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Supplement #1
Revision A

Criteria for the Inspection of and the Assessment of Residential Slab-on-Ground Foundations

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FOREWORD

The Foundation Performance Association (hereinafter referred to as the Association) was founded on an ad-hoc basis in 1991 as the Foundation Performance Committee by a group of individuals who were involved with the design, construction, inspection, and repair of residential and other forms of light construction. The name was changed to the Foundation Performance Association in 2000. Meetings were held on a regular basis and committees were formed to investigate special issues. The Association is a nonprofit corporation in the State of Texas whose mission is stated at www.foundationperformance.org.

To accomplish this mission, several committees were formed for the purpose of assembling the information available in the industry on any one subject, and compiling it into a document that would be available not only to the public, but to the industry as well. After the Committee had prepared the document, the ensuing procedure would be followed. The document would first be issued to the Association for review and comments. After such comments were resolved, the document would then be issued to the public for their comment. The final step of the procedure would be the publication of this document for industry and public use.

The purpose of every document published by the Association is to compile the available data on that subject, which the members of the Association opine to be applicable to that subject, and to formulate recommendations on how such data may be applied to the design, construction, inspection, maintenance, and repair of structural foundations for residential buildings and other forms of light construction. It is the desire of the Association that these criteria documents be used not only to inform, but also to attempt to establish a sense of uniformity in the industry on that subject for the benefit of the general public. The ultimate goal of the review process is to incorporate any comments received into the body of the published document. All decisions regarding whether to incorporate any comment rests solely with the Association. Where appropriate, the Association may elect to publish approved comments in subsequent revisions of that document.

At the time this document was prepared (1998-2003), the Texas Board of Professional Engineers (TBPE) formed a committee for the purpose of examining the status of engineering problems with residential foundations. The purpose of this document is to add information from the "*Policy Advisory Guidelines Regarding Design, Evaluation and Repair of Residential Foundations (1998)*" by the Texas Board of Professional Engineers[1] in order to conform to the "Criteria for the Inspection of and the Assessment of Residential Slab-on-Ground Foundations" (FPC 201-97) that was issued by the Foundation Performance Committee in 1997. This will provide practicing professional engineers with guidance in the preparation of designs and evaluations of residential or other light foundations to minimize the probability that most problems currently encountered by homeowners will occur. In addition, valuable research data was obtained from the ASCE publication "*Damage and Distortion Criteria for Residential Slab-On-Grade Structures*" (August 1999). Also, reference is

[1] Policy Advisory Guidelines Regarding Design, Evaluation and Repair of Residential Foundations" (1998) is no longer effective and no longer available on the TBPE website *http://www.tbpe.state.tx.us/* Since the Board Policy Advisories of the TBPE change from time to time, one should check this website for any changes in this policy.

made to recent ASCE (Texas Section) publications "*Recommended Practice for the Design of Residential Foundations*" and "*Evaluation and Repair of Residential Foundations (2002)*".

The professional engineer should not use this Foundation Performance Association document as a "checklist" of activities needed to adequately perform an engineering assignment related to residential foundations, but should always rely primarily on his own experience and expertise.

This document is made freely available to the public through the Foundation Performance Association at www.foundationperformance.org so all engineers evaluating foundations for residential and other low-rise buildings may have access to the information. To ensure the document remains as current as possible, it may be periodically updated under the same document number but with new revision numbers.

The Foundation Performance Association 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. It is essential to understand that although the information published in these documents has undergone a substantial amount of review, the use of such information is not without risk and all such risks must be assumed by the user of the document. Also, it is not the objective of the Association to establish any requirements that would inhibit the free expressions of opinion or that would limit, in any manner, the ability of any individual who performs, on a regular or intermittent basis, the inspection of property. Such limitations are instead expressed as a matter of law.

In this document, we have discussed what the Foundation Performance Association considers to be a criterion for the inspection and assessment of residential slab-on-ground foundations. The goal of the Foundation Performance Association, in creating this document, was to establish these criteria with a sufficient amount of rigor to meet the objective of establishing a reasonable degree of standardization without limiting the ability of the investigator to properly describe and assess the in-situ conditions. As previously stated, these criteria are not backed by any force of law; however, we believe that they do reflect the current accepted minimum standard for such work. As such, we are of the opinion that if one follows these criteria, the work done by an investigator is based on accepted reasoning and methodology. The inherent limitation in using this criteria, as well as any other published criteria, however, is that the ultimate responsibility for the work rests with the user who implicitly agrees that neither the authors of this document nor the Foundation Performance Association shares this responsibility, whatsoever.

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1.0 INTRODUCTION

The "Committee for the Inspection of and the Assessment of Residential Slab-on-ground Foundations" (originally called the L/360 Committee) was founded for the purpose of attempting to establish a criterion against which the performance of residential foundations could be judged with regard to their in-situ performance. The Committee consisted of the following members:

Don Lenert, PE, Lenert Engineers, Inc. -- Chairman
Michael Skoller, PE, National Structural Engineering, Inc.
Dan Jaggers, Olshan Foundation Repair Company
Comments as offered by the membership of the Foundation Performance Association and other interested parties.

It soon became apparent to the Committee that in order to uniformly apply any criterion that was written, it would first be necessary to attempt to obtain some uniformity in the manner in which residential foundation inspection data were acquired and presented. It also came to the attention of the Committee that there were engineering reports being written that attempted to convey the performance condition of residential foundations; however, there was enough disparity in the manner in which such reports were presented that disagreements sometimes ensued more from interpretation than because of differences in opinion. Thus, the Committee elected to divide the activities into the following categories:

- Types of foundation inspection
- Data acquisition and presentation
- Data analysis and criteria assessment
- Conclusions and recommendations
- Report preparation
- Preparation and publication of the analysis
- Additional research that confirms many conclusions in this FPA document.

1.1 INTRODUCTION

The Texas Board of Professional Engineers (TBPE) Newsletter No. 28 (winter 1998) had an article regarding their "Policy Approved for Residential Foundations". A disproportionate number of complaints against professional engineers performing tasks related to residential foundation design and inspection provided impetus for the TBPE to address problems associated with this area of engineering practice. At their September 1998 meeting, the TBPE approved guidelines for professional engineers and building code officials regarding the design and inspection procedures for residential foundations. The Residential Foundation Association of the TBPE drafted the basis of the recommendations during meetings held in the fall of 1997 through the spring of 1998. The TBPE implemented the residential foundation recommendations in the form of a policy advisory on Sept. 11, 1998. "The policy serves as a guideline to assist engineers, but it can never replace an engineer's judgment," said John R. Speed, P. E., previous executive director of the Board. These guidelines can be accessed from the Internet at: http://www.tbpe.state.tx.us/. Those sections of this document that apply to the inspection and assessment of residential slab-on-ground foundations have been inserted in this FPA document.

