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

by
The Structural Committee

of
The Foundation Performance Association

www.foundationperformance.org

Houston, Texas

Document # FPA-SC-13-0

ISSUE HISTORY (Initial issue and issues outside the Structural Committee)

#	Date	Description	Subcommittee Chair	Subcommittee Members
A	1 Sep 04	Issued for Committee Review	Lowell Brumley	Dan Jaggers Michael Skoller Mari Mes Ron Kelm Michael Gray John Clark Nicole Wylie Dick Peverley Denis Hanys
Z	13 Mar 07	Issued for 90-Day Peer Review to FPA and ASCE-Tx		
AA	19 Jun 07	Issued for Committee Review of all Peer Review Comments		
0	15 Jul 07	Issued for Website Publication		

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 1997 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, committees were formed for the purpose of assembling the information available in the industry on any subject, and compiling it into a criteria document, which would then be available to the industry and the public, as well.

This document was written by the Structural Committee and has been peer reviewed by the Foundation Performance Association (FPA). The FPA has published this document as FPA-SC-13 Revision 0 and has made it freely available to the public at www.foundationperformance.org so all may have access to the information. To ensure this document remains as current as possible, it may be periodically updated under the same document number but with higher revision numbers such at 1, 2, etc.

The Structural Committee authored a Microsoft Excel spreadsheet in order to develop this document. The spreadsheet developed and used by the committee also went through the FPA Peer Review process and the final version, containing sample calculations, is provided as a courtesy to FPA members at www.foundationperformance.org with no guarantee of its accuracy. In the event of a conflict between this document and the spreadsheet, this document will take precedence.

Prior to the incorporation of the Foundation Performance Association in 1997, its predecessor (called the Foundation Performance Committee) published a document titled *Criteria for the Inspection of and the Assessment of Residential Slab-on-Ground Foundations*, document No. FPC-201-97 [9]. This document contained recommendations, not only for the inspection of such foundations, but also for the assessment of their performance. Document no. FPC-201-97 was included as a part of the background documentation for the formation of this document. This document no. FPA-SC-13, once published as Revision 0, supercedes FPC-201-97.

In 1998, the Texas Board of Professional Engineers formed a committee that published a Policy Advisory 09-98-A [10] 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 committees to create a replacement for the Advisory Policy. In 2002, ASCE Texas Section published a document titled *Guidelines for the Evaluation and Repair of Residential Foundations, Version 1*.

The Structural Committee is a permanent committee of the Foundation Performance Association. At the time of writing this document, Ron Kelm, P.E., chaired the Structural Committee and 25 to 35 members were active on the committee. The committee sanctioned this paper in February 2003 and formed an ad hoc subcommittee to write the document. The subcommittee chair(s) and members are listed on the cover sheet of this document.

Suggestions for improving of this document should be directed to the current chair of the Structural Committee. If sufficient comments are received to warrant a revision, the 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 and the previous revision will be removed.

This document is specifically written to be used by Licensed Professional Engineers. The intended audiences for this document also include inspectors, foundation repair contractors, builders, owners, attorneys, and others that may be involved in the evaluation of Foundation Movement of residential and other low-rise buildings.

This document was created with generously donated time in an effort to improve the performance of Foundations. The Foundation Performance Association and its members make no warranty, expressed or implied, 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. This document was written specifically for use in Texas and should be used with caution if adapted elsewhere. Each project should be investigated for its individual characteristics to permit appropriate application of the material contained herein.

TABLE OF CONTENTS

1.0 INTRODUCTION....6

2.0 DEFINITIONS....6

3.0 LEVELS OF INVESTIGATION....10

3.1 LEVEL A INVESTIGATION....11

3.2 LEVEL B INVESTIGATION....11

3.3 LEVEL C INVESTIGATION....11

4.0 DATA ACQUISITION AND PRESENTATION....12

4.1 INTERVIEW....12

4.2 PREPARATION OF THE SKETCH OF THE BUILDING PLAN....12

4.3 DISTRESS PHENOMENA PLAN....12

4.4 ELEVATIONS....13

4.4.1 Equipment....13
4.4.2 Choosing a Reference Datum....13
4.4.3 Recording Elevations....13
4.4.3.1 Single-family Dwelling Elevation Surveys....14
4.4.3.2 Multi-Family Dwelling Elevation Surveys....14

4.5 TOPOGRAPHICAL SURVEYS....15

4.5.1 Survey (Unadjusted) Elevation Plan....15
4.5.2 Adjusted Elevation Plan....16
4.5.3 Contour Plan....16
4.5.4 Time-Change Elevation Plan....16
4.5.5 Time-Change Elevation Contour Plan....17
4.5.6 Foundation Profile Analysis....17

5.0 DATA ACQUISITION AND EVALUATION....18

5.1 DATA ACQUISITION METHODS....18

5.1.1 Visual Analysis – Used for Level A, B and C Investigations....18
5.1.2 Differential Elevations Analysis – Used for Level B and C Investigations....19
5.1.3 Forensic Analysis – Used for Level C Investigation....19

5.2 CAUSES OF SOIL AND FOUNDATION MOVEMENT....19

5.3 ITEMS AFFECTING ALLOWABLE FOUNDATION MOVEMENT CRITERIA....20

5.3.1 Age....20
5.3.2 Published Construction Tolerances....20

6.0 ALLOWABLE CRITERIA FOR FOUNDATION MOVEMENT 21

6.1 FOUNDATION STIFFNESS AND FLEXURAL DEFLECTION..................21

6.2 TILT 23

6.3 EQUATIONS AND EXAMPLES 23

6.3.1 Equations..23
6.3.2 Calculation Examples 25
6.3.3 Determining Principal Axis' Lengths and Widths for Field Measured Lengths.....26

6.4 SPREADSHEET SOFTWARE 27

6.5 OTHER ANALYSIS METHODS 27

6.6 COMMENTS ON FOUNDATION MOVEMENT 28

7.0 SUMMARY AND CONCLUSIONS 28

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 allowable acceptance criteria for Foundation Movement.

