GUIDELINES FOR THE EVALUATION OF FOUNDATION MOVEMENT FOR RESIDENTIAL AND OTHER LOW-RISE BUILDINGS

by
The Structural Committee
of
The Foundation Performance Association
Houston, Texas
www.foundationperformance.org

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PREFACE

The Foundation Performance Association (FPA) was formed on an ad hoc basis in 1991 as the Foundation Performance Committee (FPC) by a group of individuals who were involved in the design, construction, inspection, and repair of Foundations of residential Buildings and other forms of light construction. The name was changed in 2001 when the FPA was incorporated as a Texas Non-Profit Organization.

The mission of the FPA may be found at www.foundationperformance.org. To accomplish the mission, a committee is formed for the purpose of assembling the information available in the industry on a selected subject, and compiling it into a document, which is then made available to the public.

Prior to the incorporation of the FPA in 2001, its predecessor (FPC) published a document titled *Criteria for the Inspection of and the Assessment of Residential Slab-on-Ground Foundations*, document FPC-201-97 [11], and FPA published a revised document No. FPA 201-2001, Supplement #1, *Criteria for the Inspection of and the Assessment of Residential Slab-on-Ground Foundations,* Presentation Paper by Don Lenert, June 19, 2002 [10]. This document contained recommendations, not only for the inspection of such Foundations, but also for the assessment of their performance. Document FPC-201-97 was included as a part of the background documentation for the formation of this document. This document FPA-SC-13, when published as Revision 0, superseded FPC-201-97.

In 1998, the Texas Board of Professional Engineers formed a committee that published a Policy Advisory 09-98-A [12] regarding the design, evaluation and repair of residential Foundations. This Advisory Policy was later withdrawn and the Texas Section of the American Society of Civil Engineers (ASCE, Texas Section) then formed a committee to create technical guidelines. On 1 January 2003, ASCE Texas Section published a document titled *Guidelines for the Evaluation and Repair of Residential Foundations, Version 1* [4]; *Version 2* [3] of the same document was adopted by ASCE Texas Section on 1 May 2009 and contained substantially the same performance criteria as Version 1.

The Structural Committee is a standing committee of the FPA. At the time of writing Rev. 0 of the FPA-SC-13 document, Ron Kelm chaired the Structural Committee and 25 to 35 members were active on the committee during that period; 45 to 55 members were active during the writing of Rev. 1 of the FPA-SC-13 document. The Structural Committee sanctioned Rev. 0 in February 2003. An ad-hoc subcommittee was formed to create both documents. After Rev. 0 of the FPA-SC-13 was created, it was peer-reviewed and subsequently published on July 2007 as FPA-SC-13-0.

In August 2012 the Structural Committee sanctioned this Rev. 1, a revision of the Rev. 0. An ad-hoc subcommittee was formed to perform this revision. After the Rev. 1 document was revised, it was peer-reviewed and published. The document is freely available to the public at www.foundationperformance.org. To ensure this document remains current, it may be updated under the same document number but with higher suffix such as -2, -3, etc.

The subcommittee chairs and members are listed on the cover sheet of this document and are considered the document's authors.

Peer-review, of Rev. 0 and Rev. 1, was by FPA members and other select professionals familiar with Foundation performance.

The primary changes over the previous Revision 0 of this Revision 1 document include:

- Clarified how the Effective Length is to be used in the procedure.
- Required that a Contour plan or cross section analysis be used to analyze Deflection when the Foundation's performance requires checking against the Deflection Limit.
- Removed the k factor option that was previously offered to reduce the Deflection Limit in cases where the profile chosen was not on a principal axis of the Foundation.
- Provided an example showing the user how to follow the evaluation procedure from start to finish, including field observations and measurements, documentation of the site, floor plans, Phenomena, Elevations, Level Distortion Contours, Slopes, etc., and analyzing Deflection and Tilt based on chosen profiles, comparing the results with the Deflection and Tilt Limits.
- Updated the spreadsheet software available to the FPA members for analyzing Deflection and Tilt per the procedure. The update included allowing more input Data Points and ensuring the minimum Effective Length is not violated. Additional output is now provided on the spreadsheet.

The subcommittee had authored a Microsoft Excel spreadsheet in order to augment this document. An updated spreadsheet was developed for Revision 1 and vetted by the subcommittee and was made available during the FPA Peer Review process. The final version of the spreadsheet contains sample calculations and is provided as a courtesy to FPA members at www.foundationperformance.org with no guarantee of its accuracy.

> Note: The spreadsheet has not been subjected to the FPA peer review process. If "bugs" are encountered in the spreadsheet software, please provide that information to the Structural Committee chair. The Structural Committee may change the spreadsheet and add a revision date without the need for an FPA peer review. In the event of a conflict between this document and the spreadsheet, this document will take precedence.

Suggestions for the improvement of this document should be directed to the current chair of the Structural Committee. If sufficient comments are received to warrant a revision, the Structural Committee will form a new subcommittee to revise this document. If the revised document successfully passes FPA peer review, it will be published on the FPA website, superseding the previous revision.

This document is specifically written to be used by or under the responsibility of Licensed Professional Engineers. The intended audience for this document also includes Inspectors, Foundation repair contractors, builders, owners, attorneys, and others that may be involved in the evaluation of Foundation Movement of Buildings.

This document was prepared to assist in the evaluation of Foundation performance. The criteria in this document are not intended to supersede engineering judgment.

This document was created with generously donated time in an effort to advance the knowledge, performance, and standards of engineering, construction, and repairs related to Foundations, soils, and structures, particularly with respect to the analysis of Foundation performance. The text in this document represents the opinions of a majority of the subcommittee members and may not necessarily reflect the opinions of every subcommittee member, Structural Committee member or FPA member at the time of, or since, this document's publication. The FPA and its members make no warranty regarding the accuracy of the information contained herein and will not be liable for any damages, including consequential damages, resulting from the use of this document. Each project should be investigated for its individual characteristics in order to determine the appropriate application of the information contained herein.

Please refer to the FPA's website at www.foundationperformance.org for other information regarding this and other FPA publications.

1.0 INTRODUCTION

The purpose of this document is to:

1. Provide guidelines for acquisition of Foundation performance data;
2. Provide guidelines to aid in the evaluation of the performance of a Foundation;
3. Propose Deflection and Tilt Limits for Foundation Movement.

This document applies to monolithic concrete Foundations of Buildings. The performance and serviceability of monolithic concrete Foundations has been discussed and analyzed for more than 30 years. The Foundation's primary job is to support the Superstructure.

A majority of Buildings are supported on monolithic slab-on-ground concrete Foundations. Many of the other constructed Foundations are shown in document FPA-SC-01-0 [5].

All Foundations experience some degree of movement. Even when designed, constructed, or repaired in accordance with comprehensive geotechnical and accurate load information, a properly designed and constructed Foundation is not only likely, but also expected and designed to move differentially. In most cases, movement begins the day the Foundation's concrete is placed, and is likely to continue throughout the life of the Building.

Foundation performance has been analyzed, categorized, and quantified by various codes, articles, organizations, private groups, and trade standards. However, when viewing the variety of analytical procedures and the problems associated with analyzing Foundation performance, it is apparent that a consensus for analysis has not been achieved. This FPA-SC-13 document attempts to move the industry toward such a consensus by presenting a peer reviewed procedure, which has been developed and revised by various stakeholders, and includes the presentation of various definitions, levels of investigation, guidelines for data acquisition, presentation of data, and prescriptive criteria for Foundation Movement, coupled with the guidelines for computation.

Design limits are not the same as performance limits. While the subcommittee considered design Deflection Limits in developing this document, the user should be aware that the performance limits given in this document might not be in agreement with the Deflection or Tilt Limits that may have been used for a particular design. Instead, the performance limits established in this document were based upon review of dozens of case histories that complied with this document's guidelines for processing the data. These case histories consisted of Foundations that the submitting subcommittee members believed had experienced either acceptable or unacceptable performance, thereby establishing the final limiting performance limits.

If the practitioner does not collect and analyze the data in accordance with this document, then the performance limits provided herein may not apply.

Nearly all Foundation Movement occurs as a result of movement of the supporting soil. Soil that is expansive can rise or fall at the surface by comparatively large amounts, sometimes as much as 12 inches or more. Often movements are not detected or detrimental because they are sufficiently uniform throughout the Building Foundation. However, soil movement can be non-uniform, causing differential movement of the soil supporting the Foundation. If the anticipated differential movement was properly reported in a geotechnical report, a properly engineered and constructed Foundation will have been sufficiently stiffened and reinforced to resist a portion of the differential soil movement so that the Negative Phenomena that occurs is reduced and the Superstructure remains functional.

Many types of soil movement cause Foundation Movement. Three of the more common types of movement causing Negative Phenomena in residential and other low-rise structures include Settlement, Subsidence, and Heave.

The most effective way to stop distress in the Superstructure due to differential Foundation Movement would be to eliminate movement of the soil. Since this is not practically possible, a reasonable option is to design a Foundation that will allow for predicted Foundation Movement and perform within acceptable limits.

Older structures typically show more distress than newer structures. This document may be used to investigate and evaluate a Foundation of any age, though, as the Foundation ages, it can become increasingly difficult to accurately determine the cause(s) of Foundation Movement due to the often incomplete history of the structure, the increased probability of past Foundation and Superstructure repairs, and /or the possibility that there is more than one cause of Foundation Movement.

It is recommended that buyers of Buildings obtain a Baseline Elevation survey, which may be found useful if Foundation Movement should occur in the future.

See Section 2.0 for definitions of commonly used terms in this document, Section 3.0 for guidelines on the three levels of investigations, Section 4.0 for guidelines on acquiring data, Section 5.0 for guidelines on data analysis and presenting the data, Section 6.0 for guidelines for determining if the Foundation Movement is within the Foundation Movement limits, Section 7.0 for the summary, procedure and conclusions of the document, and Section 8.0 for the references.