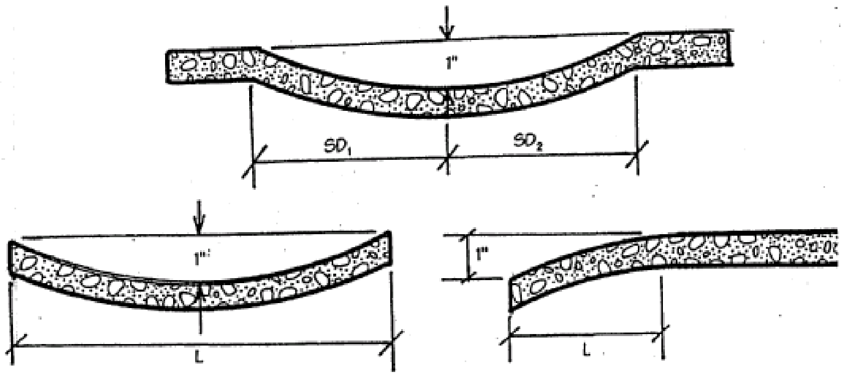
As of this date, there is an increasing uniformity among Engineers in the real estate inspection business in evaluating foundation performance. Such uniformity did not exist until more recent times. The Foundation Performance Association* and its' associated members, through their background in the discipline of quality engineering, were able to set a standard of practice to which a majority of others in the real estate inspection business have subsequently followed.

* *The FPA welcomes any suggestions from practicing structural engineers and other experts in the field in order to improve this document. We invite interested parties to attend our regularly scheduled meetings held at 5:00 PM on the third Wednesday of every month and to offer positive feedback towards revising this document. See the Foundation Performance Association website at "**www.foundationperformance.org**" for scheduled events and additional information.*

1.2 DEFINITIONS

Deflection is the vertical difference in elevation between two points, where curvature or bending has occurred and is defined[2], as follows:

$$M = \frac{EId^2y}{dx^2}$$



The terms x and y are the abscissa and ordinate, respectively, of a point on the neutral axis. The first integration gives the slope and the second integration gives the deflection. The significance of this definition is that if y = 0, there is no deflection, but tilting has occurred. Deflection only occurs where y > 0; i.e., there is bending in the foundation. It is the bending in the foundation that induces the type of stresses in the upper structure that causes damage to occur. If no damage is present, it is possible that the foundation was originally built out of level or that previous damage had been repaired. Deflection may be measured as the vertical height occurring between two supports (i.e., as a simple supported concrete beam spanning between two supports) or occurring as a cantilevered beam where adequate soil support does not exist at one end. See "**Slope**" for a definition of SD.

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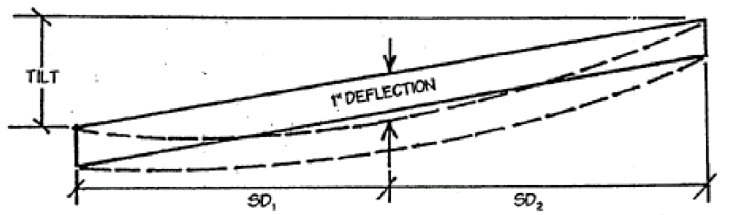
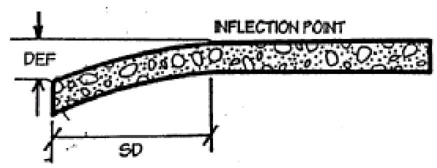
[2] Manual of Steel Construction, American Institute of Steel Construction. *Please note that deflection does not necessarily imply movement.*

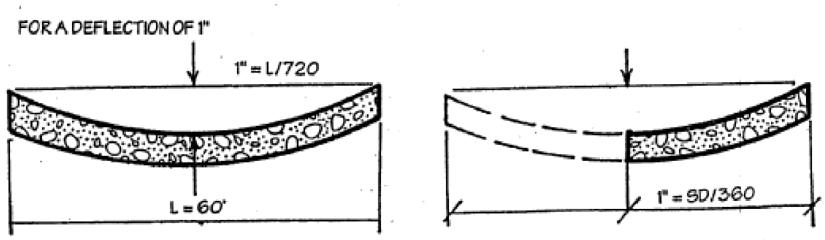
Differential Deflection is defined as the amount of curvature occurring between two separate points. Due to the cyclic nature of many soil movements, there is no assurance that the differential deflection at the time of measurement will be at its maximum value.



The ***Inflection Point*** is the location in the foundation where the direction of curvature changes. Refer to standard structural texts for elaboration of this term.

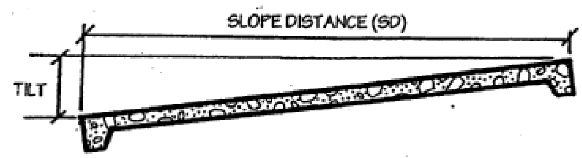


Slope is defined, in this document, as the vertical difference at the ends of two horizontal points, as shown below. In foundation analysis, slope may or may not be a straight line. When slope is a curved line, the curvature may be irregular, or even reversed, along its length. The length in which a slope occurs is called the ***Slope-Distance (SD)***[3] and is usually expressed in slab-on-grade systems as the maximum vertical difference that occurs at the high and low points of a foundation system. SD may be calculated along the exterior walls of a building, and at the high and low points of the interior.



[3] Lenert, Donald: "Foundation Distress Evaluation and Assessment for Residential Structures." Soil Structure Interaction Seminar, Foundation Performance Committee, July 25,1996

Tilt is a relatively uniform slope from one end of a building to another. Tilting can occur as the result of soil heaving or settlement, but without foundation bending having occurred. Typically, there is little damage when tilting occurs, especially if the foundation design is adequate. Framing and walls are perpendicular to the foundation. Counters, sills, etc. are parallel to the floors. Tilting can also be the result of the foundation slab having been originally built in an unlevel condition. Under such conditions, walls are generally vertical and counters, sills, etc. are in a level plane. An out-of-plane bending analysis may also be considered, since the upper structure can develop a horizontal component that may be a factor.



Foundation Includes the slab, grade beams, footings, void boxes and soil that together form the foundation system.

Foundation Failure has occurred when a foundation system no longer performs its intended function of providing a stable support for applied loads (observed performance falls short of normal, expected or building code structural design requirements). the word "*stable*" is the key word in defining foundation failure in terms of performance. *stable* means that foundation movement, elevation changes and/or negative phenomena are minimal or non-existent.

Foundation Collapse Failure has occurred when the performance and the allowable deflection have been exceeded and the foundation cannot be repaired without rebuilding.

Distress A change caused by movement (foundation, framing, soil, thermal, etc.) that is reflected by the creation of cracking or other negative phenomena.

Damage Visible distress in building components, such as drywall cracks, door frames out of square in their frames, concrete cracks, etc. see "*negative phenomena*" below for examples of types of damage caused by foundation movement.