This document addresses the foundations of residential and other low-rise buildings that are 4-stories or less. The performance and serviceability of residential and other low-rise building concrete slab Foundations has been discussed and analyzed for over 30 years. The Foundation system's primary job is to support the Superstructure. In areas with active clay soils, the Foundation system must also act as a buffer between the active soils and the Superstructure.

A major portion of the residential and other low-rise buildings that are constructed are supported by slab-on-grade Foundation systems that are allowed to bend and move with the soils. All Foundation systems move. Even with complete and correct geotechnical information, a properly designed and constructed Foundation system will still move. Generally, movement begins the day the Foundation is placed, and continues throughout the life of the structure.

To date, Foundation Movement 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 them, it is apparent that a consensus for analysis of the performance of Foundation systems has not been reached. This document attempts to present a more acceptable procedure through the presentation of various definitions, including levels of investigation, data acquisition, including both presentation and methods, and prescriptive criteria for Foundation Movement, coupled with the method for computation.

2.0 DEFINITIONS

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

Benchmark is a specially installed Reference Point near the Foundation and is designed 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, curbs, light stanchions, manhole covers, etc., have been shown to move significantly, relative to Foundations and are usually not reliable choices for a Benchmark.

Contours are lines that connect points of equal Elevation and do not cross. Contours may be drawn on an Adjusted Elevation Plan to determine the vertical Deformation (sometimes called "level distortion") 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.

Crack is a flaw 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 distorted shape of a structural element due to bending. An example of this is when an initially straight beam is loaded with a transverse load, it will distort into a curved shape. The Deflection at any point within the span length on the beam is the translation of that point from its initial position to its position on the Deflection curve. As shown in Figure 6.3.1-1 and in Section 6.3.2, examples A, B and C, Deflection is the vertical distance between any point 2 on the surface and a line L_{13} that connects two end points 1 and 3 on that surface. Note: Actual Deformations are perpendicular to the chord line L_{13}. The difference between the actual Deflections and the measured Deformations (i.e., Deflection) is inconsequential and not considered.

> ***Allowable Design Bending Deflection*** is measured as a ratio of the Effective Length (L, in inches) divided by a number. This number generally ranges from 240 to 480 for wood frame structures, depending on the type of bending or flexure (i.e., edge lift or center lift) and the type of structure.
>
> ***Deflection Ratio*** is defined as the Deflection divided by the horizontal distance over which the Deflection occurs, and is used as criteria of acceptance when evaluating Foundation Movement. Additional information is provided in Section 6.1.
>
> ***Deflection Limit*** is defined as the Effective Length divided by a number, and is used as criteria of acceptance when evaluating Foundation Movement. Additional information is provided in Section 6. Deflection Limit is the length times the maximum Deflection Ratio.

Deformation is any change of shape after the original foundation construction.

Effective Length is the length of a straight line (L) drawn along a minimum of three points in the plan view for which the Elevations are known, multiplied by the "k" factor (i.e., kL). Two of the points are end points of the line and the third point is between the two end points and located a certain vertical distance from the horizontal straight line as shown in the sketches in Section 6.3. The maximum Effective Length is the overall length or width of the Foundation. It is recommended that the minimum Effective Length used be 20 feet or the width of the Foundation, whichever is less. The use of Effective Lengths less than 20 feet may be misleading due to the fact that construction irregularities and measurement tolerances may skew the elevation data.

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

Forensic Engineer is a Licensed Professional Engineer who performs a comprehensive evaluation (typically Level C, see Section 3.3) of the problem, performing testing needed to more accurately determine the root cause of the problem being investigated.

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 the combination of Deflection and Tilt that occurs after construction. Visible signs of distress may accompany Foundation Movement.

Geotechnical Engineer is a Licensed Professional Engineer who performs the geotechnical investigation of the site and provides the test results along with the geotechnical design parameters necessary for the structural design of the Foundation.

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 suction potential and an available moisture source.

Inspector is a person licensed by the State or other governing authority employed for the purpose of providing an opinion as to the Foundation's performance.

k is defined as a dimensionless coefficient used to modify the measured length in a direction other than the direction of the principal axes (see section 6.1).

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. It is the Inspector's discretion to record an adequate number of Monitor Points.

Negative Phenomena are the observable symptoms of distress that may or may not be caused by Foundation Movement. Such distress is reflected by the creation of Separations, Cracks, or other symptoms of distress. Negative Phenomena are further classified by the following:

> ***Architectural Phenomena*** are defined as Negative Phenomena resulting from minor Separations in the walls, floors, ceilings, paving, etc., that are often noticeable by the

building's occupants. Architectural Phenomena are sometimes referred to as "cosmetic phenomena" or simply, "distress".

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, and vertical pavement offsets sufficient to cause tripping.

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, Foundation, or pavement elements such that the member can no longer safely carry load.

Reference Point (also, Datum or Reference Datum) is the location used as a baseline in computing Time-change Elevations over the Foundation. The Reference Point may be the Benchmark, or it may be an interior or exterior point that may move up or down but is assigned an arbitrary value such as 0.0". Typically the Reference Point is 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.

Settlement is downward movement of an underlying supporting soil stratum due to loading in excess of the bearing capacity of the soil below. When the vertical loads from above are in excess of the bearing capacity of the soil strata directly below the Foundation, the Foundation and Superstructure move downward. Encompassed in Settlement are a) the immediate elastic consolidation and distortion of granular or clay soil particles, b) slope instability, and c) the 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 defined as the differential Elevation (rise) between two points divided by the horizontal distance (run) between them. For the purpose of this document, the horizontal distance is approximated as the distance measured along the Foundation. Slope is not necessarily the result of movement. Slope may be a combination of Tilt, Deflection, and as-built surface irregularities.

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 move downward. Subsidence normally occurs within clayey soils and is often the result of soil desiccation that is caused by trees or other large vegetation.

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

Survey Elevation Plan is the set of raw (unmodified) Data Point Elevations recorded during an Elevation survey. It should be recorded on an architectural floor plan and include the date the survey was made. The data shown in the Survey Elevation Plan are not adjusted for differences in floor covering thicknesses and steps. The data on the Survey Elevation Plan are as-measured values.

