive clays and sandy clays are typical. The shrink/swell potential is high with high risk of foundation distress.
Kingwood	Generally, the soils in Kingwood are loose sandy soils and sandy clays on the surface underlain by impermeable clays with low to high shrink/swell potential. Perched water tables can cause upper soils to lose some bearing capacity resulting in foundation distress. Some areas of Kingwood, such as the Kings Point area, are underlain with very expansive soils overlain with silty sands interacting with perched water tables.
Kirbywoods	Highly expansive clays and sandy clays are typical. The shrink/swell potential is high with high risk of foundation distress.
Lake Olympia	Highly expansive clays and sandy clays are typical. The shrink/swell potential is high with high risk of foundation distress.
Lakewood Forest	This area is characterized by a number of different soil formations. The soils are generally sandy clays that ranging from low to moderate shrink/swell potential. The soils are poorly drained and some formations have perched water tables after heavy rains and during the cool months of the year.
Memorial	Sandy clays, sands and clay soils. The clays are generally moderately expansive. There are some faults in Memorial. Ravines can pose special foundation problems.
Memorial Northwest	This area is characterized by a number of different soil formations. The soils are generally sandy clays ranging from low to moderate shrink/swell potential. The soils are poorly drained and some formations have perched water tables after heavy rains and during the cool months of the year.
Meyerland	Highly expansive clays and sandy clays are typical. The shrink/swell potential is high with high risk of foundation distress.

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Montrose	The Montrose area contains clays with shrink/swell potentials that range from high to severely high. Most homes in this area are shallow pier and beam construction that will require periodic releveling.
New Territory	Highly expansive clays and sandy clays are typical. The shrink/swell potential is high with high risk of foundation distress.
Northgate Forest	This area is characterized by a number of different soil formations. The soils are generally sandy clays that range from low to moderate shrink/swell potential. The soils are poorly drained and some formations have perched water tables after heavy rains and during the cool months of the year.
Oaks of Devonshire	Loose sandy soils and sandy clays on the surface underlain by impermeable clays with low to high shrink/swell potential. Perched water tables can cause upper soils to lose some bearing capacity resulting in foundation distress.
Oyster Creek	Sandy soils in some areas. Soil conditions are variable with a shallow water table.
Pecan Grove	Highly expansive clays and sandy clays are typical. The shrink/swell potential is high with high risk of foundation distress.
Piney Point	Sandy clays, sands and clay soils. The clays are generally moderately expansive. There are some faults in Piney Point. Ravines can pose special foundation problems.
Plantation Colony/Quail Valley	Highly expansive clays overlaying loose silts and sands are typical. The shrink/swell potential is high with high risk of foundation distress.
River Oaks	Moderately expansive to highly expansive clays with a high potential for excessive foundation movement.
Sharpstown	Moderately expansive to severely expansive clays with a high

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potential for excessive foundation movement.

South Shore Harbour	Highly expansive clays and sandy clays are typical. The shrink/swell potential is high with high risk of foundation distress.
Spring Branch	The Spring Branch Area is characterized by moderately expansive soils that are poorly drained.
Sugar Mill and Sweetwater	The surficial soils consist of highly expansive clays. Below are loose silts and sands. Typically a floating slab foundation is used. Piers can be used on some lots if the underlying soil is suitable.
Tanglewood	Clay soils that are highly expansive. High risk that slab-on-grade foundation will need underpinning.
Twin Lakes	Many of the lots in this area contain fill material necessitating pier-supported slab-on-ground foundations.
Vicksburg	Highly expansive clays and sandy clays are typical. The shrink/swell potential is high with high risk of foundation distress.
West University	Clay soils that are highly expansive. High risk that slab-on-grade foundations will need underpinning.
Westbury	Westbury is underlain by clays that range from moderately expansive to highly expansive. There has been a lot of foundation repair work done in the Westbury area; many houses have been underpinned more than once.
Weston Lakes	Variable soil conditions with highly expansive soils in some locations.
The Woodlands	Loose sandy soils and sandy clays on the surface underlain by impermeable clays with low to high shrink/swell potential. Perched water tables can cause upper soils to lose some bearing capacity resulting in foundation distress.