2.0 GLOSSARY

For the purposes of this document capitalized terms are defined as follows:

Benchmark is a specially installed Reference Point near the Foundation and is intended and assumed to have zero or negligible movement for the monitoring activities. A Benchmark may be installed in cases where the direction of Foundation Movement is not easily diagnosed. If a Benchmark is used, the Elevation of the interior Reference Point is recorded relative to the Benchmark during each site visit. When a specially installed Reference Point is not feasible, a Benchmark may be selected as a designated point on a surface convenient to the subject Foundation. It should be noted that trees, fire hydrants, curbs, light stanchions, manhole covers, etc., have been shown to move significantly relative to Foundations and are usually not reliable choices for a Benchmark.

Building is a residential or other low-rise structure.

Contours are lines that connect points of equal Elevation. Contours may be drawn on an Adjusted Elevation Plan or Level Distortion Plan to determine the Elevation changes of the Foundation, or on a Time-change Elevation Plan to determine the direction and magnitude of movement over a specific time period. Contours should be plotted in equal vertical intervals that are greater than or equal to the data collection accuracy and should never cross.

> ***Extrapolated Contours*** are lines that extend Contours or connect two Contours across an area where no Data Points exist. The Extrapolated Contours should be dashed to differentiate them from the Contours based on measured Elevations. The Extrapolated Contours should not be used for Deflection and Tilt calculations.

Crack is a Separation on the surface of a material along which a split has occurred without breaking into separate parts.

Data Point is the location where an Elevation is measured.

Datum (see *Reference Point*).

Deflection is the post-construction vertical displacement of a structural element due to bending. The Deflection at any point within the Effective Length is the measurement of the vertical translation of that point from its initial to its deflected position. As shown in Figure 6.4.1-1 and in Section 6.4.2, examples A, B and C, Deflection is the vertical distance between point 2 on the deflected surface and a line L_{13} that connects two end points 1 and 3 on that surface. Note: Actual Deflections are perpendicular to the chord line L_{13}. Since the difference in magnitude between the actual Deflections and the measured Deflections is inconsequential, this difference is neglected in the procedure.

> ***Deflection Ratio*** is defined as the Deflection divided by the horizontal distance over which the Deflection occurs, and is used as limits of acceptance when evaluating Foundation Movement.

Deflection Limit is defined as the Effective Length divided by a specified number, and is used as limits of acceptance when evaluating Foundation Movement. Additional information is provided in Section 6.2. Deflection Limit is equal to the length times the Deflection Ratio. The Deflection Limit is $\frac{1}{360}$L (0.0028L or L/360).

Distortion is any deviation from level. Distortion can include deviations from as-built construction and/or subsequent Survey Elevations.

Effective Length is the length of a straight line (L) drawn through a minimum of three points in the Adjusted Elevation Plan. Two of the points are end points of the line and the third point is between the two end points as shown in the sketches in Section 6.4. *The Foundation Performance Association recommends that the minimum Effective Length used for determining Deflection be 20 feet or the width of the Foundation, whichever is less.*

Elevation of a Data Point is the measured vertical height above (+) or below (-) the Reference Point.

Adjusted Elevations is a set of Data Point Elevations, some of which are vertically translated to adjust for changes in floor covering thicknesses, design Slopes and steps. The purpose of adjusting the Data Point Elevations is to provide a common reference plane across the surveyed areas. The translated Data Point Elevations annotated onto a scaled floor plan is called an Adjusted Elevation plan. This plan should include the date of measurement, the address or location, the person or organization measuring, the vertical units, and the horizontal scale. If no Survey Elevation plan is included in the report, the differences in the floor covering thicknesses should be provided on the Adjusted Elevation plan.

Baseline Elevations is the first Elevation readings of a particular set of points in the Building to which future measurements can be compared.

Initial Elevations are the first Elevations recorded, and should be taken after floor finishes are installed, preferably just prior to occupancy. If Initial Elevations are recorded, they are considered Baseline Elevations. Elevations recorded immediately after Foundation placement should not be considered Initial Elevations.

Level Distortion Elevations are measured vertical Distortions from an assumed level Foundation. These Elevations are a special case of the Time-change Elevations for which Initial Elevations were not recorded or are unavailable and all Data Points of the as-built Foundation are assumed to have been at the same Elevation, i.e. the Foundation is assumed to have been built level. The Level Distortion Elevations should be based on Adjusted Elevations and indicate the Foundation’s current Distortion from level at each Data Point.

Survey Elevations are the set of raw (unadjusted for flooring thickness, steps, and constructed Slopes) Data Point Elevations recorded during an Elevation survey. When annotated onto a scaled floor plan it becomes a Survey Elevation plan.

Time-change Elevations are the changes in Elevation of Monitor Points over a Monitor Period. Each Time-change Elevation is determined by subtracting the earlier Elevation of a particular Data Point from the more current Elevation of the same point. Only equivalent plans may be used to calculate the Time-change Elevations; i.e. it is not correct to calculate Time-change Elevations between an Adjusted Elevation Plan and a Survey Elevation (i.e., unadjusted) plan. The Time-change Elevations should be recorded on a scaled floor plan and should include the dates of the two sets of data used, the name of the person or organization that recorded the data, and any assumptions made in the comparison of the two sets of data that may not be obvious to someone reviewing the Time-change Elevations.

Forensic Engineer is a Licensed Professional Engineer who performs an evaluation (minimum Level B, see Section 3.2) of the foundation, including investigation and testing as needed to determine the cause or causes of the issues being evaluated.

Foundation is defined as a system that is a combination of materials designed to work together to provide a base that supports a Superstructure, while transferring loads to and from the soil below.

Foundation Movement is vertical Elevation change that occurs after construction.

Heave is upward movement of an underlying supporting soil stratum usually due to the addition of water to an unsaturated expansive soil in the active zone. When moisture is added to a soil with clay content, expansion occurs within the structure of the soil, and the corresponding area of the Foundation and Superstructure is moved upward. Heave normally only occurs within clayey soils that have a high swell/suction potential and an available moisture source. Heave is the reverse process of Subsidence.

Inspector is a person who is qualified to collect pertinent data relative to a Foundation's performance and who may be licensed by the State or other governing authority or working under the supervision of such a licensed person. Forensic and Structural Engineers are considered Inspectors.

Monitor Period is the time between any two Elevation surveys.

Monitor Point is a Data Point at the top of the floor covering or Foundation surface that is easily found again, such as a corner of a room or under a ceiling light fixture. Monitor Points should not be located on a wearing surface, such as a high-traffic carpeted area in a doorway. Monitor Points are normally distributed over the entire surface of the Foundation as described in Section 4.4.3.

Negative Phenomena are the observable symptoms of distress that may have been caused by Foundation Movement. Such distress includes Separations, Cracks, or other symptoms. Negative Phenomena are further classified by the following:

> ***Architectural Phenomena*** are defined as Negative Phenomena such as Cracks, Separations, and other damages that are often noticeable by the Building's occupants. Separations typically become noticeable at approximately 0.02" (0.5mm) in drywall and stucco and 0.04" (1.0mm) or wider in concrete or masonry. Architectural Phenomena are sometimes referred to as "cosmetic phenomena".

> ***Functional Phenomena*** are defined as Negative Phenomena affecting the use of the Building. Examples are doors or windows that leak, stick, or will not close, and doors which open or close on their own (i.e., ghosting doors). Some other examples include noticeable floor Slopes or wall tilts, tilted countertops, vertical pavement offsets sufficient to cause tripping, bricks or other components in danger of falling, standing water, leaking walls and roofs that allow water intrusion, and non-functioning essential equipment and services such as HVAC, plumbing and electrical.

> ***Structural Phenomena*** are defined as Negative Phenomena affecting the ability of the Building to support normally imposed loads. This would encompass Separations or Distortions to structural support members such as studs, columns, beams, or Foundation, such that the member can no longer carry its intended design load with an adequate safety factor.

Reference Point (also, Datum or Reference Datum) is the location used as a baseline in computing Initial Elevation differentials or Time-change Elevations over the Foundation. The Reference Point may be the Benchmark, or it may be an interior or exterior Data Point that may move up or down but is assigned an arbitrary value such as 0.0". The Reference Point is typically located near the center of the Foundation.

Separation is the moving apart of two adjacent building materials, or at a joint of common building materials. The opposite of a Separation is a buckling, bulge or compression ridge caused by building materials moving together in compression.

Settlement is downward movement of an underlying supporting soil stratum due to loading from above in excess of the bearing capacity of the soil below. When the vertical loads from above exceed the bearing capacity of the soil strata directly below the Foundation, the Foundation and Superstructure move downward. Encompassed in Settlement are a) immediate elastic consolidation and Distortion of granular or clay soil particles, b) Slope instability, c) soil erosion, d) fault movement, and e) long-term consolidation resulting from gradual expulsion of pore water from voids between saturated clay soil particles. Settlement may occur in all types of soils.

Slope (%) is the difference in Elevation between two points divided by the horizontal distance between them (rise over run as a percentage). Slope may be the result of differential movement, the result of original construction or a combination of these factors.

Structural Engineer is a Licensed Professional Engineer who performs an evaluation of the Foundation to determine the performance of the Foundation and the advisability of Foundation repair.

Subsidence is downward movement of an underlying supporting soil stratum due to the withdrawal of moisture. When moisture is extracted from the soil, shrinkage occurs within the structure of the soil, and the corresponding area of the Foundation and Superstructure moves downward. Subsidence normally occurs within clayey soils and is often the result of soil desiccation caused by trees or other large vegetation, particularly during drought conditions. Subsidence is the reverse process of Heave.

Superstructure is defined as the Building components above the Foundation, the structural framing and the architectural coverings for constructed structural elements such as the floor, walls, ceilings, and roof.

Tilt is defined as a post-construction planar rotation, measured over the entire length, width, or diagonal of the Foundation. Refer to Section 6.3, Figure 6.4.1-1 and Section 6.4.2 for more information.

> ***Tilt Limit*** is defined as 1.0% measured over the entire length, width, or diagonal of the Foundation. It is calculated as the difference of the Elevations of two end Data Points divided by the distance between the points.