Adjusted Elevation Plan is the set of Data Point Elevations, some of which are vertically translated to adjust for changes in floor covering thicknesses and steps. The Adjusted Elevation Plan should include the date the survey was made and should be presented on an architectural floor plan that shows walls, showers, sinks, countertops, etc.

Baseline Elevations are the first Elevation readings of a particular set of points in the structure to which future measurements will 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.

Time-change Elevation is the change in Elevation of a Monitor Point over a Monitor Period. It is determined by subtracting the earlier Elevation from the more current Elevation. Only equivalent plans may be used to calculate the Time-change Elevation, i.e. it is not possible to calculate Time-change Elevations between an Adjusted Elevation Plan and a Survey Elevation Plan. The set of Time-change Elevations should be recorded on an architectural floor plan and should include the dates of the two sets of data used and the name of the company(s) that recorded the data.

Tilt is defined as a planar rotation, measured over the length or width of the Foundation. Refer to Figure 6.3.1-1 and Section 6.3.2.

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] that may be performed in assessing the performance of a Foundation. Level A requires a broad visual overview, Level B requires a more in-depth investigation, and Level C is a forensic level investigation. The client and/or the Inspector typically establish the required level of investigation. The Inspector is generally expected to recommend and perform the lowest level of investigation needed for adequate analysis of the situation. If a report is issued, it should advise which level is followed. Use of the method proposed in Section 6 of this document requires either a Level B or Level C investigation.

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 available, regarding a history of the property and performance of the structure,
- Document visual observations made during a physical walk-through, and
- Observe factors influencing the performance of the Foundation.

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

- Scope of services,
- Observations,
- Discussion of factors identified as influencing the Foundation performance and rationale in reaching opinions concerning the Foundation, and
- Conclusions and 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 requires the following actions:

- Review pertinent documents including geotechnical reports, construction drawings, field reports, repair documents,
- Determine relative Foundation Elevations to assess levelness and establish a baseline,
- Document locations of large trees and other vegetation,
- Determine whether site drainage issues exist,
- Document the analysis process, data and observations, and
- If requested by the client, provide a report containing a list of the reviewed documents, an Survey Elevation Plan, and a phenomena plan in addition to the report requirements listed under Level A.

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 would include, but are not limited to, the following:

- Site specific soil sampling and testing,
- Hydrostatic leak test, with leak location and flow test if applicable,
- Material testing,
- Post tensioning cable testing or steel reinforcing survey, and
- Aerial photographs to determine prior land usage or construction issues.
- Scaled drawings,
- Description of factors that affect soil moisture,

- Observations of cut and fill,
- Site Photographs,
- Detailed Phenomena Plan, and
- If requested by the client, provide a report per the requirements under Level B, incorporating the above data.

4.0 DATA ACQUISITION AND PRESENTATION

Following is a discussion of the examination methods that are typically employed during the investigation of a residential 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 structure may be made or acquired. Where applicable, the plan may be of the structure alone or it may include appropriate features in the yard, such as outbuildings, patios, driveways, sidewalks, trees, planter beds, drainage ditches, and/or swales and berms. The building plan may be a sketch with limited proportionality or a detailed drawing based upon measured distances. It is prudent to make the drawing to scale rather than to draw it on a free-hand basis since proportionality can become an important factor in Foundation movement evaluation.

4.3 DISTRESS PHENOMENA PLAN

A phenomena plan documents all Negative Phenomena observed in a structure at the time of the site investigation. Phenomena can fit within one of three categories: Architectural Phenomena, Functional Phenomena or Structural Phenomena.

Unlike Elevation measurements, phenomena are generally observed and recorded on all levels of the interior structure, as well as on the exterior. Exterior phenomena can be recorded on a site plan or floor plan and interior phenomena should be recorded on an appropriate floor plan. In addition to recording a phenomenon’s location, other information may be included, such as whether the 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 phenomena are not required Levels A and B investigations. However, if the client desires the physical record or the Inspector believes it is necessary, photographs should be taken of the phenomena. Whether to photograph all phenomena or a select few of the more pronounced phenomena is at the discretion of the Inspector and the client.

Photographs may later be useful if monitoring is done, to help determine whether changes have occurred.

4.4 ELEVATIONS

This section details the steps involved in obtaining accurate floor Elevations using a level-measuring device for the purpose of determining the levelness of the Foundation. Recommendations are given for the number of measurements to record and the method for doing so.

4.4.1 Equipment

Floor Elevations should be measured using a level measuring device with an accuracy of ±1/8" or better. A spirit level may be useful to determine levelness of countertops, doorframes, window stools, wall plumb, etc, but should not be used to measure the Slope of the Foundation. Equipment should be calibrated, maintained and operated according to the manufacturer's instructions to ensure accurate measurements.

4.4.2 Choosing a Reference Datum

Unless a Benchmark is available, a point should be chosen for the Reference Datum and all readings recorded relative to the Reference Datum. More than one Reference Datum may be used but the possibility of error may be increased with each new setup. Because the fluid line of the typical digital level is limited in length, if the Foundation is large it is recommended that the Reference Datum be more centrally located in order to allow the Elevations to be recorded with a minimum number of Reference Points, thereby reducing the possibility of error.

Although it is usually at the Inspector's option, the selection of the Reference Datum should be in a place that is easy to duplicate for future readings. A location in a corner or next to a column near the center of the structure is ideal. The location of the Reference Datum should be recorded on a floor plan along with the subsequent measurements. If prior Elevations are available for the structure, calculations are simplified by using the same Reference Datum used in the prior survey.

If an interior Reference Datum is used, it should be anticipated that the Reference Datum may move vertically over time. However this vertical movement does not affect the computations presented in this document.

4.4.3 Recording Elevations

To facilitate future measurements by others, the drawings presenting the recorded Elevations should indicate 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. The drawings should also show the date of measurements. The report should state the type of equipment used to make the measurements and the advertised accuracy of the equipment.