Relative) Flatness is the relationship of the foundation elevations as related to itself. the relative vertical elevation differences between different types of floor coverings, such as between carpeting and floor tile, are adjusted in order that their elevations are relative to each other. the relative difference between adjacent carpeting and floor tile should be zero, since the concrete slab would be at the same elevation below both types of finishes.

Foundation Movement is an apparent post-construction movement of a foundation system that is detectable by changes in elevation accompanied by visible signs of distress, such as drywall cracks, doors out of square in their frames, concrete cracks, etc. These changes are necessary in order to confirm that movement has occurred after the original construction was completed. We use the term as also meaning "*differential foundation movement*" or "*foundation deflection*."

Differential Foundation Movement is the difference in vertical elevations as a result of post-construction movement. For example: Even though there may be a measured vertical elevation difference (that might be interpreted as post-construction foundation movement), unless negative phenomena are present to confirm that a movement actually occurred, the building may have originally been built this way.

Foundation Deflection is the configuration of a foundation system in relation to a horizontal (level) condition. It may be depicted on a profile drawing as the elevation difference between the extreme high and low points.

Post-Construction Movement is observed or confirmed via changes from the original construction, such as the formation of new cracks, colors, levelness, binding doors, etc.

Manometer A water level; i.e. a U-tube manometer or Bulb manometer.

Electronic Level A device that measures the relative elevations of floor coverings to within approximately +/-1/8" accuracy.

Laser (or Optical) Level A device that generally consists of a rotating light mounted on a tripod that registers vertical elevations via an electronic receiving instrument mounted on a surveyor's rod.

Negative Phenomena is seen as cracking, doors binding or out of square in their frames, or other evidence that movement occurred after the original construction was completed. This movement may have been the result of changes in the foundation, framing or thermal configuration. See "Observable Phenomena" for examples. It is clear that negative phenomena should be considered more important than survey elevations when considering evidence as to whether nor not a foundation actually moved or whether it was originally built out of level. In other words, negative phenomena are necessary in order to prove that post-construction movement actually occurred. On a building that is being investigated for potential foundation problems, design and construction are already completed. The performance may be assessed by the use of micro-elevations, but should be compared** with existing negative phenomenon, including items that are shown on the <u>Phenomena Plan</u>. The following are examples of commonly found negative phenomena:

Concrete crack	Vertical trim separation
Vertical, diagonal or horizontal brick crack	Crown molding trim separation
Vertical, diagonal or horizontal drywall crack	Roof frieze board movement
Binding door	Sloping countertops
Ceiling drywall crack	Tile floor crack
Drywall crack @ window/door head	Baseboard separation

Obvious sloping floors
Binding doors or "pie-shaped" gaps between doors and frames
Brick chimney leaning outwards away from main building
Floor tile pulling away from baseboards
Presence of algae at the exterior, indicating super-saturated conditions exist
Existence of earth cracks next to exterior walls indicating an extremely dry condition exists
"Popped" nails in drywall walls
Separation of wood trim from wall elements at windows, brick, stucco or drywall
Roof leaks despite roofing material that is in good condition

Poor concrete and reinforcing placement or lack of curing
"Soft" concrete that suggests lack of durability
Corner drywall cracks at the top of windows or doors

The following items may also be shown on the structural drawings:

<------ Direction of downward slope (the total amount of change between the high and low points may be shown when appropriate)

* Contradiction between observation & elevation data *(this is used when an elevation change indicates a slope in one direction while the negative phenomena may suggest a slope in another direction).*

**Note: The micro-elevation survey plan and phenomena plan should be compared to confirm whether differential foundation movements have occurred. The presence of a change in the slab elevation (slope) does not necessarily mean that differential movement has occurred. The construction of slabs-on-grade is typically within 3/4" in vertical elevation control for homes of normal size. However, it is essential that any measured sloping floor systems be accompanied by some type of negative phenomenon, such as itemized above. If these are not present, then it is quite possible that the building was originally cast out of level. Refer to “Distress Phenomena Often Mistaken for Foundation Movement” in Appendix C for additional discussion.

2.0 TYPES OF FOUNDATION INSPECTIONS

2.1 EVALUATION OF FOUNDATIONS

When evaluating an existing residential foundation, engineers will be expected to report their findings in a manner that clearly identifies:

The purpose of the evaluation;
The level of evaluation at which the work was performed; and
Limitations regarding the conclusions that are drawn given the level of evaluation used.

The client and/or the engineer establish the level of evaluation. The engineer is typically expected to recommend and perform the lowest level of evaluation needed for adequate analysis of the situation. All evaluations, regardless of the level at which they are performed must be of professional quality as evidenced by communication using clear and concise language with sufficient and appropriate data, careful analyses, and disciplined and unbiased judgment when drawing conclusions and stating opinions that can be readily understood by their client or other expected audiences. For the purpose of aiding the client in determining the type of evaluation performed, the following three levels of evaluation are recommended:

2.1.1 **<u>Level A</u>:** Furnish a report of first impression conclusions and/or recommendations that will not imply any higher level of evaluation has been performed.

a. Define the scope, expectations, exclusions, and other available options;
b. Interview the homeowner and/or client if possible, regarding the history and problems of the property;
c. Document visual observations personally made by the engineer during a physical walk-through;
d. Describe the analysis process used to arrive at any performance conclusion;
e. Provide a report containing one or more of the following: scope, observations, opinions, performance, conclusions and recommendations based on the engineer's first impressions of the condition of the foundation.

2.1.2 **<u>Level B</u>:** In addition to the items included in Level A, the following will typically apply:

a. Review available documents such as geotechnical reports, construction drawings, field reports, prior additions to the foundation and frame structure, etc.;
b. Using a probing rod, establish grade beam depth & visual soil information (relative moisture content, soil strength, plasticity index);
c. Determine relative foundation elevations to assess levelness at the time of evaluation and to establish a datum;
d. Determine existing site drainage and/or problems around building and site; document large tree locations near building;
e. If appropriate, perform non-invasive plumbing tests;
f. Document the analysis process, data and observations;
g. Provide conclusions and/or recommendations;
h. Document the process with references to pertinent data, research, literature and the engineer's relevant experience, if appropriate.

2.1.3 **<u>Level C</u>:** In addition to the items included in Levels A and B, the following will typically apply:

a. Conduct non-invasive and invasive plumbing tests as required;
b. Conduct site specific geotechnical and/or geophysical investigations as required;
c. Survey and document drainage slopes within 10' of building perimeter (and elsewhere on lot if appropriate);
d. Conduct materials and other tests as required to reach a conclusion, such as post-tensioning cable testing, concrete core samples, etc.;
e. Obtain other data and perform analyses;
f. Document the analysis processes, data and observations;
g. Provide detailed drawings and/or photographs showing locations of negative phenomena, trees, planter beds, drainage, sub-surface moisture variations, etc.
h. Provide conclusions and/or recommendations.