3.0 LEVELS OF INVESTIGATION

There are three levels of investigations, based on ASCE Texas Section's *Guidelines for the Evaluation and Repair of Residential Foundations* [3] [4] that may be performed in assessing the performance of a Foundation. Level A requires a broad visual overview, normally used in real estate inspections. Level B requires a more in-depth forensic investigation. Level C is a forensic level investigation that is normally used in instances where a more accurate cause of damages is required such as in legal disputes. Level C should be performed under the supervision of a Forensic Engineer.

The client and/or the Inspector/Structural Engineer/Forensic Engineer typically establish the required level of investigation. The Inspector is generally expected to recommend and perform the lowest level of investigation needed for adequate review of the situation. If a report is issued, it may state which level of investigation has been conducted. Use of the guideline proposed in Section 6 of this document requires either a Level B or Level C investigation. The following are the three levels of investigation outlined in the ASCE Guidelines [3] [4] with some additional recommendations by the Foundation Performance Association.

3.1 LEVEL A INVESTIGATION

A Level A investigation is one of first impressions. This type of investigation requires the following actions:

- Interview the occupant, owner and/or client, if possible, regarding a history of the property and performance of the Superstructure and Foundation
- Document visual observations made during a physical walk-through
- Observe factors influencing the performance of the Foundation

If the client requests a report, it should contain the following:

- Date of investigation
- Scope of services
- Observations
- Discussion of factors identified as influencing the Foundation performance and rationale in reaching opinions concerning the Foundation
- Conclusions and, if requested, recommendations for further investigation, remediation, or preventative measures

3.2 LEVEL B INVESTIGATION

In addition to the items included in a Level A investigation, a Level B investigation typically includes the following actions:

- When available, review pertinent documents including geotechnical reports, construction drawings, field reports, repair documents

- Provide relative Foundation Survey Elevations on scaled drawings, along with Contours per Section 5.4, and/or cross sections per Section 5.8, and Deflection and Tilt calculations to assess performance and establish a baseline
- Description of factors that affect soil moisture such as locations of large trees and other vegetation and locations of poor site drainage
- Document the analysis process, data, observations, and conclusions
- If requested by the client, provide a written report, which may contain, in addition to the items listed above under a Level A report, any or all of the following: a list of the reviewed documents, Site Plans, Survey Elevation plans, Contour plans, Negative Phenomena plans, and the bases of all presented conclusions.

3.3 LEVEL C INVESTIGATION

In addition to the items included in Level A and Level B investigation, a Level C investigation includes additional services, and testing deemed appropriate by the Engineer. These may include, but are not limited to, the following:

- Site specific geotechnical sampling and testing
- Hydrostatic leak test, with leak location and flow test if applicable
- Groundwater Monitoring
- Concrete coring, Petrographic Analysis and other material testing
- Post tensioning cable testing or steel reinforcing survey
- Historical aerial photographs review
- Foundation Excavation and observations of cut and fill
- Topographic Maps
- Site photographs
- Detailed Negative Phenomena plan
- If requested by the client, provide a report per the requirements under Level B, incorporating the above data
- Water Chemistry
- Rainfall Data

4.0 DATA ACQUISITION

Following is a discussion of the examination guidelines that are typically employed during the investigation of a Building Foundation.

4.1 INTERVIEW

The owner, occupant, and/or client, if available, should be interviewed for any information concerning the history and any known present or past problems with the Building or site.

4.2 PREPARATION OF THE SKETCH OF THE BUILDING PLAN

A drawing or a sketch of the floor plan of the Building may be made or acquired. Where applicable, the plan may be of the Building alone or it may include appropriate features in the yard, such as outbuildings, patios, driveways, sidewalks, trees, felled trees, swimming pools, previous foundation repair locations, planter beds, drainage ditches, and/or swales and berms.

It is prudent to make the drawing to scale since proportionality can become an important factor in Foundation Movement evaluation. The sketch or drawing must be to scale for use in Levels B and C investigations. The drawing should include interior walls.

4.3 NEGATIVE PHENOMENA PLAN

A Negative Phenomena plan documents all Negative Phenomena observed in a Building, or on the Building’s site, at the time of the site investigation.

Unlike Elevation measurements, Negative Phenomena are generally observed and recorded on all levels of the Building’s interior, as well as on the exterior. Exterior Negative Phenomena can be recorded on a site plan or floor plan and interior Negative Phenomena should be recorded on an appropriate floor plan. In addition to recording a Negative Phenomenon’s location, other information may be included, such as whether the Negative Phenomenon is located in the ceiling or floor, above or below a window or door or at mid-height, the direction of the Slope of an out-of-square door, and whether evidence of a previous repair is observed. Widths of Cracks or Separations may also be recorded.

Photographs of the Negative Phenomena are not required for Levels A and B investigations. However, if the client desires the physical record or the Inspector believes it is necessary, it is recommended that Negative Phenomena be photographically recorded. Whether to photograph all Negative Phenomena or a select few of the more pronounced Negative Phenomena should be at the discretion of the Inspector and the client. Photographs may later be useful if monitoring is done, to help determine whether or not changes to Negative Phenomena have occurred.

4.4 ELEVATIONS

This section details the steps involved in obtaining floor Elevations using an Elevation-measuring device for the purpose of determining the levelness of the Foundation for use in this procedure. Recommendations are given for the number of measurements to record and the guideline for doing so.

4.4.1 Equipment

Floor Elevations should be measured using a level measuring device utilizing a base unit set to read to a precision of no greater than 1/8", i.e. with an accuracy of ±1/16" or less. A spirit or carpenter's level or equivalent may be useful to determine levelness of countertops, doorframes, window stools, wall plumb, etc., but is not sufficient to provide information to create an Elevation plan. Equipment should be calibrated, maintained and operated according to the manufacturer's instructions to help ensure accurate measurements. The type of equipment used to make the measurements and the advertised accuracy of the equipment should be stated in the report.

4.4.2 Choosing a Reference Point

Unless a Benchmark is available, a point should be chosen for the Reference Point and all readings recorded relative to the Reference Point. More than one Reference Point (turning point) may be used due to line-of-sight or accessibility limitations but the possibility of error may be increased with each new setup. Because the cord of the typical digital fluid level is limited in length, it is recommended that the Reference Point be centrally located in order to allow the Elevations to be recorded with a minimum number of Reference Points, thereby reducing the possibility of measurement errors. In addition, the center portion of the foundation is generally less susceptible to Foundation Movement.

The selection of the location of the Reference Point should consider past locations, ease of re-location at future inspections, within reach of all areas to be measured, floors not sloped, floor covering transition, and hard flooring surface. A location in a corner or next to a column near the center of the Building is ideal. The location of the Reference Point should be recorded on a floor plan along with the subsequent measurements. If prior Elevations are available for the Building, calculations will be simplified by using the same Reference Point used in the prior survey, especially if the Reference Point has not moved vertically.

If a Reference Point, rather than a Benchmark is used, it should be anticipated that the Reference Point may move vertically over time.

4.4.3 Recording Elevations

When recording Elevations, the following should be considered:

a) All Elevations are recorded at the top of floor coverings and are relative to the Reference Point. To facilitate future measurements by others, the recorded Elevations should indicate whether the documented Elevations are at the top of the floor coverings or if they have a correction applied to adjust for different floor covering thicknesses and steps.

b) When future Survey Elevations are a possibility it is helpful to record Elevations on sloped areas such as those in attached garages and monolithic porches. In these areas, it is particularly important to clearly note the floor covering on which the Elevation at the Reference Point was taken, as well as the magnitude of any floor covering thickness adjustments that were made to Elevations taken on these sloped areas. It is also important to note whether there is any covering, such as brick or tile, on porch areas, since such coverings may be added between surveys.

c) The exact density of measurements is dependent upon the size, layout, and Slope of the Building Foundation, as well as the purpose of the measurements. Given these variables, readings should be taken every 30 to 100 square feet, if practical. Ideally, this would include a measurement in each corner of each room and the middle of larger rooms. Measurements should be taken near masonry fireplaces and other heavily loaded areas. The adequacy of the number of Monitor Points to be recorded is left to the Inspector’s discretion.

d) The Elevations should be recorded on the floor plan next to a symbol (such as a dot or a star) representing the location of each Data Point. A larger, unique symbol and/or text should be used for the Reference Point to help future monitoring Inspectors identify and use the same Reference Point.

e) Floor plans in the form of architectural drawings or prior Elevation plans may be utilized if they are representations of the actual layout of the Building. If no floor plans are available, the Inspector will need to measure and sketch a scaled floor plan for presentation purposes.

f) When floor coverings change or steps are encountered, from carpet to vinyl, for example, adjacent measurements should be taken and recorded on both floor coverings to determine the height difference. Because this height difference can vary by several tenths of an inch in the span of a doorway, it is more exact to take several measurements on each side of a flooring change and use the average of the readings.

g) During the course of the measurements, return to the Reference Point periodically to ensure that the survey equipment still reads the same. If the reading has changed, the survey instrument should be reset and previous measurements checked.

h) Typically, measurements are only recorded on the first level of a Building; however other floors may also be measured, if desired.

i) If a prior Elevation plan is available, measurements should be recorded in the same locations as the previous Elevation plan to allow the possibility of computing Time-Change Elevations. Additional measurements may be taken if the prior plan did not record the proper quantity of measurements.

j) If Survey Elevations are not taken on top of floor coverings, but rather were measured from other surfaces such as the ceiling or garage curbs, it should be stated as such on the Survey Plan.

k) If Level Distortion Elevation plans include Adjusted Elevations or Contours in stepped or sloped areas of the Foundation, the assumed design step heights or foundation Slopes should be quantified on the plans.