4.4.3.1 Single-family Dwelling Elevation Surveys

Elevation measurements should be recorded uniformly throughout the structure. It is helpful for future analysis to also record Elevations in attached garages and porches on the same Foundation as the main home. The exact density of measurements is dependant upon the size, layout, and Slope gradient of the structure, 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 be one measurement in each corner of small rooms such as bathrooms and utility rooms, and double or triple the number in large rooms. The Elevations should be recorded on a floor plan next to a symbol (such as a dot or a star) representing the location of each measurement. An ideal situation exists where floor plans are made available, in the form of architectural drawings or prior Elevation surveys. In the worst-case scenario, the Inspector may need to draw floor plans on an as-you-go basis.

All Elevations are recorded at the top of floor coverings and are relative to the Reference Datum. When floor coverings change or steps are encountered, from tile to wood or carpet to linoleum, 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.

During the course of the measurements, return to the Reference Datum to ensure that the survey equipment still reads the same at the Datum. If the reading has changed, the machine should be calibrated and the previous measurements should be checked.

Typically, measurements are only recorded on the first level of a structure, however other floors may also be measured if desired. 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 required if the prior plan did not record the proper quantity of measurements.

4.4.3.2 Multi-Family Dwelling Elevation Surveys

For the purpose of this document, a multi-family dwelling is an individual building with conjoined single-family units. The limited height for such a building is defined herein as four stories. Any building comprised of more than four stories is beyond the scope of this document. For the purposes of this discussion, a single building has only one monolithic Foundation. There are some multi-family buildings that have two or more individual Foundations with a Superstructure that is joined on the second, third and/or fourth stories. As such, the recommendations contained herein may not be applicable. It may be feasible in some situations to analyze each Foundation segment separately.

Multi-family dwelling Elevation surveys should be provided in a manner similar to those described in the above Section 4.4.3.1 for single-family surveys, except that a survey turning point across dividing walls between adjacent units is recommended so that the survey is continuous over the entire Foundation area.

Unlike most single-family residential buildings, multi-family dwellings can often incur both negative and positive Deflections, particularly when the ratio of longitudinal axis to lateral axis length is large. Thus, measurement Data Points in a multi-family dwelling may need to be more closely spaced than may be required 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 a given; 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 separate individuals to perform such coordination.

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. In the worst-case scenario, the Inspector may need to measure and sketch floor plans during the initial site visit.

To obtain a more accurate assessment of Foundation performance, Elevation measurements are recommended to be made, as a minimum, on the interior floors of each of the individual living units on the first story of each building, assuming that the units above have the same floor plan. Where such is not the case, Elevation measurement may be required in each individual unit, on each individual floor to filter out Deflection anomalies, which may be primarily framing related. The procedure for acquiring such Elevations is the same as was recommended for a single-family dwelling (Section 4.4.3.1), with the noted exceptions above.

4.5 TOPOGRAPHICAL SURVEYS

The following describes various methods for making topographical surveys from the Elevation measurements. Included in this section is a discussion of Elevation plans, Contour plans, Time-change Elevation plans, Time-change Elevation Contour plans and Elevation profiles. Furthermore, a method of comparing prior Elevation surveys to the current Elevation survey is discussed.

4.5.1 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, prior to adjustment for the floor cover thicknesses and steps. The presentation of Survey Elevation Plan is not necessary, but may be useful for comparing subsequent Elevation surveys.

4.5.2 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 present the true level distortion of a foundation.

4.5.3 Contour Plan

It is often advantageous to convert the adjusted Elevation data into Contours. Contours provide a visual method of rapidly determining Foundation levelness, amount of Slope and Slope direction. Much like a topographic map shows mountains and valleys, a Contour plan shows the Elevation differences across the Foundation. Where the surface is relatively flat, the Contour plan can be somewhat meaningless. It is more meaningful in areas where the degree of Slope is more pronounced.

Contours are lines of equal Elevations over the plane of the Foundation and are drawn from the level distortion plan either manually or with the aid of computer software. When drawing Contours manually, points of equal Elevation should be connected to form smooth lines or curves and labeled as such. For example, all points 1.5" above the Datum should be connected and labeled as +1.5".

It is important to consider the number of Elevation points and the inaccuracy of the machine used to make Elevation measurements. To account for this inaccuracy it is typical to draw Contours in 0.5" increments when documenting a survey showing Time-change Elevations between an as-built survey and a reasonably current survey. When one of the Elevation surveys used to make a Time-change Elevation survey is not an as-built survey, smaller increments may be used if there are an adequate number of points recorded. At best, the increments should correspond to the accuracy of the surveying instrument.

Unless a Benchmark is used, Contours alone do not indicate whether Heave or Subsidence has occurred if a non-stationary Reference Datum is used. A contour of -0.5" indicates that the area 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 correlated with geotechnical information or other anomalies may allow a Forensic Engineer to opine whether Heave or Subsidence has occurred.

4.5.4 Time-Change Elevation Plan

A Time-change Elevation plan illustrates the changes in Elevations between two distinct 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 results 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.

Foundation Movement can be evaluated by a Time-change Elevation plan by using a prior survey, and the current Elevation survey for the most recent. 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 within construction tolerances (see Section 5.3.2). 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. Measurements made in the centers of rooms may be difficult to duplicate and may introduce additional error into the Time-change Elevation plan.

When a prior Survey Elevation Plan or Time-change Elevation plan is available, it can be compared to a current Survey Elevation Plan or Time-change Elevation plan, respectively, showing the change in Foundation levelness over a period of time. However, first it must be determined whether the prior plan is a Survey Elevation Plan or a Time-change 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 a Time-change Elevation plan.

4.5.5 Time-Change Elevation Contour Plan

Contours may be drawn based on the Time-change Elevation plan using the methodology described in the Section 4.5.3. 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 rapid visual representation of the direction and the extent that a Foundation is moving.

4.5.6 Foundation Profile Analysis

A Foundation profile analysis, in its most basic form, is simply a conventional movement analysis of a profile of a slab-on-ground Foundation modeled as a strip beam. The profile 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.

If the Elevations are from a Survey Elevation Plan, the profile analysis is a method of analyzing the survey Elevation data as part of a Level B engineering evaluation. If the data does not come from a floor plan Elevation survey, then the profile analysis may be part of a Level A engineering evaluation. There are three issues that should be emphasized:

- There is no requirement in a Level B evaluation that any analysis of the Elevation data is made, only that Elevation measurements be made and recorded on a Survey Elevation Plan to show the overall shape of the Foundation surface.
- There is no requirement that a Level A evaluation include any Elevation measurements.
- It may be helpful to use regression analysis with the Elevation data to estimate the shape of the Deflection curve. See Section 6.5 for more detail.