The engineer should substantiate all assumptions, conclusions, and recommendations using appropriate references when the engineer's opinion is contrary to generally accepted scientific and engineering principals. Terms such as "failure", "distress", "damage", etc. are defined herein. When an evaluation is to be used in comparison with another report, the engineers should make every effort to provide a correlation to the definition used in the previous report in addition to any other definitions used in their own report. Engineers must draw any needed distinctions between "failures" discussed from a structural aspect and "failures" discussed from a performance aspect. ***Note:*** *repair procedures are not included in the scope of this document, although the Foundation Performance Association has presented several day-long seminars over the past several years that included this subject.*

2.2 INSPECTION PROCEDURE

Professional engineers should base their reports for foundation evaluations by one of the three levels of evaluation described in this Supplement and understand the scope and limitations associated with each level. If a particular purpose is intended for the evaluation (such as the development of a repair plan or a forensic report), the engineer should establish the minimum level of evaluation required for adequately accomplishing that purpose.

The examinations that may be anticipated for each type of inspection are listed in Table 1 below:

2.2.1 **TABLE 1**

FOUNDATION INSPECTION METHODS

INSPECTION METHODS	INSPECTION TYPE		
	HOME OWNER	REAL ESTATE	FORENSIC
Preliminary Walk-Thru & Initial Examination	X	X	X
Preparation of the Building Plan Sketch	O	X	X
Preparation of the Negative Phenomena Plan	O	O	X
Measure the Relative Flatness* of the Slab (* *see page 18 for definition*)	O	X	X
Data Presentation	X	X	X
Conduct Geotechnical, Structural and/or Other Tests	O	O	X
Drainage Investigation	O	O	O
Monitoring at Regular Intervals	O	O	O

X Recommended **O** Optional

2.2.2 **Owner Consultation (Level A, B or C):** The significance of foundation problems has received an increasing amount of publicity in the recent past. As a result, a majority of homeowners in this general area when confronted with negative phenomena, such as cracks, distortions, etc., seek the advice of an expert with regard not only to the seriousness of the damage but also with regard to any remedies that may be required. One of the major differences between this, and a real estate inspection, is the need to be as specific as one can be, considering the inherent limitations to any diagnoses that may be produced. For example, any inspection and diagnoses of a foundation problem, which includes a recommendation for foundation repair, should include the presence of those environmental factors, such as near-by trees, drainage, etc., that may have adversely affected the performance of the foundation. Also, the presence of sloping floors in an older building, where the owner has no current intent to sell, may not be as significant as it would be if the purpose of the examination was to provide information to a potential buyer or to a jury. Sometimes monitoring a foundation system over a period of time is recommended to determine if the seasonal variation of the foundation is within a range that is reasonable for this type of structure or to determine the cause of distress.

2.2.3 **Real Estate Transactions (Level B):**
The purpose of such inspections is to provide a potential buyer of a residential property with an opinion regarding the current performance of the foundation along with an analysis of its current

state compared to other residential buildings of similar age, type of construction, and similar location. The performance of residential foundations generally falls into one of the three following categories: (1) very good, (2) very bad, or (3) somewhere in between (not so good, yet not so bad). Unfortunately, a majority of the foundation conditions fall within the third category. Thus, the objective of such an inspection is to simply provide information to the potential buyer so that an informed decision can be made with regard to whether or not to purchase the property and, if so, at what price. Thus, there is, in reality, no absolute pass/fail criterion that applies in this type of inspection. The individual conducting such an examination most often must provide the potential buyer/seller with conclusions based on acceptable engineering standards and sound engineering practice so that the buyer/seller may make an educated decision.

2.2.4 Forensic Examination (Level C):

The word forensic, as used in this application, implies that the results are to be used in conjunction with legal matters. An expert conducting a forensic examination has one, and only one, objective in such a task and that is to provide a listing and an assessment of the existing available facts and not to act as an advocate for either party in a legal matter. On this basis, the examination of the foundation and its attached structure for this purpose is, by far, the most detailed type of examination conducted and the examiner must obtain all of the data that can be acquired within the budget limitations assigned by the client. Any results of such an examination must be accurate and pointed. The diagnoses must be based upon the evidence which has been made available and which has been analyzed on the basis of existing engineering principles.

There is, within the forensic industry, a principle, which has been upheld by the U. S. Supreme Court, that the resume of the examiner is not, alone, sufficient but the presentation must be based on methodology that, as a minimum, has survived a peer review. Such an examination has been referred to as a "Daubert attack”. Such requirements have been further refined by the Texas Supreme Court in the Dupont vs. Robinson case.[4]

[4] Du Pont vs Robinson, Supreme Court of Texas, No. 94-0843, July 8, 1996

3.0 DATA ACQUISITION AND PRESENTATION

The following is a discussion of the examination methods that may be employed during the inspection of a residential foundation. Included in this discussion will be an analysis of the viability of each method.

3.1 <u>Initial Examination</u>: The first part of this inspection process involves the visual examination of the residential building. The first thing an examiner should do is to make a cursory tour of the property both inside and outside of the building. The purpose of such an examination is to be able to formulate a more detailed plan for the remainder of the investigation. The negative phenomena (cracks, distortions, separations, etc.) should be examined to determine their extent so that a phenomena plan can be prepared. Such a plan can be put to writing or simply be mentally planned out by the examiner. The owner/tenant/agent should be interviewed for any information concerning the history and any known present or past problems on the building (if known). Inquire about the age of the structure, tree removals, repairs or remodeling, recent changes in watering patterns and recent repairs to the plumbing, drainage or foundation.

<u>3.2 Preparation of the Sketch of the Building Plan:</u> The next step in the procedure should be the preparation of a drawing or a sketch of the building plan. Where applicable, the plan may be of the residential building 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. An example of one such sketch is shown in Figure 1. One of the most significant items on any drawing is the relative location of any trees and other landscaping features to the foundation. It is prudent to make the drawing to scale rather than to do it on a free-hand basis since proportionality can become an important factor.

<u>3.3 Phenomena Plan</u>: Having the drawing in possession, a phenomena plan can then be prepared. This plan must be prepared in such a manner as to give the reader an understanding of the relationship between the distortions that currently exist in the foundation being examined and the damage (expressed sometimes as “negative phenomena”) that has occurred. The phenomena plan can best be illustrated in a hypothetical example, such as is contained in Figure 2. In this example, the damage is limited to the degree that it can be illustrated on a comparatively simple diagram. In some cases, the number of distress features may become so great that any attempt to find any correlation may be futile.