When recording Elevations for multi-family dwellings, also consider the following:

- Multi-family dwelling Elevation surveys should be provided in a manner similar to those described above for single-family surveys with the additional considerations: Elevations at both sides of the common wall as near to each other as possible will allow the Elevations throughout the Building to be corrected to one Reference Point. Survey turning points across dividing walls between adjacent units are recommended so that the survey is continuous over the entire Foundation area. Thus, measurement Data Points in a multi-family dwelling may need to be more closely spaced than for a single-family dwelling.

- The examination of the performance of the Foundation of multi-family dwellings can present unique problems, which often require a significant amount of planning and execution. For example, access to the interior of a single-family dwelling for the purpose of acquiring Foundation Elevation measurements is straightforward; whereas, the access to a number of multi-family units in an orderly manner requires coordination between the individual occupants. In apartment Buildings, the manager may have keys and maintenance personnel who can assist in the entry processes. In adjoining townhomes and condominiums, however, the Inspector may be required to employ others to perform such coordination. If access is not provided to all of the first floor units, the analysis may be compromised.

- The results of the Building surveys (Elevation and Negative Phenomena) should be superimposed on the floor plans of the conjoined units. An ideal situation exists where floor plans are made available, in the form of Building plans or advertisement brochures.

5.0 DATA ANALYSIS AND PRESENTATION

Items included in the data analysis may consist of a visual analysis, Elevation analyses, and non-destructive and destructive testing. Report drawings should include the following information:

a) Scale and scale bar (graphic scale)
b) Amount and location of the vertical adjustments (such as floor coverings and vertical floor offsets)
c) Date of the measurements
d) Whether the Elevations are at the top of the floor coverings or if they have a correction applied to adjust for different floor covering thicknesses and steps and the amount of each correction
e) The type of floor finish should be shown on the Elevation Plan.

5.1 VISUAL ANALYSIS

Visual observation, used for Level A, B and C investigations, is the oldest and the basic method for evaluating Foundation performance. It is based upon the premise that symptoms of Foundation Movement can be seen and judged by the eye or sensed by walking the floor. Symptoms of Foundation Deflection may include, but are not limited to, Cracks in exterior veneer, Separations of upper trim boards, Separations at the junction of brick veneer and window and door frames, Cracks and buckling/bulge/compression ridges on interior walls and ceilings, out-of-square door frames, out-of-level countertops and window stools, Separations of framing members, and sloping floors.

It should be noted that not all distress is necessarily caused by Foundation Movement. For further information on this, see document FPA-SC-03-1, *Distress Phenomena Often Mistakenly Attributed To Foundation Movement* [7].

5.2 SURVEY (UNADJUSTED) ELEVATION PLAN

A Survey Elevation plan presents the Elevation data, unadjusted for changes in floor cover thicknesses and steps that were recorded per the above sections. The inclusion of the Survey Elevation plan is not necessary, but may later be useful for comparing subsequent Elevation surveys, i.e. monitoring and for verifying the Elevation adjustment calculations. It is recommended that the Inspector keep all raw Elevation data, as well as notes of any adjustments made to the data to create an Adjusted Elevation plan.

5.3 ADJUSTED ELEVATION PLAN

An Adjusted Elevation plan presents the Elevation data, adjusted for changes in floor cover thicknesses and steps. This plan type is useful to represent the true Level Distortion of a Foundation.

5.4 CONTOUR PLAN

It is often advantageous to use the Adjusted Elevation or Time-change Elevation data to create Contours. Contours provide a visual guideline of determining deviations from levelness, amount of Slope and Slope direction, aiding the user in quickly identifying the critical profiles to make objective performance measurements. Much like a topographic map shows mountains and valleys, a Contour plan graphically shows the Elevation differences across the Foundation. Where the surface is relatively flat, the Contour plan may not be useful. It is more meaningful in areas where the Elevation differentials are more pronounced.

Contours lines drawn either manually or with the aid of computer software. Data Points of equal Elevation and the interpolated value of equal Elevation should be connected to form smooth lines or curves and labeled. For example, points that are 1.5” (or 0.5”, 1.0”, etc.) above the Reference Point should be connected and labeled as +1.5” (or +0.5”, +1.0”, etc.).

When drawing Contours it is important to consider the number of Elevation points and the level of accuracy of the survey instrument used to make Elevation measurements. To account for this level of accuracy, it is typical to draw Contours in 0.1” to 0.5” increments when documenting a survey showing Time-change Elevations between an as-built survey and a reasonably current survey. The increments should be equal to or greater than the accuracy of the surveying instrument, coupled with other probabilities of measurement error, such as each survey being done by different personnel or companies. For example, if the accuracy of the equipment plus data retrieval process is 0.2” (i.e. + or – 0.1”), the Contour increments should not be less than 0.2”.

Contour lines should only be shown where there is survey data. Where survey data is not available, Contour lines may be extrapolated and shown as dashed lines through these areas. Extrapolated Contours should not be used for Deflection and Tilt calculations.

Because of the minimum Effective Length required per Section 6.2, it makes little sense to use a very fine increment in the Level Distortion Contours since some will have to be skipped in the analysis. Unless a Benchmark is used, Contours alone may not indicate whether Heave or Subsidence has occurred. A Contour of -0.5” indicates that the Elevation along the line is one-half inch lower than the Datum, not that the area has translated 0.5” downward. However, when no Benchmark is used, the examination of the Contour plan or the Adjusted Elevation plan, in conjunction with the Phenomena plan discussed above and other information such as sewer leaks or other anomalies correlated with geotechnical information, historical aerials, drainage issues, etc. or other anomalies may allow a Forensic Engineer to opine whether Heave or Subsidence has occurred.

A Contour plan or cross section analysis must be used to compare actual performance with the performance limits in Section 6. This plan provides the necessary smoothing of the survey data that normally contains inconsistencies from the construction of the Foundation and floor covering and inaccuracies of the Survey Elevations. Use of Slope arrows drawn approximately perpendicular to the more critical Contours (see Section 6.6.3 for example) may be useful to identify the critical profiles to analyze.

5.5 TIME-CHANGE ELEVATION PLAN

A Time-change Elevation plan illustrates the changes in Elevations between two Elevation surveys, each recorded on a different date. To make a Time-change Elevation plan, subtract the older measurement from the more recent measurement to determine the Time-change Elevation at each Data Point. The result should be recorded on a floor plan next to a symbol (such as a dot) showing the exact location of the measurement. The dates of both measurements and the names of the companies or individuals that made the measurements should be noted on the drawing.

The most accurate means of evaluating direction of Foundation Movement for a Time-change Elevation plan is by referencing a Benchmark.

Foundation Movement can be evaluated by a Time-change Elevation plan by using a prior survey and the current Elevation survey. If an as-built or other prior Elevation survey is not available or if it is desired to have a Foundation Level Distortion plan, for convenience of calculation the Foundation may be assumed to have been placed in a level condition or within construction tolerances if sufficient data is available to evaluate such (see Section 5.7). This should be done with the understanding that new Foundations are rarely level and often move during construction. This understanding should be noted on the drawing or in the report.

Note that when comparing a current Elevation survey to an as-built Elevation survey, different floor-covering thicknesses must be measured and taken into consideration when calculating the Time-change Elevation. For example, if the surface is covered in tile and carpet, with the carpet 0.5” higher than the tile, rather than assuming all Elevations are 0.0” at the time of construction, one must assume that the carpeted areas had an as-built Elevation of 0.5”. When an as-built Elevation survey exists, it is more accurate to compare only the measurements made in corners or other easily duplicated locations.

In order to develop a Time-change Elevation plan, the Forensic/Structural Engineer must be assured that the comparison is based upon two Survey Elevation plans or two Adjusted Elevation plans. It must be determined whether the prior plan is a Survey Elevation plan or an Adjusted Elevation plan. If the survey type is not noted on the drawings or in the report, it may be determined by checking differences in Elevation measurements at floor covering changes. If adjacent Elevation measurements appear to be the same on both sides of an obviously stepped floor covering change, then the plan is likely an Adjusted Elevation plan. If adjacent Elevation measurements were not recorded on both sides, the Engineer must look at the relationship between several Elevation points in the vicinity of the floor covering change and compare to the relationship of the same Elevation points recorded in a known Survey Elevation plan or Adjusted Elevation plan and make a determination. Any assumptions made should be noted on the Time-change Elevation plan.

5.6 TIME-CHANGE ELEVATION CONTOUR PLAN

Contours may be drawn based on the Time-change Elevation plan using the methodology described in the Section 5.5. It is useful to combine the Time-change Elevation plan and the

Contour plan on the same floor plan. Contours on a Time-change Elevation plan give a visual representation of the direction and the extent that a Foundation is moving.

5.7 LEVEL DISTORTION PLAN

When no baseline or as-built Elevation plan is available or when it is desired to know the Distortion from level at a point in time, a Level Distortion plan may be drawn as a special case of the Time-change Elevation plan wherein the first set of Survey Elevation readings are assumed to be 0.0”. This is done in conjunction with an Adjusted Elevation plan (Section 5.3).

5.8 CROSS SECTION ANALYSIS

A Foundation cross section analysis, in its most basic form, is simply a conventional analysis of a cross section of the surface of a Foundation modeled as a section. The cross section Elevations can be taken on the Foundation surface, on the finished flooring, or on a course of brick veneer. The Elevations can come from a floor plan on which Elevations have been recorded or the Elevations may be taken for the specific purpose of performing a movement analysis for a specific profile of interest. A Contour plan may be useful in determining the section where the Slope and Deflection are the greatest.

If the Elevations are from a Survey Elevation plan, the cross section analysis is a guideline for analyzing the Survey Elevation data as part of a Level B engineering evaluation. Because of inaccuracies incurred in the construction of the Foundation and floor covering levelness and in the recording of Survey Elevations, in order to be compatible with the performance limits presented in Section 6, a cross section analysis must use regression analysis with the Elevation data to estimate and smooth the shape of the Deflection curve, as is done when drawing a Contour plan.