See Section 3.0 for further detail on levels of investigation.

5.0 DATA ACQUISITION AND EVALUATION

5.1 DATA ACQUISITION METHODS

Items included in the data analysis may consist of a visual analysis, a differential Elevation analysis, and non-destructive and destructive testing.

5.1.1 Visual Analysis – Used for Level A, B and C Investigations

Visual observation is the oldest and basic method for evaluating Foundation performance. It is based upon the premise that symptoms of Foundation Deflection can be seen and judged by the eye. 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 compression ridges on interior walls and ceilings, out-of-square door frames, out-of-level countertops and window stools, Separations of upper framing members, and sloping floors.

It should be noted that not all distress in the Superstructure is necessarily caused by Foundation Movement. For further information on this, see Document No. FPA-SC-03-1, *Distress Phenomena Often Mistakenly Attributed To Foundation Movement* [5].

5.1.2 Differential Elevations Analysis – Used for Level B and C Investigations

Another valuable tool for assessing Foundation performance is the use of relative Elevations of the interior floors. These measurements can be utilized to complement the visual observations (see Section 5.1.1) 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 they could also indicate poor quality control in the original placement of the concrete slab.

A set of level measurements can be used to complement the visual observations. The best use of level measurements is when a previous set of relative measurements is available, and Foundation performance can be evaluated with observations over time. 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.

5.1.3 Forensic Analysis – Used for Level C Investigation

Refer to Document No. FPA-SC-12-0, *Guidelines for Evaluating Foundation Performance by Monitoring* [7] for more information on the following Level C investigation techniques:

- Geotechnical Testing
- Coring
- Petrographic Analysis
- Geophysical Testing
- Plumbing Leak Testing
- Groundwater Monitoring
- Aerial Photos
- Topographic Maps
- Foundation Excavation
- Rainfall Data

Other investigation techniques are also available.

5.2 CAUSES OF SOIL AND FOUNDATION MOVEMENT

Nearly all Foundation Movement occurs due to soil movement. Soil that is expansive can rise or fall at the surface by comparatively large amounts, sometimes as much as 12 inches. Residential and other relatively light low-rise buildings typically follow the movement of the upper soil. Often movements are not detected or detrimental because they are sufficiently uniform throughout the building pad. However, occasionally the soil movement is non-uniform such that differential movement of the soil supporting the Foundation occurs. If the anticipated differential movement was properly reported in the geotechnical report, a properly engineered 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 minimal.

They are many types of soil movement that cause Foundation Movement. Several of the more common types of movement causing Negative Phenomena in residential and other low-rise structures include Settlement, Subsidence, and Heave.

The most logical way to stop distress in the Superstructure due to Foundation Movement is to eliminate movement in the soils. Outside of completely controlling the soil's movement, the next most logical option is to allow for some soil movement and to design a Foundation that will perform within allowable parameters and standards for those movements.

5.3 ITEMS AFFECTING ALLOWABLE FOUNDATION MOVEMENT CRITERIA

Included in this section are some items that affect allowable Foundation Movement criteria.

5.3.1 Age

The older the structure is, the more distress the structure is likely to show. For an older and a newer structure with differential Deflections occurring over similar time periods, the Deflections should be analyzed the same for both structures. Ten (10) years is the usual cutoff for residences from a warranty standpoint. This document may be used in evaluation of a Foundation of a structure of any age, even though after ten years it becomes increasingly difficult to accurately determine the cause(s) of Foundation Movement due to the often-incomplete history of the structure and the increased probability of past Foundation repairs and / or more than one cause of Foundation Movement.

5.3.2 Published Construction Tolerances

Two authoritative 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 FPA 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-grade Foundations as-built level and flatness tolerances, which could be applied if desired by the building owner.

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. However, 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 committee locally finds that most residential slabs are constructed to a higher standard, i.e., within 1.0" of level.

The Texas Residential Construction Commission (TRCC) [11], which addresses both construction and performance tolerances from a warranty perspective, endorses the 1.5" initial out-of-level tolerance from *ACI 117* [1]. However, TRCC does not require an as-built Elevation survey and is unclear on how the TRCC's construction tolerance should be applied when no as-built Elevation survey was required to be performed or retained. TRCC is 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 in case of a later performance evaluation or dispute.

To exemplify the TRCC dilemma, when no as-built Elevations are recorded or retained, if one corner of a problematic 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 performance Deflection 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 comply with TRCC as far as construction tolerance of the Foundation. It will require an experienced TRCC Inspector or Forensic Engineer to correlate the distress phenomena in order to determine the more likely initial as-built Elevation of the corner.

6.0 ALLOWABLE CRITERIA FOR FOUNDATION MOVEMENT

ASCE's *Guidelines for the Evaluation and Repair of Residential Foundations* [3] and TRCC [11] contain published allowable criteria for Foundation Movement. However, because the specified allowable criteria in those publications are not fully coupled with related definitions, data acquisition methods, presentation methods and computational methods, the committee has found both methods to be open to varying interpretations. Together with previous sections of this FPA document, which have specified definitions, data acquisition methods, and presentation methods, this section provides the computational methods and allowable criteria needed to assess reasonable Foundation Movement limitations with less room for varying interpretation than the ASCE and TRCC publications.

6.1 FOUNDATION STIFFNESS AND FLEXURAL DEFLECTION

Distress induced in the Superstructure of a residence or low-rise building by Foundation Movement is generally caused by flexure (bending) of the Foundation system. When the supporting soil moves differentially in the vertical direction, the Foundation may experience differential vertical Deflection. Foundations are designed with some degree of stiffness. The stiffer the Foundation, the lower the amount of flexural Deflection for a given amount of soil movement. The design stiffness is determined based on the Geotechnical Engineer’s Foundation design parameters, the geometry of the Superstructure and Foundation, and the allowable flexural Deflections.