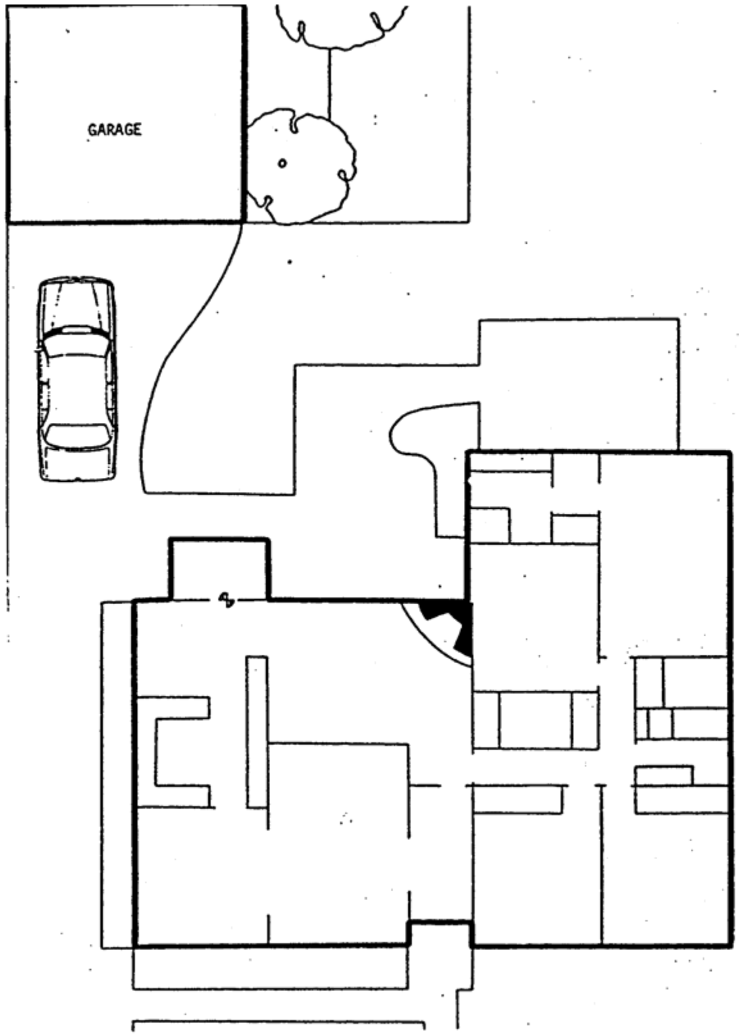


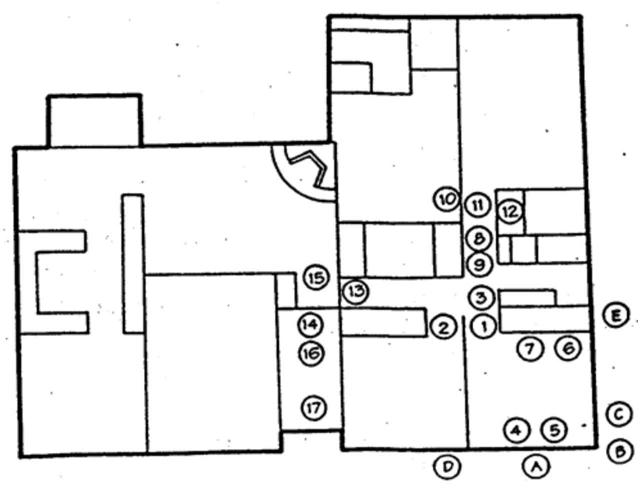
FIGURE 1. TYPICAL PLOT PLAN

DAMAGE DESCRIPTION

1. Door frame distortion
2. Door frame distortion
3. Crack at door frame corner
4. Window frame distortion
5. Vertical/horizontal crack
6. Door frame distortion
7. Crack @ register corner
8. Door frame distortion
9. Crack @ door frame corner
10. Crack @ door frame corner
11. Door frame distortion
12. Door frame distortion
13. Door frame distortion
14. Door frame distortion
15. Door frame distortion
16. Crack @ door frame corner
17. Front door binds

A. Brick veneer crack
B. Brick veneer crack
C. Brick veneer crack
D. Brick veneer crack
E. Brick veneer crack

FIGURE 2. TYPICAL PHENOMENA PLAN



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3.4 Measuring the Relative Flatness of the Foundation: The next step in the procedure should be determination of the sloping conditions that exist on the interior floors of the building since they should, in most cases, provide a direct indication of the deflection or tilting that has occurred in the foundation. The presence of negative phenomena is one way to determine if post-construction movement has occurred. Any difference between deflections and tilting will be discussed in more detail later in this paper. The term **"foundation movement"** is not technically definable since the uniform movement of the soil in this area as it expands and contracts over the seasons is not readily detectable and does not ordinarily cause any damage to the foundation as it moves. We use the term to mean **"differential foundation movement"** or **"foundation deflection."** In pier-supported buildings, natural bending deflection of grade beams between piers should be included in the evaluation if necessary.

There are three basic types of measurement devices that have been used in some degree of success in providing foundation relative elevation data: The **manometer**, as it is used in this application, is based upon the principle that water will seek its own level; i.e. the surface of the water will be parallel to the surface of the earth. There are two basic types of manometers that are used; i.e., the U-tube manometer and the Bulb manometer. Either of these devices will provide satisfactory results. Several **electronic levels** manufactured by various companies are manometer based and provide relatively accurate elevation readings. The **laser (or optical) level** has been used for decades.

The choice of which device to use depends on which one is more convenient to the user. The laser and optical levels are best used for large open areas, such as warehouses, where only a few turning points are required. The **water level** and **electronic level** are advantageous for residences that have numerous small rooms that can be measured without the line-of-sight and numerous turning points needed by the optical and laser instruments.

A typical procedure for the use of both the manometer and the electronic level is as follows. An arbitrary reference point is established some place inside or outside the residential building. One end of the manometer is placed on a reference point while the other end is moved to various locations around the room for the purpose of measuring relative heights in selected points. The choice of the reference point is totally arbitrary. It is often convenient to place the reference point some place on the interior of the building and/or at a location where floor finishes of different heights above the foundation system come together. The selection of a reference point, if properly done, can eliminate the possibility of having turning points and/or having to compensate for differences in floor covering heights. It is essential that adjustments be made for variations in the heights of floor coverings so that the measurements reflect the true heights of the foundation slab. Once the data have been acquired the measurements can then be annotated on the plan drawing of the residential building.

Another device that has been used frequently in this type of work is a **laser level**. This device generally consists of a rotating light mounted on a tripod in such a manner that the head of the tripod can be leveled. Once the laser light is set up at some location, one can move a measuring stick from point-to-point throughout the line-of-site of the laser device and read the differences in elevations between points off of a scale. Compensation can be made for variations in floor height covering by taking a reading off of the top of the thicker covering and one off of the adjacent floor. The amount of difference between the two would then become an adjustment for the remaining measurements that are taken. Where it is desirable to take readings that are not in the line-of-site with the laser source, it will need to be moved. The operational procedures for acquiring these data are similar to those used when making the survey with a water level.