5.9 DIFFERENTIAL ELEVATION ANALYSIS – USED FOR LEVEL B AND C INVESTIGATIONS

For a differential Elevation analysis a necessary tool for evaluating Foundation performance is the use of relative Elevations of the interior floors. These measurements can be utilized to complement the visual observations in Section 4.3 in order to make a judgment concerning the amount of Foundation Movement experienced across a specific profile. When properly presented, relative Elevations of the interior floors can provide the client with information that can later be used as a reference so that an Inspector can monitor the future performance of the Foundation. Differential level measurements of floors may indicate movement of the Foundation, although the measurements could also indicate poor quality control in the original placement of the concrete slab.

A set of Survey Elevations is used to complement the visual observations. It is helpful when a previous set of relative measurements is available, and Foundation performance can be evaluated with observations over time with Time-change Elevations. In some cases, when the Foundation is slightly-to-moderately out-of-level and it can be established that the Foundation presently appears to be stable, one can conclude that it is performing its intended function.

6.0 PERFORMANCE LIMITS FOR FOUNDATION MOVEMENT

The ASCE's Guidelines [3] and the TRCC Standards [13] contain published limits for Foundation Movement. However, because the specified limits in those publications are not fully coupled with related definitions, data acquisition guidelines, presentation guidelines and computational guidelines, the committee has found both guidelines and standards to be open to varying interpretations. Together with previous sections of this FPA document, which have specified definitions, data acquisition guidelines, and presentation guidelines, this section provides the coupled computational guidelines and Foundation Movement limits needed to assess Foundation Movement with less room for varying interpretation than provided in the ASCE and TRCC publications

6.1 PUBLISHED CONSTRUCTION TOLERANCES

Two publications concerning the construction tolerances of slab Foundations are American Concrete Institute's *ACI 302* [2] and *ACI 117* [1]. However, it is rare that concrete Foundations within the scope of this document would be required by the Building owner to meet construction levelness or flatness tolerances specified in these two ACI publications. Both of these ACI publications address slab-on-ground Foundations as-built level and flatness tolerances, which could be applied if desired by the Building owner. An overall Foundation levelness tolerance of 1.5" (i.e., + or – 0.75"), which *ACI 117* [1] specifies is widely considered to be an acceptable construction tolerance for slab-on-grade Foundations, even though the 2010 version does not apply to single-family residential construction. The committee found that most residential slabs are constructed to a higher standard, i.e., within 1.0" of level.

Because this FPA document addresses performance (rather than construction) of Foundations, these two ACI publications are not considered applicable, at least as far as flatness, particularly since residential slabs are typically floated and finished with carpet, wood, tile, etc., such that the peaks and valleys of the cast concrete are not a major concern.

The defunct (sunsetted) Texas Residential Construction Commission (TRCC) [13], which addressed both construction and performance tolerances from a warranty perspective, presumed a +/- 0.75 inch (total 1.5 inches) initial out-of-level tolerance, the same as specified in *ACI 117* [1]. However, TRCC did not require an as-built Elevation survey and was unclear as to how TRCC's construction tolerance should be applied when no as-built Elevation survey was available. TRCC was also unclear on whether as-built slab Elevations should be recorded on the exposed slab or on the finished flooring materials in order to provide a set of Baseline Elevations for possible use later in the event of a performance evaluation or dispute.

To exemplify the TRCC dilemma, when no Baseline Elevations are recorded or retained, if one corner of a flat and level Foundation has Heaved 2" relative to the rest of the Foundation, the Building contractor may contend that the Foundation could have been cast 1.5" higher at that corner, thereby arguing that the Foundation Movement is 2" – 1.5" = +0.5". However the Building owner may argue that the corner was cast 1.5" lower, meaning the performance Deflection is 2" + 1.5" = +3.5", or a difference in interpretation of 3" (3.5" – 0.5") between the two parties. Both hypotheses complied with TRCC as far as construction tolerance of the

Foundation. It requires an experienced Forensic Engineer to correlate the Negative Phenomena in order to determine the more likely initial as-built Elevation of the corner. In any case, an accurate determination of movement is not possible without using a Baseline Elevation Plan.

6.2 DEFLECTION

Distress induced in the Superstructure of a Building by Foundation Movement is generally caused by bending, also called Deflection, of the Foundation. Foundations are designed with some degree of stiffness. The stiffer the Foundation is, the lower the amount of Deflection for a given amount of soil movement. The design stiffness is determined by the design engineer based on the geotechnical report design parameters, the geometry of the Superstructure and Foundation, and the allowable Deflection Ratios.

The allowable design Deflection is characterized by a ratio of the Effective Length (in inches) divided by a number typically between 240 and 360. The TRCC [13] required computation of a Deflection Limit using the distance over which the Deflection occurs divided by 360 by adopting the recommendations in the ASCE Guidelines [3].

ASCE [3] does not quantify a minimum recommended Effective Length to analyze when considering a given Deflection, stating, “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.” The committee concurs with ASCE [3] that Effective Lengths that are too short may be misleading due to the fact that construction irregularities and measurement tolerances may skew the Deflection computations. Given the ACI 117 [1] guidelines used to construct Foundations, the local unlevelness ACI 117 [1] commonly allows, and the empirical evidence reviewed, *the Foundation Performance Association recommends that the* ***minimum*** *Effective Length used for determining Deflection be 20 feet or the width of the Foundation, whichever is less*.

Empirical evidence has shown that the onset of excessive distress in the Superstructure appears to occur when Deflection exceeds the span divided by 240 to 480. There are exceptions where this range of Deflection is exceeded and the distress in the Superstructure is minimal, but the opposite has also been found to occur. Architectural finishes such as carpet and wood paneling are more flexible and therefore more forgiving than brittle finishes like tile, masonry and drywall.

Foundations may move prior to completion of the architectural finishes. Oftentimes, craftsmen compensate for movement that occurred during construction by leveling the surfaces of the architectural finishes. Therefore, Negative Phenomena may not reflect the total movement measured after construction is complete, particularly when the construction duration is lengthy.

For purposes of setting a reasonable performance standard for flexure of slab-on-grade Foundation systems, *the Foundation Performance Association recommends that Deflection not exceed the Effective Length, L, divided by 360 (or 0.0028L)*, the same value recommended by ASCE [3] and TRCC [13]. These recommendations were adopted by the committee after analyzing dozens of actual problematic Foundations using the procedure presented in Section 6.4.

The guideline for calculating the Deflection is illustrated in Section 6.4.

6.3 TILT

Tilt does not produce bending stresses in the Foundation. Even though the differential Elevations between the high and low points may be significant, it is oftentimes considered to be acceptable movement of the Foundation. Floor Slopes of one percent or more may be noticeable.

Negative Phenomena may not occur with a Tilt of more than one percent, although functionality of the Building may be compromised. Recognizing excessive Tilt conditions as Functional Phenomena*, the Foundation Performance Association recommends that Tilt be less than or equal to one percent (1%) over the entire length, width, or diagonal of the Foundation*. This limit for Tilt is in concurrence with TRCC [13]. See Section 6.4.1 for Tilt calculations and Section 6.4.2 for an example of evaluating Tilt.

Extrapolated Contours should not be used for Tilt calculations.

6.4 EQUATIONS AND EXAMPLES

This section includes the equations to be used to calculate the Deflection, Deflection Ratio and Tilt, as well as several examples for computing Deflection Ratio and Tilt.

6.4.1 Equations

The guideline presented for computing Deflection, Deflection Ratio and Tilt is as follows:

L_{AB} = Overall length width, or diagonal of Foundation for Tilt or Deflection

Points 1 & 3 = End points of the Effective Length being considered for Deflection, spaced not less than the smaller of 20 ft. or L_{AB}

Point 2 = a Foundation intermediate point between, and vertically coplanar with, points 1 & 3 (i.e. in plan view, points 1, 2 and 3 are collinear)

$L = L_{13}$ = Horizontal projection of deflected span being considered, but not less than the smaller of 20 ft. or L_{AB}

Y_i = Vertical Elevation of any point "i" along L_{AB} (relative to Datum)

$$\text{Deflection} = \Delta = Y_2 - [Y_1 + (\frac{L_{12}}{L})(Y_3 - Y_1)]$$

$$\text{Deflection Ratio} = \frac{\Delta_{\text{inches}}}{L_{\text{inches}}}$$

$$\text{Tilt} = \frac{|Y_B - Y_A|}{L_{AB}} \text{ x } 100\%$$

The foregoing equations use the variables and dimensions shown in Figure 6.4.1-1 below.

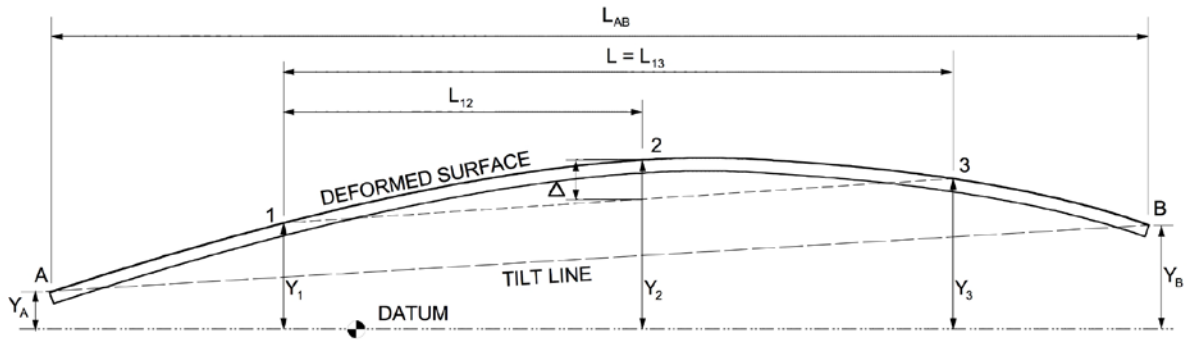


Figure 6.4.1-1 Sketch for computing Deflection and Tilt

Please note the following in using these equations:

1. Span length (L) and Elevations (Y) are measured in the horizontal and vertical directions, respectively.

2. Span length from point 1 to point 3 (L_{13}) may be anywhere along the Foundation, whether in orthogonal or skewed directions, provided L_{13} = at least the smaller of 20 ft. or L_{AB} and the span contains three Elevations (Y_1, Y_2, Y_3) derived from Contour lines or similarly smoothed Adjusted Elevations. Discretion should be used when analyzing a slab less than 20 ft. wide.