The allowable design bending Deflection is characterized by a ratio of the Effective Length (in inches) divided by a number. This number generally ranges from 240 to 480 for wood frame structures, depending on the type of bending (i.e., edge lift or center lift) and the type of structure. TRCC [11] requires computation of a Deflection Limit using the distance over which the Deflection occurs divided by 360. Experience 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.

Foundations may move substantially prior to completion of the architectural finishes. Oftentimes, craftsmen compensate for movement that occurs during construction by leveling the surfaces of the architectural finishes. Therefore distress phenomena may not reflect the total movement measured after construction is complete, particularly when the construction schedule is lengthy.

For purposes of setting a reasonable standard for flexure of slab-on-grade Foundation systems, *the Foundation Performance Association recommends that the Effective Length be divided by 360*, which is the same value specified by the TRCC [11]. TRCC's allowable was adopted by the committee after analyzing dozens of actual problematic foundations using the procedure presented in Section 6.3. However, the FPA has added a modification factor, k, as defined below~~,~~ that may be used to relax the Deflection Limit when the profile being considered is in a direction that is not parallel to one of the foundation's principal axes.

The k factor is computed as follows:

$$k = \frac{\sqrt{\text{length}^2 + \text{width}^2}}{\text{length}}$$

where:

length = distance along the longer principal axis

width = distance along the shorter principal axis

k = a factor varying from 1.000 (if along a principal axis) to 1.414 (if diagonally across a square) that modifies the Deflection Limit.

Various examples of determining principal axes and associated k values on a sample foundation are presented in Section 6.3.3.

The formulation presented here is for a foundation footprint that consists of a combination of rectangles with co-linear sides, which are typically parallel to the exterior walls. The principal axes are defined to be parallel to the perimeter edges of the foundation. Allowable Design Bending Deflections are typically calculated along a principal axis, thus the k factor is used to equate the measured Deflection along any diagonal to the Deflection along the principal axis. The k factor modifies the L/360 Deflection Limit to fall between L/360 (along a principal axis) and L/255 (diagonally across a square that is parallel to a principal axis) to compensate for measurements in a direction other than the principal axis.

The method for calculating the Deflection is illustrated in Section 6.3.

6.2 TILT

Foundation Tilt due to ground movement does not normally produce excessive bending stresses in the slab that affect the structural integrity of the Foundation. Therefore, 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 with a Tilt of one percent are usually noticeable to the trained Inspector. Symptoms of excessive Tilt (i.e. Tilt that creates Negative Phenomena), include:

- Brick veneer that rotates out of plumb to some degree that it becomes laterally unstable,
- Studs or other vertical support members of the Superstructure that rotate around the horizontal axis and become laterally unstable, and
- Roof support members of the Superstructure that have additional stresses from gravity loads that have increased due to the resulting eccentricity of the loads.

Although Structural Phenomena oftentimes will not occur when Tilt reaches one percent, the complaint from the building owners is typically one of functionality of the building when this much floor slope occurs. 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 [11]. See Section 6.3.1 for Tilt calculations and Section 6.3.2 for an example of evaluating Tilt.

6.3 EQUATIONS AND EXAMPLES

This section includes the equations to be used in conjunction with the allowables in Section's 6.1 and 6.2, as well as several examples for computing Deflection and Tilt.

6.3.1 Equations

The method presented for computing Deflection and Tilt is as follows:

L_{AB} = Overall Length or Width of Foundation for Tilt or flexure

Points 1 & 3 = End points of the span portion being considered for flexure

Point 2 = a Foundation intermediate point between, and vertically coplanar with, points 1 & 3

$L = L_{13}$ = Horizontal Projection of Deflected Span being considered

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 6.3.1-1.

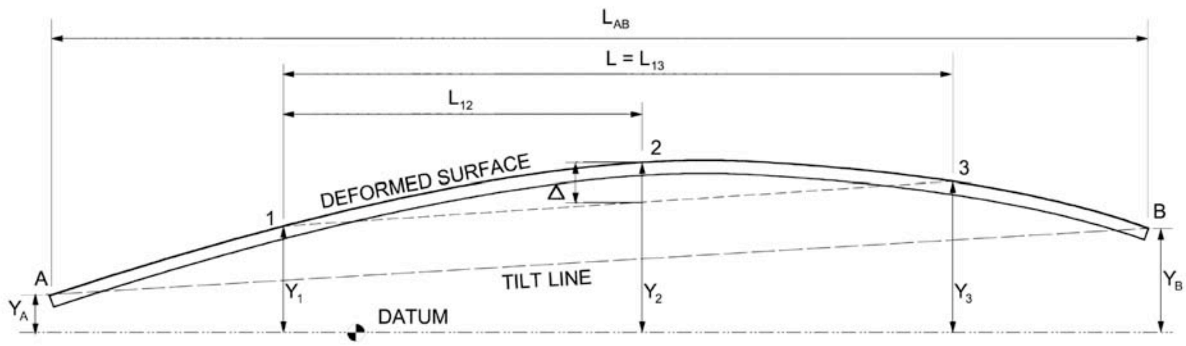

Figure 6.3.1-1 Sketch for computing Deflection and Tilt

Please note the following in using these equations:

1. Span Length (L) and survey Elevations (Y_i) are measured in the horizontal and vertical directions, respectively.

2. Survey Elevations (Y_i) may either be direct survey Elevation data or may be extracted from a Contour plan.

3. Span Length (L) may be anywhere along the foundation, whether in orthogonal or skewed directions, provided the span contains three survey Elevations (Y_1, Y_2, Y_3).