In terms of accuracy, considering the numerous interior rooms in a residence, all of the foregoing devices give approximately the same results. The presentation of the plans may be in architectural (1/8” = 1’-0”; 3/16” =1’-0”) or engineering (1” = 10’; 2” =10’) scale measurements. The elevation data may also be presented in either fractions of an inch (3/4”, 1/2”) or decimals of an inch (0.75”, 0.50”). The accuracy of either scale is approximately the same; however, there are other factors that contribute to the accuracy of the measurements taken:

1) Floor coverings, such as carpeting or tile, have thickness variations well over 1/16". If one were to move the measurement device a short distance away, it would not be unusual to find small variations in the elevation readings due to localized unevenness of the slab surface.
2) Each time it is necessary to make a turning point, as is often required when using a laser level, the accumulated reading error can double. Electronic or water levels usually do not share this problem.
3) Garages or other areas having sloped floors may be measured at either the bottom plate at the curb, the exterior brick or the ceiling elevations.
4) The analysis of these data generally involves making assumptions that would negate any benefits that might be accrued in improving the overall accuracy of such measurement systems. One can produce an accuracy of +/- 0.1" in any one set of measurements and a repeatability of +/- 0.2" between sets of measurements made at the same locations in the same building, but at different times. Such data are usually sufficiently accurate for an adequate analysis to be made.

3.5 <u>Data Presentation:</u> Data should be presented in a manner that may be equally understood by the client as well as other professionals. This can obviously be a difficult task in some cases. We have found that presenting the data in raw numerical form, in contour form or in cross sectional form can often achieve these results. We have utilized data taken from an actual residential building to illustrate how this can be done. We recommend that all the survey data be included in the report. It is extremely important that the level measurements be presented in the report so that a comparison can be made in future surveys. The summary of the survey data may include a plan with equally spaced contours. Showing the maximum slopes between high and low points may help to interpret the data (see figure 6). When necessary, profiles cut through high and low points have a similar benefit. The needs for the drawings below are left to the discretion of the inspector.

Figure 3 shows the raw measurement data taken during the first inspection of the property. The measurements are shown on an engineering scale in tenths of an inch. From these data, one can ascertain that there is a definite downward slope of the floors toward the lower right quadrant as well as at the interior of the building. The number of survey points is left to the discretion of the inspector, although sufficient readings should be made to reasonably ascertain the highest and lowest areas of the foundation. The four corners and middle of each room are normally sufficient. If the difference between adjacent survey points is greater than 10’ horizontally or _” vertically, then additional points should be considered.