3. Tilt is considered over a span L_{AB} that extends from edge-to-edge of the Foundation over the entire length, width, or diagonal of the Foundation.

6.4.2 Calculation Examples

Several examples for computing Deflection, Deflection Ratio and Tilt using the equations in Section 6.4.1 are presented in Figure 6.4.2-1 below:

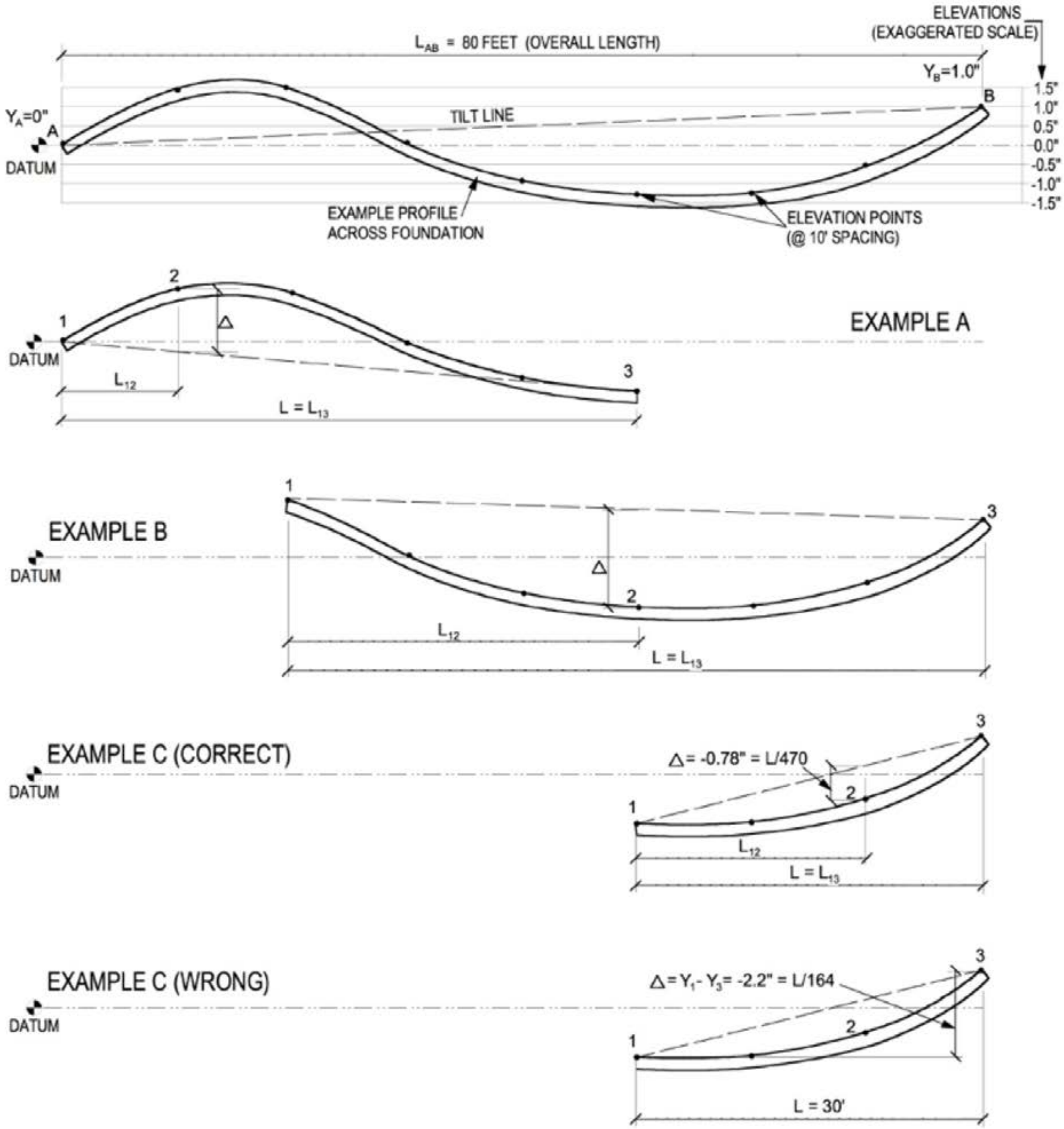


Figure 6.4.2-1 Examples A, B, and C

Note that a common misconception when computing the Deflection of an end is exemplified in Example C. This example shows how some may incorrectly compute the Deflection to be L/164, which exceeds the Deflection Limit, rather than correctly computing the value of L/470, which is within the Deflection Limit.

From Section 6.3, the Tilt must be less than or equal to 1%. For the 80 ft. profile in Figure 6.4.2-1:

$$\text{Tilt} = \frac{|Y_B - Y_A|}{L_{AB}} \text{ x } 100\% = \frac{|1.0" - 0"|}{80' \text{x} 12 \text{in/ft}} \text{ x } 100\% = 0.10\% < 1.0\%$$

Therefore, the example profile does not exceed the Tilt Limit.

Computations for Deflections (Δ) for the above examples are shown in the following Table 6.4.2-1:

Table 6.4.2-1 Deflection and Tilt Examples

Ex.	$L = L_{13}$	L_{12}	Y_1	Y_2	Y_3	Δ (inches)	
A	50’	10’	0”	1.4”	-1.2”	1.64	L/366
B	60’	30’	1.4”	-1.2”	1.0”	-2.4	L/300
C	30’	20’	-1.2”	-0.5”	1.0”	-0.78	L/462

Using the equations in Section 6.4.1, in these examples, A and C are within the L/360 Deflection Limit criterion, while B exceeds the Deflection Limit. Note that there can be other spans within this profile that may also exceed the Deflection Limit. In fact, for this profile, using the software described in the next two sections, the maximum actual Deflection was found to be L/253.

6.5 SPREADSHEET SOFTWARE

Spreadsheet software is a useful tool to perform the calculations shown in the above sections, though a calculator can also be used. The spreadsheet that the committee used to analyze actual projects is available on the FPA website (see Preface for more detail). By analyzing actual projects, the committee was able to correlate acceptable and unacceptable distress phenomena with actual Survey Elevations in order to arrive at the Foundation Movement limits presented in Section 6.2 and Section 6.3.

An example demonstrating the entire procedure and utilizing Contours, equations and spreadsheet is included in the next section.

6.6 PROCEDURE EXAMPLE

Following is a case study exemplifying use of the procedure from start to finish. The investigation conducted was a Level C investigation and followed the guidelines of this document and those of FPA-SC-12-0 [9].

6.6.1 Case Study Background

The project is a 25-year old two-story brick veneer and drywall covered residence with detached garage in Southeast Texas. The Foundation is a conventionally reinforced stiffened concrete slab-on-ground Foundation on expansive soil.

6.6.2 Visual Analysis

Site reconnaissance showed the house Foundation has mature trees in close proximity to three corners, with the largest tree in the back yard near the left rear corner of the Foundation. Because the homeowner regularly maintained the architectural finishes of the residence, there was very little distress in the architectural finishes even though the Foundation had experienced pronounced edge Subsidence over a period of many years.

The site plan is shown in the following figure:

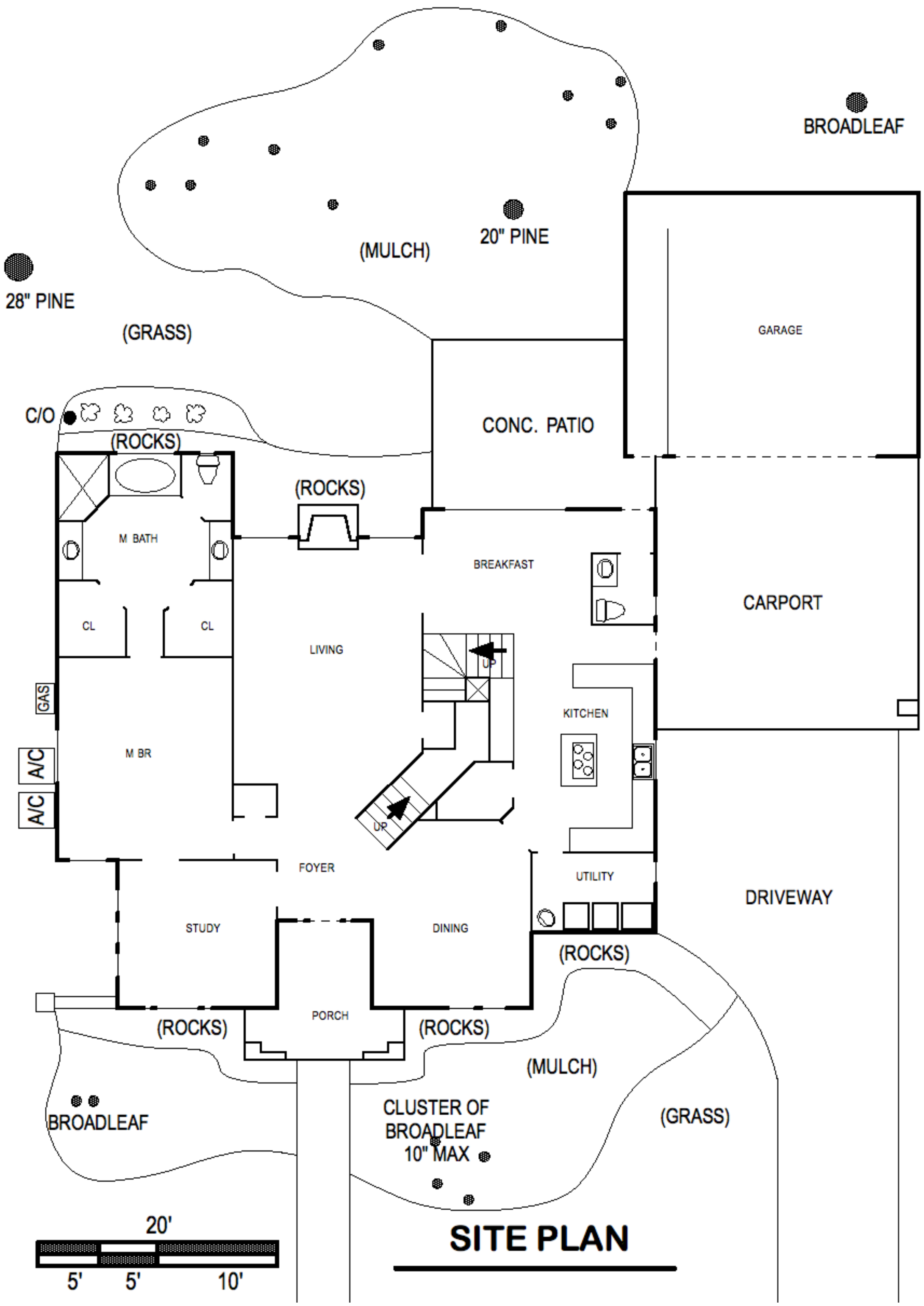


Figure 6.6.2-1 Site Plan

6.6.3 Elevation Analysis

Survey Elevations were recorded for the slab. The Survey Elevations were then adjusted for steps and floor covering thickness changes such that a Level Distortion plan with Contours could be drawn. This Level Distortion plan is shown in the following figure along with some of the more pronounced Slopes (dashed arrows) away from the high point, which was near the center of the slab at the Reference Point:

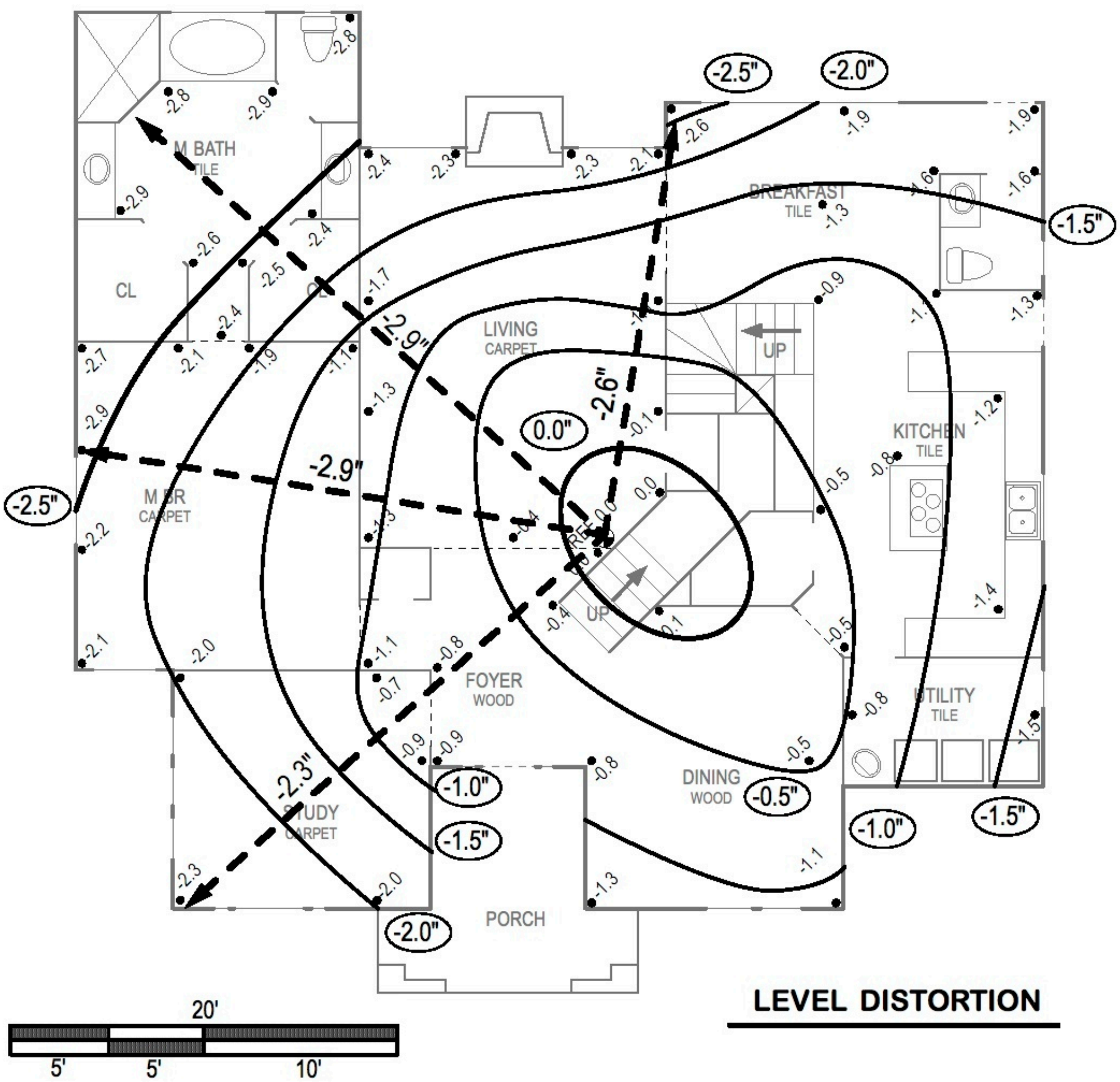


Figure 6.6.3-1 Level Distortion Plan

From the above figure, the most severe Slopes were diagonally toward the left and left rear corner of the Foundation with a maximum differential Elevation of 2.9”.

6.6.4 Profiles and Performance Analysis

From the above Level Distortion plan with Contours and Slopes across the Contours, the Forensic/Structural Engineer could narrow down the critical profiles to analyze in order to determine if the Deflection Limit was exceeded. Two profiles were analyzed. These two profiles (Profiles #1 & #2) are shown as heavy solid lines on the following figure:

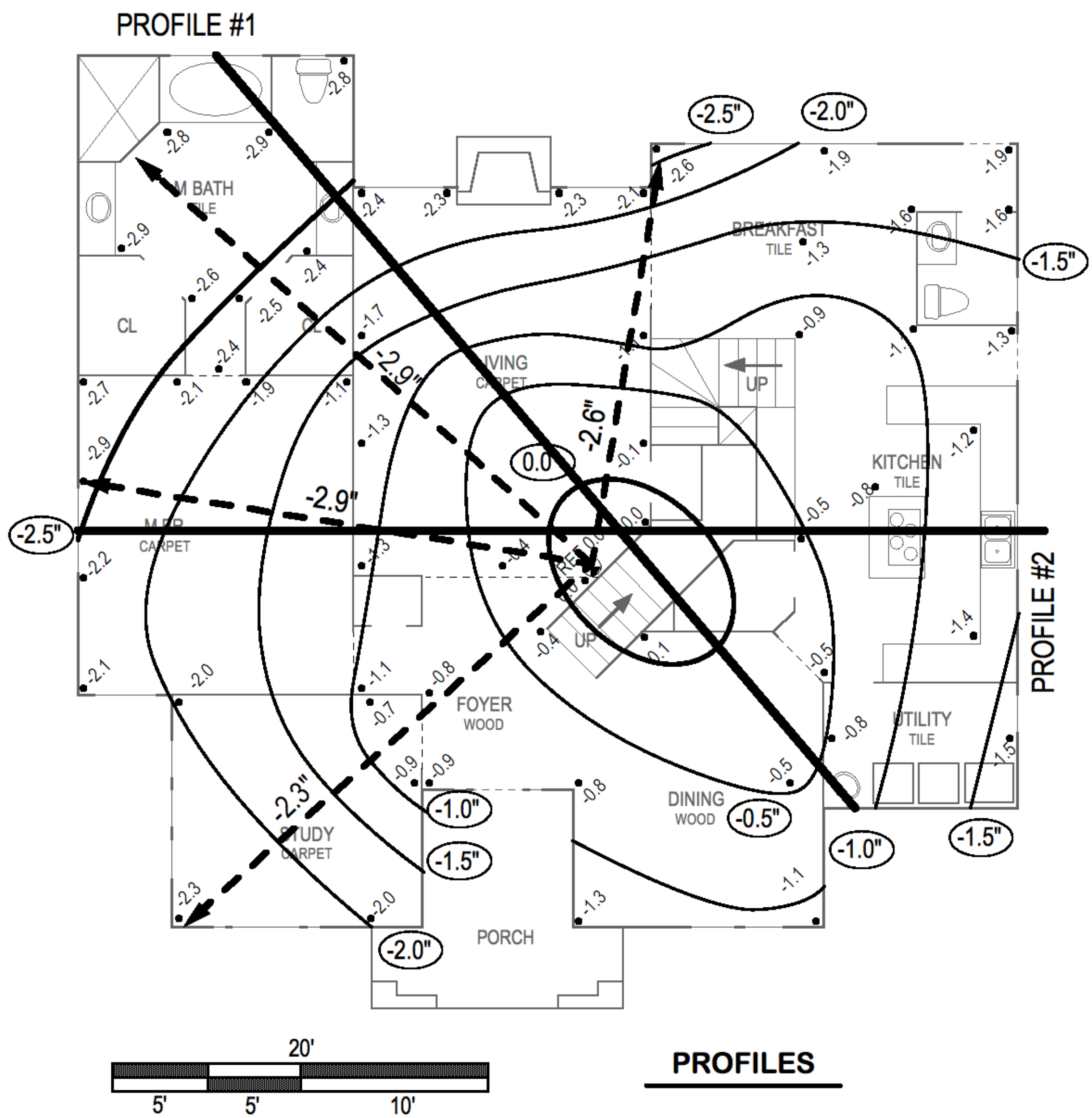
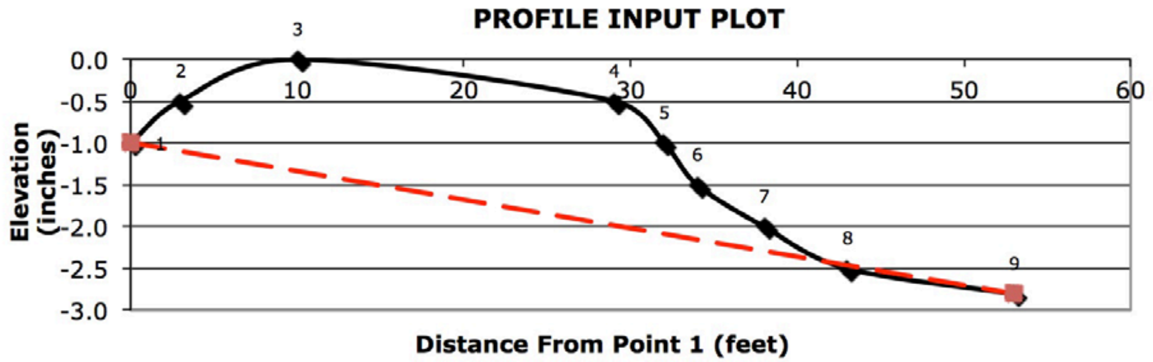