4. Tilt is considered over a span L_{AB} that extends from edge-to-edge of the foundation in any direction.

6.3.2 Calculation Examples

Several examples for computing Deflection and Tilt using the equations in Section 6.3.1 are presented in Figure 6.3.2-1:

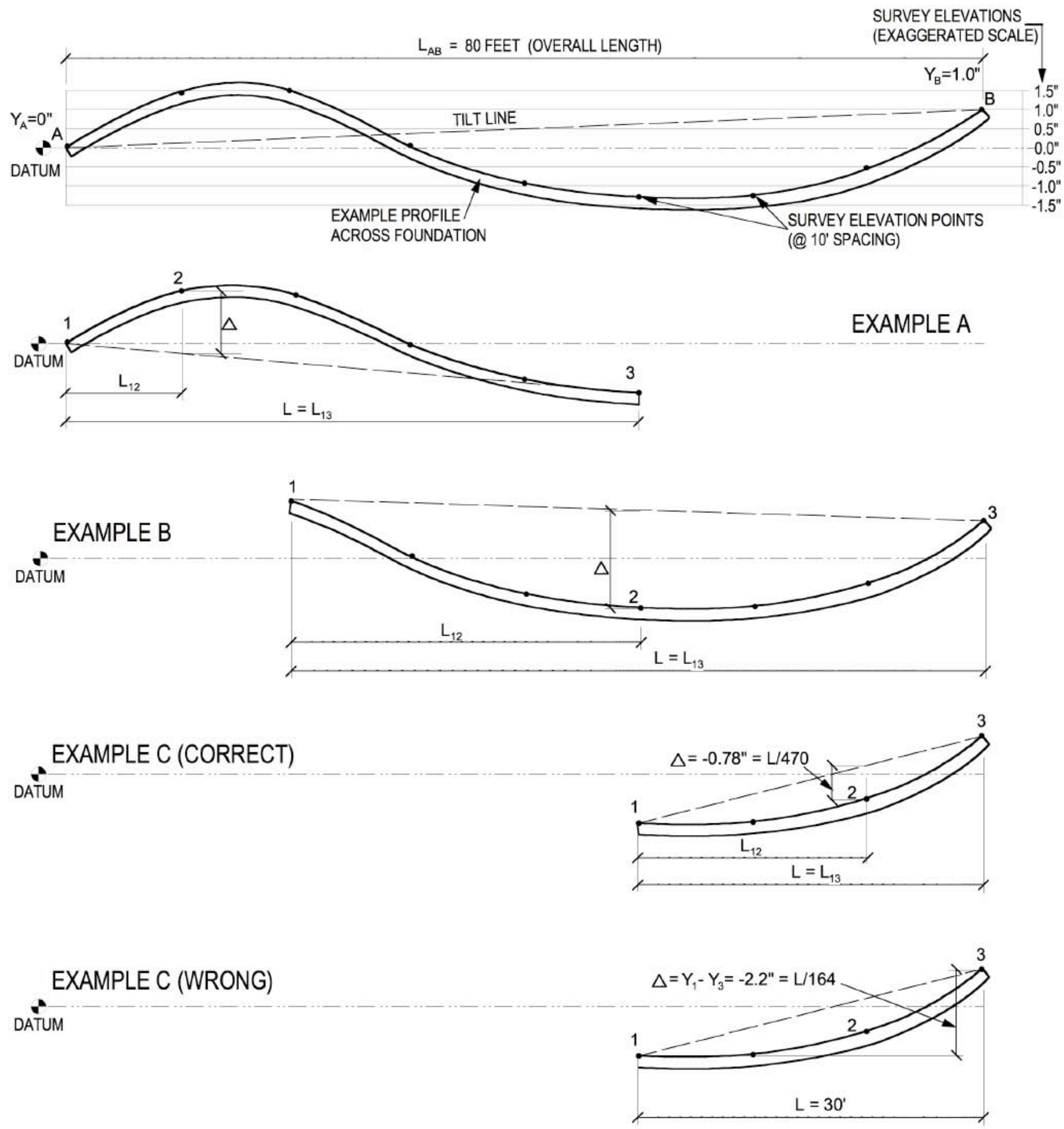

Figure 6.3.2-1 Examples A, B, and C

Note that a common misconception of 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 fails the Deflection Limit, rather than correctly computing the value of L/470, which passes.

From Section 6.2, the allowable Tilt must be less than or equal to 1%. For the 80 ft. profile in Figure 6.3.2-1:

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

which means the example profile passes for Tilt.

Computations for Deflections (Δ) for the above examples are shown in the following Table 6.3.2-1:

Table 6.3.2-1 Deflection and Tilt Examples

Ex.	L	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/470

For this example, A and C pass the L/360 Deflection Limit criterion, while B fails. Note that there can be other spans that will also fail if a spreadsheet is used to check all spans. In fact, for this profile, the maximum actual Deflection was found to be L/253 when a spreadsheet was used.

From Section 6.1, the Deflection Limit is L/360 unless the profile is *not* along a principal axis. As an example, suppose the above 80 ft profile is the diagonal of a rectangle measuring 59 ft x 54 ft along the principal axes. In that case:

$$k = \frac{\sqrt{\text{length}^2 + \text{width}^2}}{\text{length}} = \frac{\sqrt{59^2 + 54^2}}{59} = 1.36$$

The Deflection Limit is then: $\frac{kL}{r} = \frac{1.35\text{x}L}{360} = \frac{L}{266}$, which means Examples A, B, and C (see Table 6.3.2-1) pass the Deflection Limit criterion. However, in actuality another span not included in the example would still fail at L/253 (noted above).

Examples of how to decide whether the chosen profiles fall along a principal axis are presented in Section 6.3.3.

6.3.3 Determining Principal Axis' Lengths and Widths for Field Measured Lengths

The sample foundation presented in Figure 6.3.3-1 shows 12 possible profiles, each denoted as "L" (= "L_{AB}" for Tilt considerations if the profile extends from end to end of the foundation), in order to demonstrate how rectangles parallel to the principal axes may be chosen to adjust the L/360 Deflection Limit for conditions when the chosen profile does not follow the principle axes of the foundation.