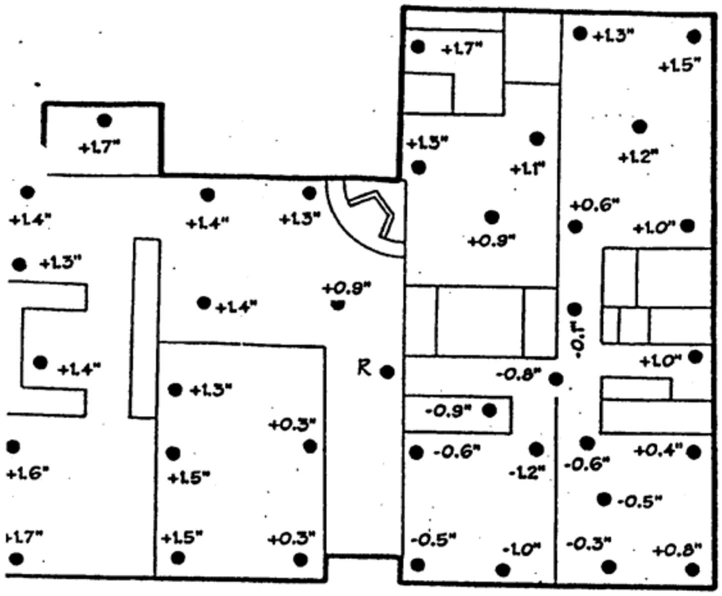

FIGURE 3. MEASUREMENT OF RELATIVE HEIGHTS

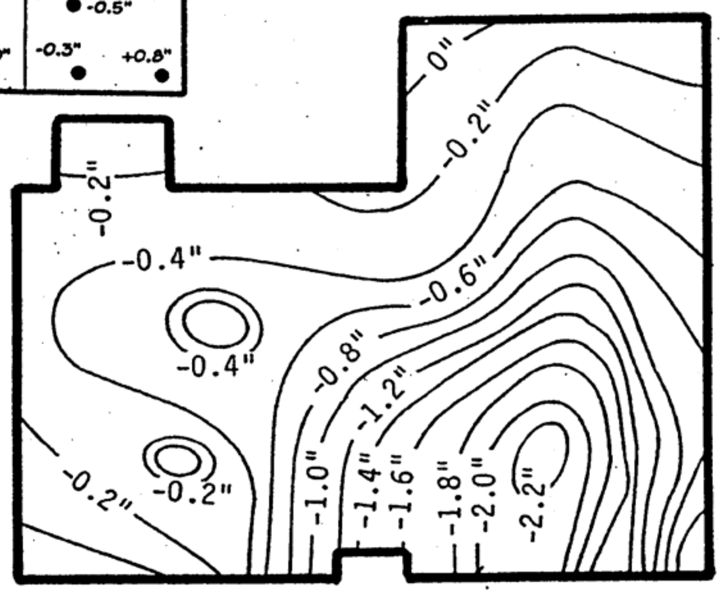

FIGURE 4. CONTOURS OF EQUAL HEIGHTS

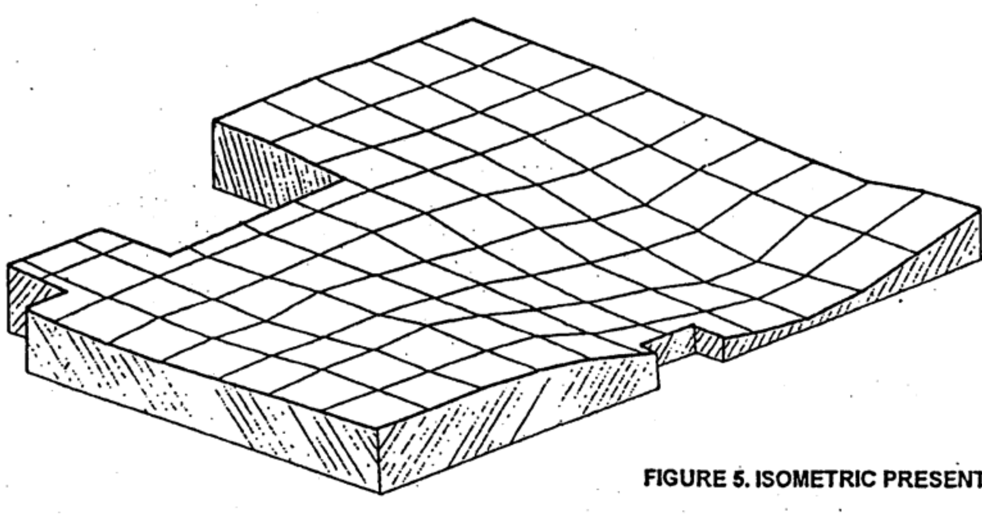

FIGURE 5. ISOMETRIC PRESENTATION

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- Figure 4 shows the contours of equal height that were drawn using the data from Figure 4. These contour lines display the trend in the building towards a downward slope from the left hand side towards the right. The use of contour lines is recommended in order to convey the overall configuration of the foundation system in an uncomplicated way.
- Figure 5 shows, as a matter of interest, an isometric drawing that displays the surface of the foundation in a different way. The drawing was made in the following manner. The outline of the building was drawn in an isometric plane. The plane was then divided into intervals of five feet in either direction. From the contour drawing, the contour heights were read at the intersection between the horizontal and the vertical interval line and were vertically plotted using a different scale. The purpose of such a drawing is to convey the surface of the foundation slab plane in a 3-D perspective.
- Figures 6 and 7 show the same type of data in a different format using slope arrows to designate the elevation variations between the high and low points. It is not our intent to dictate the manner in which such data are displayed so long as the meaning is conveyed to the reader.

One should not ignore the second story phenomena in two-story buildings. Where damage is limited to the upper stories, one must take such measures as described above to insure that the damage is not the result of framing deficiencies. The need to survey the second floor (for comparison with the first floor) is left to the discretion of the inspector. Note that the wood framing members will sag between supports, so care should be taken to compare points over load bearing walls with the same points below.

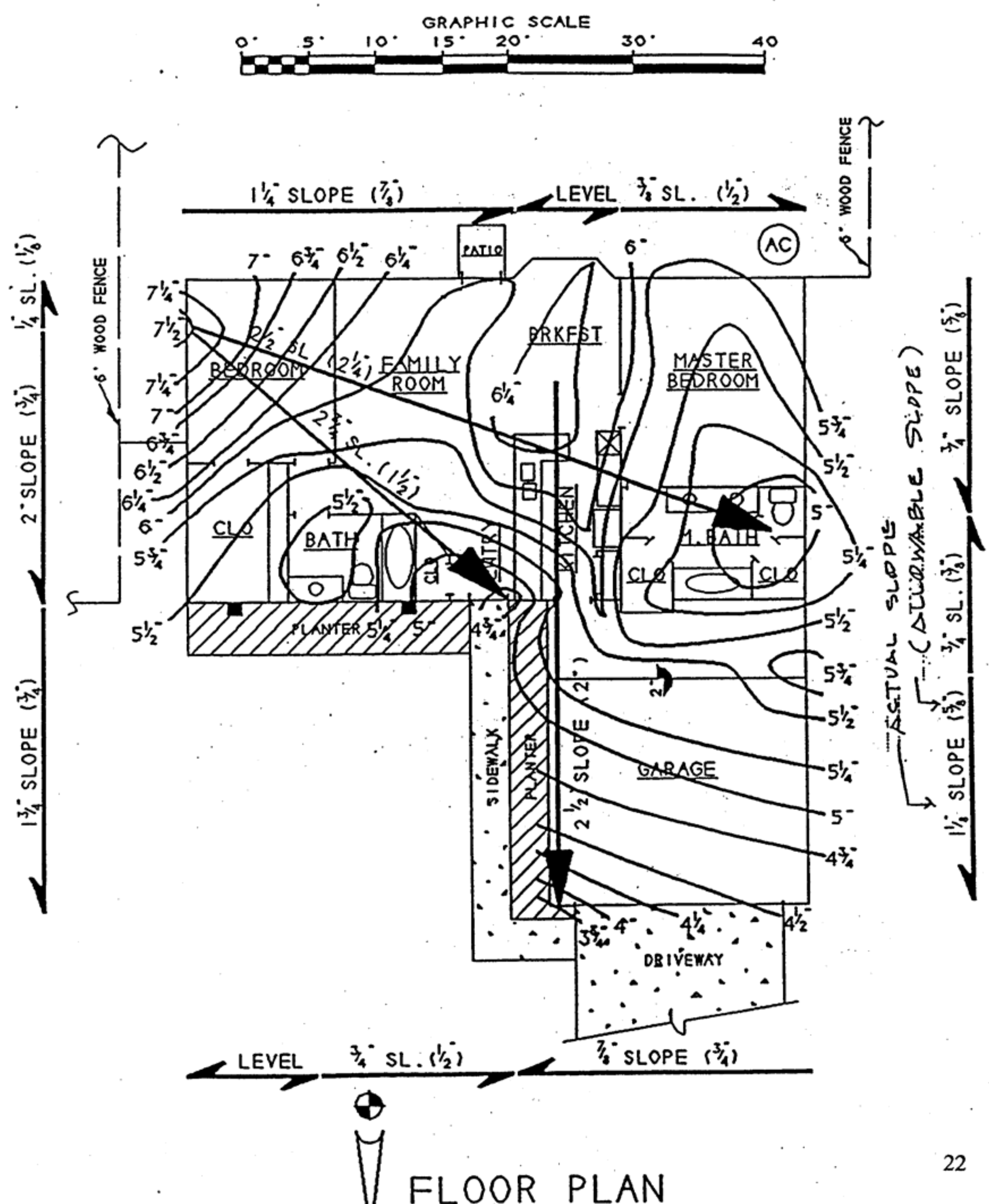
3.6 FIELD TESTING

There are some occasions where geotechnical or other testing is required to determine the cause of failure and/or provide the data necessary to specify repairs. This includes leak testing, geophysical testing such as ground penetrating radar, resistivity, chemical testing, instrument testing, etc. The following are typical of the type of tests that can be conducted for review by the structural engineer:

3.7 <u>Geotechnical Type Testing:</u>

Soils testing requires subsurface exploration (i.e., borings or other types of excavations) and the analysis of data to include, but not necessarily limited to type classification, Atterburg limits determination, soil strengths, moisture content, dry density, potential vertical rise (PVR), potential subsidence, suction values between stratums, root depth and the presence of perched water table conditions.