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Worthom

Loose sandy soils and sandy clays on the surface underlain by impermeable clays with low to high shrink/swell potential. Perched water tables can cause upper soils to lose some bearing capacity resulting in foundation distress.

OTHER SOURCES OF INFORMATION

Below are several sources of additional information concerning slab-on-ground foundation performance and repair.

Websites

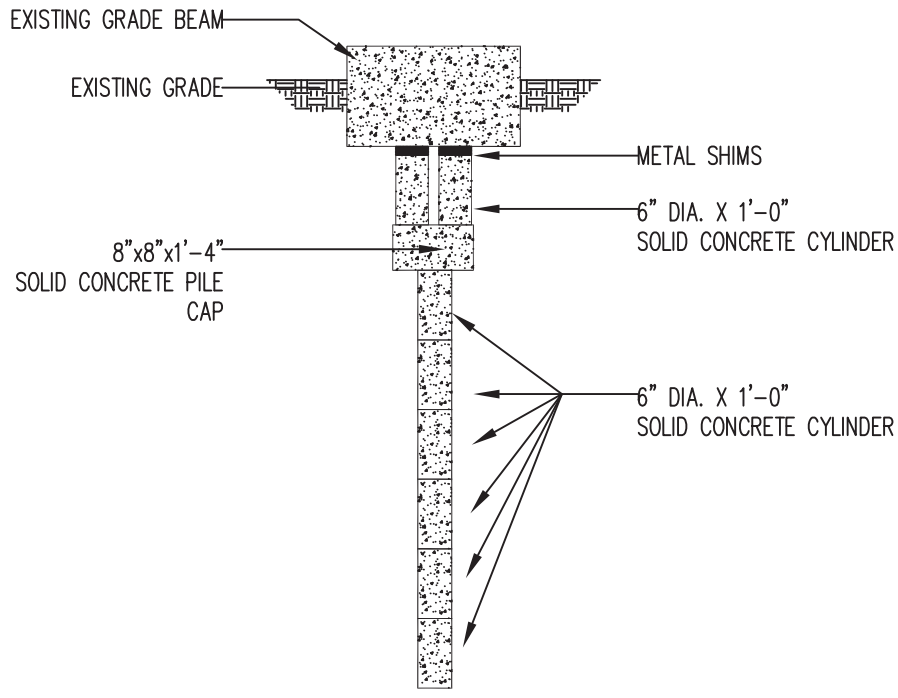
www.houston-slab-foundations.info: This website is the best single source of information for Greater Houston Area home buyers and sellers concerning foundation performance evaluation and repair. This brochure is abbreviated version of this website.

www.fundamentals.com: This is easily the most informative foundation repair website that we know of.

Books for Homeowners

So Your Home is Built on Expansive Soils: A Discussion of How Expansive Soils Affect Buildings; This small book is a gem. The book was written by the Shallow Foundation Committee of the American Society of Civil Engineers. It is written for homeowners in language that is easy for the non-expert to understand. There are only two drawbacks to this book. It does not specifically address the issues commonly seen in real estate transactions and it does not address issues specific to the Greater Houston Area. The book can be ordered online from the American Society of Civil Engineers at www.pubs.asce.org

Has Your House Got Cracks?, 2nd edition; This small book is another gem. It is also written for homeowners in language that is easy for the non-expert to understand. There are, however, three drawbacks to this book. In addition to the same drawbacks applicable to the ASCE book, *So Your Home is Built on Expansive Soils: A Discussion of How Expansive Soils Affect Buildings*, it also suffers the drawback that it was written and published for a British audience. In the United Kingdom, house damage due to foundation movement is normally covered by homeowner's insurance; this is not the case in the United States. The book can also be ordered online from the American Society of Civil Engineers at www.pubs.asce.org



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