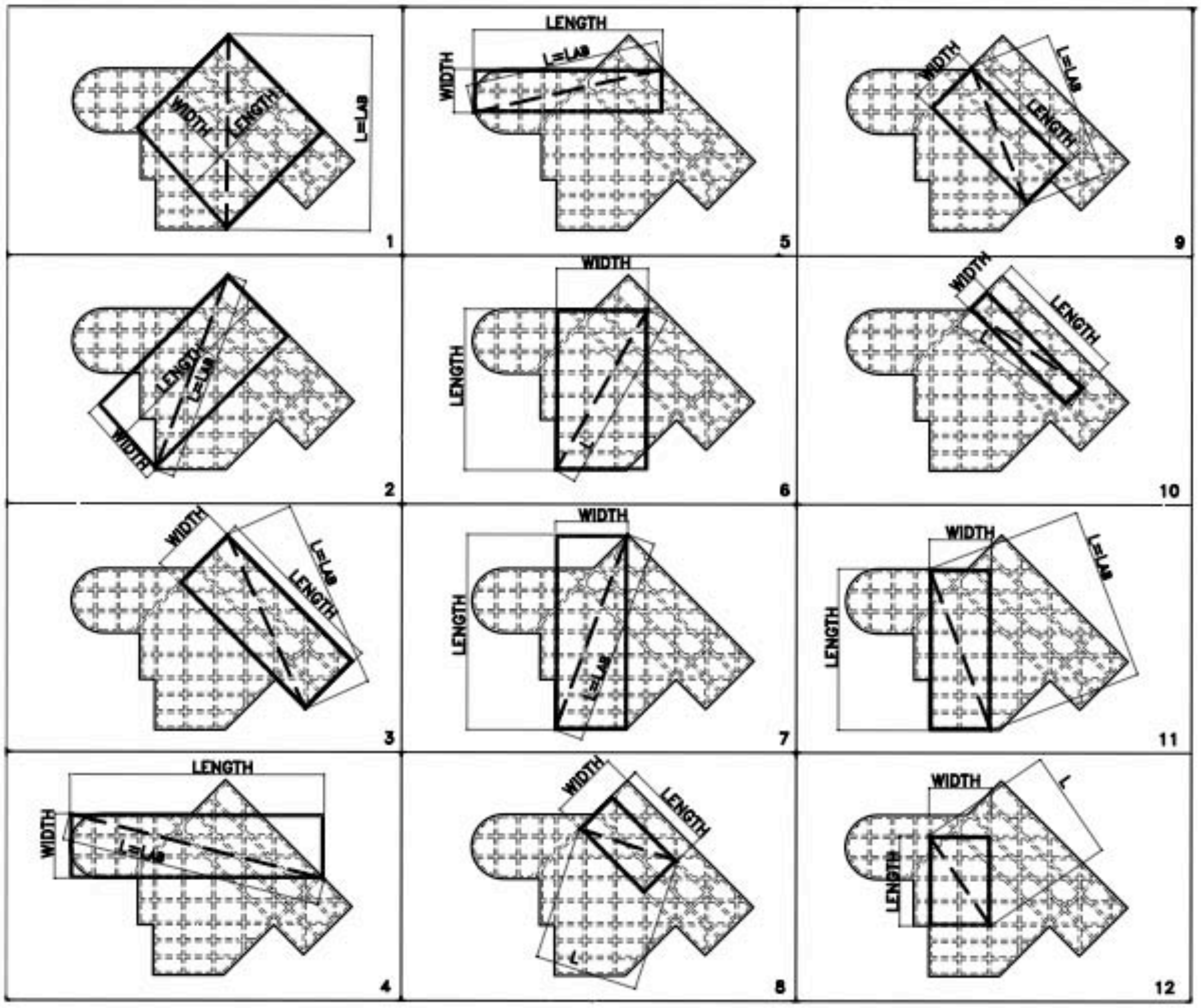

Figure 6.3.3-1 Sample Principal Axes to determine k Value

6.4 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 for reference purposes (see Preface for more detail). By analyzing these actual projects, the committee was able to correlate acceptable and unacceptable distress phenomena with actual survey Elevations in order to arrive at the maximum Foundation Movement allowables that are presented in Sections 6.1 and 6.2.

6.5 OTHER ANALYSIS METHODS

Any analysis method of Deflection must be tuned to the chosen Deflection Limit. There are other methods available to compute Foundation Deflection that may or may not necessarily fit the allowable criteria presented in this document. One method used by some engineers includes a polynomial curve fit or other regression type analysis. The presentation of other methods was outside the scope of this document.

6.6 COMMENTS ON FOUNDATION MOVEMENT

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

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

- 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 yards, landscaping, and watering programs are established.

- Seasonal movements, which are 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, improper roof gutter systems, faulty pool or pool deck installation, etc. Currently, the geotechnical reports typically provide no 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. Until the typical geotechnical report addresses these issues, these issues need to be addressed by the contractor and by the building owner through Foundation maintenance procedures as outlined in Document No. FPA-SC-07-0, *Foundation Maintenance and Inspection Guide for Residential and Other Low-Rise Buildings*. [6]

7.0 SUMMARY AND CONCLUSIONS

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

1. Terms defined for the purpose of this method are presented in Section 2.

2. This method requires a Level B or C investigation as defined in Section 3 and recommends data acquisition and presentation as defined in Sections 4 and 5.

3. This method requires calculations for Foundation Deflection and Tilt per the equations in Section 6.3.

4. Based on actual projects in the Houston area, the committee has proposed the following allowable criteria to be used in conjunction with the equations in Section 6.3.1:

   - Deflection Limit = $\frac{kL}{360}$
   - Maximum Allowable Tilt = 1.0%

   Where:

   a) Deflection is computed using any three points that are vertically coplanar. The plane may be along or at an angle to a Principal Axis of the Foundation (see Section 6.3.3),

   b) Tilt is measured from edge-to-edge of the Foundation in any direction (i.e., orthogonal or skewed, see Figure 6.3.1-1), 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 distress phenomena or by other means that a non-level condition more accurately represents the as-built condition.

5. The FPA understands there are other analysis methods [3,11] used in the industry. However, it is the opinion of the FPA that the method presented in this document is one of the first complete guidelines that combines allowable criteria with Deflection and related defined terms, data acquisition methods, presentation methods, and computational methods in a single guideline. Therefore, utilizing this guideline as an evaluation tool will provide less subjectivity when assessing whether a foundation is properly performing.

REFERENCES

1. American Concrete Institute (ACI) *117R-90, Commentary on Standard Specifications for Tolerances for Concrete Construction and Materials*, Re-approved 2002

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 1, January 1, 2003

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

6. 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

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

8. 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

9. 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

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

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