Figure 6.6.4-1Profile Plan

6.6.5 Spreadsheet Calculations

The FPA spreadsheet software was used to make the performance calculations along the above profiles. The input and output from these analyses are shown in the following figures:

Profile #1 From Utility to Master Bath



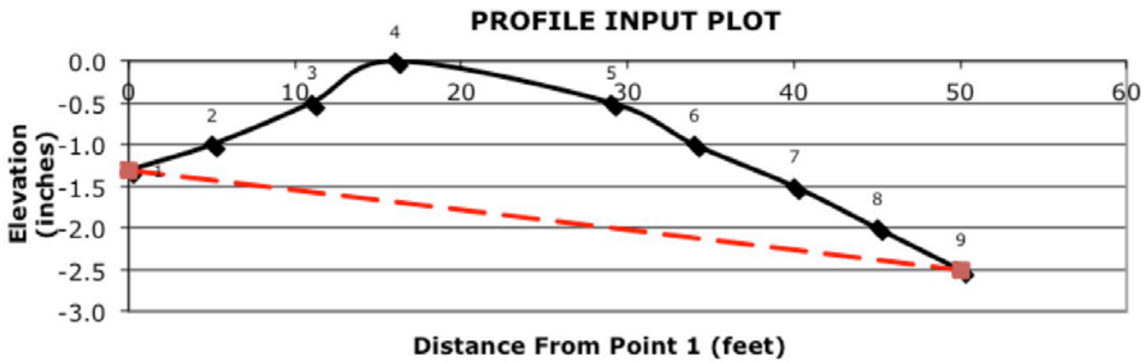
PERFORMANCE OUTPUT RESULTS

	ACTUAL	RESULT	PT. 1	PT. 2	PT. 3
Deflection 1 =	L / 341	****EXCEEDS L/360 LIMIT BY 5%****	1	4	8
Deflection 2 =	L / 356	***EXCEEDS L/360 LIMIT BY 1%***	1	3	6
Deflection 3 =	L / 361	100% OF L/360 LIMIT	1	3	7
Tilt =	0.28 %	28% OF 1% LIMIT			

Figure 6.6.5-1

The above figure shows Profile #1 exceeded the L/360 Deflection Limit by 5% and did not exceed the Tilt Limit with a Slope of 0.28%, i.e., 28% of the Tilt Limit of 1%.

Profile #2 From Kitchen to Master Bedroom



PERFORMANCE OUTPUT RESULTS					
	ACTUAL	RESULT	PT. 1	PT. 2	PT. 3
Deflection 1 =	L / 348	****EXCEEDS L/360 LIMIT BY 4%****	1	4	7
Deflection 2 =	L / 348	***EXCEEDS L/360 LIMIT BY 3%***	2	4	6
Deflection 3 =	L / 349	**EXCEEDS L/360 LIMIT BY 3%**	1	4	8
Tilt =	0.20 %	20% OF 1% LIMIT			

Figure 6.6.5-2

The above figure shows that Profile #2 exceeded the L/360 Deflection Limit by 4% and Tilt did not exceed its limit with a Slope of 0.20%, i.e., 20% of the Tilt Limit of 1%.

6.6.6 Conclusions

The Foundation exceeded the Deflection Limit and repairs were recommended to bring the Foundation closer to level. For the repair, multiple mature trees were felled and other trees' roots were severed near the Foundation to a depth of 24" depth. Then over the course of 2 years the Foundation gradually overcame most of its Level Distortion that was caused by Subsidence from the trees. Some repairs to the architectural coverings were then necessary since the homeowner had made prior repairs to the doorframes, masonry and drywall.

6.7 COMMENTS ON FOUNDATION MOVEMENT

Aspects of Foundation Movement that should be considered in the guideline presented herein include, but are not limited to:

- Movement of the Foundation during construction and prior to occupancy.

- The Negative Phenomena, or lack of, should be correlated with the Foundation Distortion.

- The initial movement or "settling in" period of the Foundation and Superstructure after occupancy. Most go through a 12 to 24 month adjustment period as landscaping and watering programs are established.

- Seasonal movements due to changes in the climate that affect soil moisture content.

- Foundation Movement due to unanticipated issues such as removal of established trees and other vegetation, plumbing leaks, inadequate site drainage, lack of or improper roof gutter systems, conditions of pool and pool deck installation, etc. Geotechnical reports may not provide design values to accommodate these issues, even though in the case of the removal of mature vegetation just prior to Foundation construction, the lack of appropriate design recommendations in many geotechnical reports has been the cause of extensive damages. Unless the geotechnical report addresses these issues, these issues need to be addressed by the contractor and by the Building owner. As a minimum, Foundation maintenance procedures such as those outlined in document FPA-SC-07-0, *Foundation Maintenance and Inspection Guide for Residential and Other Low-Rise Buildings* should be followed. [8]

7.0 SUMMARY, PROCEDURE AND CONCLUSIONS

This document proposes a procedure for evaluating the performance of a concrete slab Foundation. The contents of this document are summarized as follows:

1. This procedure requires a Level B or C investigation as defined in Section 3.0 and recommends data acquisition per Section 4.0 and data analysis and presentation as defined Section 5.0.

2. This procedure requires calculations for Foundation Deflection and Tilt per the equations in Section 6.0.

3. The committee has proposed the following performance limits to be used in conjunction with the equations in Section 6.4.1 correlated with the Distress Phenomena:

   - Deflection Limit = L/360 (or 0.0028L)
   - Tilt Limit = 1.0%

   Where:

   a) Deflection is computed using any three points that are vertically coplanar and the two end points are spaced no less than 20 ft. or the width of the Foundation, whichever is less;

   b) Tilt is measured over the entire length, width, or diagonal of the Foundation (see Figure 6.4.1-1), and;

   c) The Elevations used are Time-change Elevations between the survey in question and either the Baseline Elevations or any other previously recorded Elevations. If no previously recorded Survey Elevation plan exists, the previously recorded Elevations shall be assumed to be a level as-built condition, except that *ACI-117* [1] tolerances may be employed if:
      - It can be shown through the existence or non-existence of Negative Phenomena or;
      - It can be shown by other means that a non-level condition more accurately represents the as-built condition.

4. The FPA understands that there are other analysis procedures [3] [13] used in the industry. However, it is the opinion of the FPA that the procedure presented in this document is one of the first complete guidelines that combines Deflection and Tilt Limits and related defined terms, data acquisition guidelines, presentation guidelines, and computational procedures in a single guideline. Therefore, utilizing this guideline as an evaluation tool will tend to provide less subjectivity when evaluating whether a Foundation is properly performing.

8.0 REFERENCES

1. American Concrete Institute (ACI) *117-10, Specification for Tolerances for Concrete Construction and Materials and Commentary*

2. American Concrete Institute (ACI) *302.1R-04, Guide for Concrete Floor and Slab Construction*

3. American Society of Civil Engineers (ASCE), Texas Section, *Guidelines for the Evaluation and Repair of Residential Foundations*, Version 2, May 1, 2009

4. American Society of Civil Engineers (ASCE), Texas Section, *Recommended Practice for the Design of Residential Foundations*, Version 1, January 1, 2003

5. Foundation Performance Association, Document No. FPA-SC-01-0, *Foundation Design Options for Residential and Other Low-Rise Buildings on Expansive Soils*, 30 June 2004

6. Foundation Performance Association (FPA) Document No. FPA-SC-02-0, *Test Methods for Evaluating Existing Foundations*, November 29, 2010

7. Foundation Performance Association (FPA) Document No. FPA-SC-03-1, *Distress Phenomena Often Mistakenly Attributed To Foundation Movement*, May 1, 2004

8. Foundation Performance Association (FPA) Document No. FPA-SC-07-0, *Foundation Maintenance and Inspection Guide for Residential and Other Low-Rise Buildings*, March 23, 2003

9. Foundation Performance Association (FPA) Document No. FPA-SC-12-0, *Guidelines for Evaluating Foundation Performance by Monitoring*, January 9, 2006

10. Foundation Performance Association (FPA), Document No. FPA 201-2001, Supplement #1, *Criteria for the Inspection of and the Assessment of Residential Slab-on-Ground Foundations*, Presentation Paper by Don Lenert, June 19, 2002

11. Foundation Performance Committee (FPC, since renamed to Foundation Performance Association, i.e., FPA), Document No. FPC 201-97, *Criteria for the Inspection of and the Assessment of Residential Slab-on-Ground Foundations*, 1997

12. Texas Board of Professional Engineers (TBPE), *Policy Advisory 09-98-A - Guidelines Regarding Design, Evaluation and Repair of Residential Foundations,* 1998

13. Texas Residential Construction Commission (TRCC), *Limited Statutory Warranty and Building and Performance Standards*, 2005