EXAMPLE 2 - MICRO-ELEVATION CONTOUR PLAN



FLOOR PLAN

FIGURE 6 MICROELEVATIONS & CONTOURS

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EXAMPLE 3 - MICRO-ELEVATION PHENOMENA PLAN

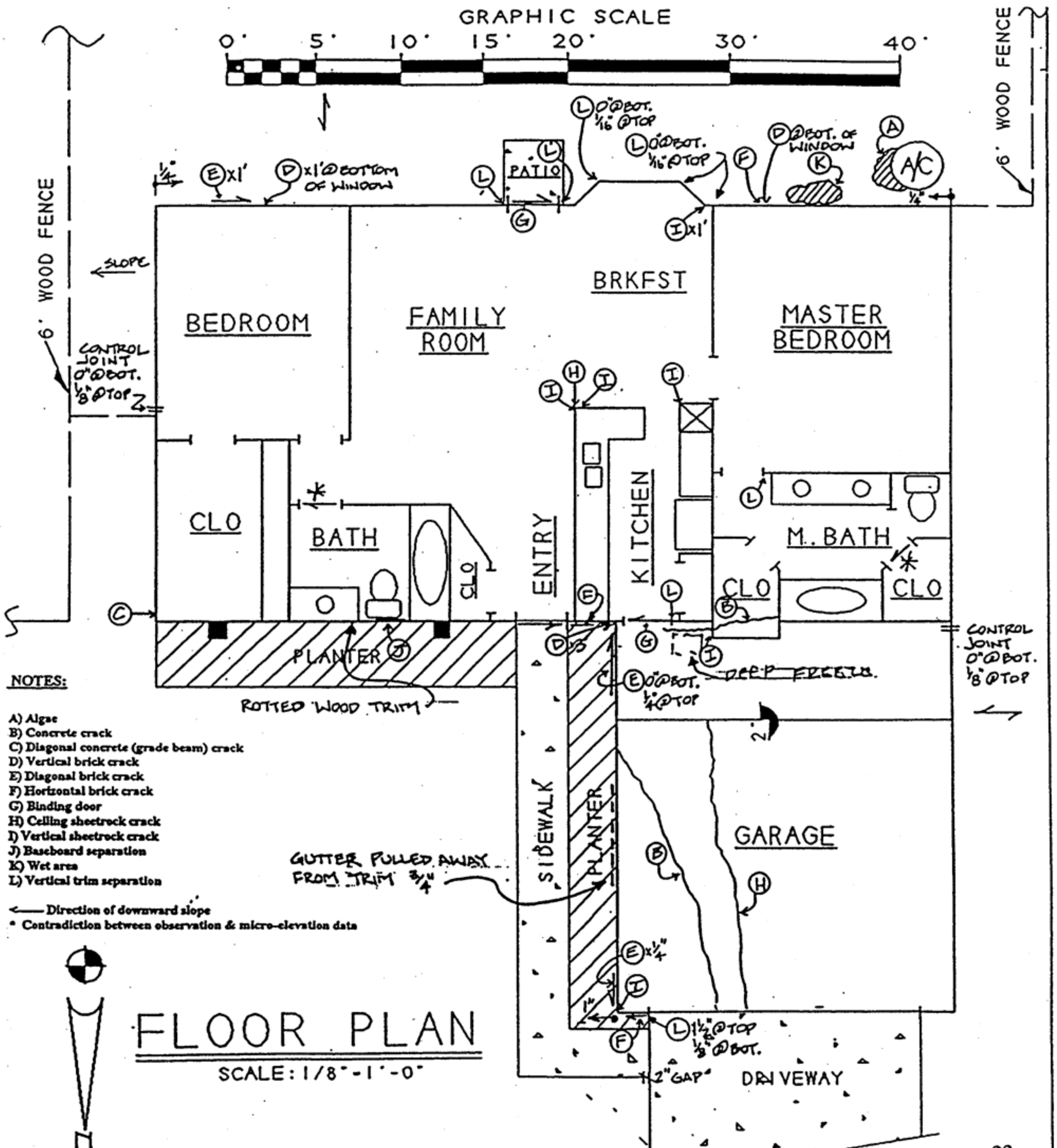

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FIGURE 7. PHENOMENA PLAN

3.8 Structural Type Testing:

There may be some benefit in conducting structural tests for the purpose of assessing the quality of the concrete structure. It is preferred to use a A2LA laboratory whenever possible. Such testing is commonly seen in Level C examinations and may include, but may not necessarily be limited to, the following:

3.8.1 Concrete cores can be extracted from the foundation slab and tested to determine concrete strength and the presence/location of reinforcement. A minimum of 3 cores is required per ACI 318. The cores must be tested in accordance with ASTM C-42. The acceptability of the results must be analyzed in accordance with ACI-318. In addition, soil samples should be extracted through the core holes and the soil under the foundation examined for type, polyethylene vapor barrier, foreign material, and depth of bedding sand, select fill, etc.

3.8.2 Excavations can be made along the side of the foundation grade beams for the purpose of determining the depth and width of the grade beam as well as soil conditions along the side and under the grade beam. This field data should be compared to the original structural design requirements.

3.8.3 If the foundation is supported on drilled piers, excavations can be made along the side of the piers down to their bottom, for the primary purpose of determining pier depth, bell diameter and pier-to-beam connection.

3.8.3 Metal detection tests can be conducted to determine the presence of reinforcement, including location and depth.

3.8.4 If the foundation had post-tensioning reinforcement, tests can be conducted to verify that the cables have been properly tensioned.

The above tests are, of course, comparatively expensive and may ordinarily be justified only in conjunction with a level C (forensic) examination.

3.9 Drainage Investigations:

Surface drainage is an extremely important part of any foundation assessment. Level A evaluations should discuss general visual observations of any drainage problems, e.g., compliance with generally accepted 5% slope for first 10' from building perimeter and 1 to 2% slope elsewhere. Level B should specify general drainage slopes around building on drawings. Level C should provide a thorough engineering drainage study and preparation of a topographic survey. Calculations should then be done using average rainfall data to determine the amount of water that must be handled by the property, to determine the need for yard drainage systems and to specify optimum sizing. Such a process is somewhat expensive and time-consuming and may, perhaps, be beyond the need for most foundation performance assessments. In such cases, engineering judgment may be used along with limited yard slope measurements. A trained observer can spot areas of negative slope or water ponding. The presence of landscape berms can also be identified. Simple means of correcting obvious drainage deficiencies can then be specified.

4.0 DATA ANALYSIS AND CRITERIA ASSESSMENT

This document will present various national and local Building Code requirements used to help determine allowable deflections for new structures (i.e., under 10 years of age). Modification of these Codes is usually necessary in order to apply them to existing residential slab-on-grade construction. The theories and alterations that allow the inspecting expert to use the acceptable Building Code values are presented, along with some special variations that pertain to residential type slab-on-grade applications. Criteria for buildings older than 10 years of age are contained later in this section.

The Building Codes usually specify that engineers should only use one value (usually the most restrictive) for *design,* but a single deflection value may not be appropriate for *performance.* For example, the Uniform Building Code 1985 Edition stipulates in Table 23-D that a roof or floor member supporting live and dead loading not deflect more than L/240, while a member supporting masonry is limited to L/500 to L/600 maximum deflection. While it may not be possible to *design* the components of a single building foundation using separate deflection criteria, it may be appropriate to *analyze* it for performance using applicable criteria for different types of materials.

The first attempt to define foundation design requirements was a document titled "Criteria for the Selection and Design of Residential Slabs-on-Ground," or the BRAB[5] Report, which was sponsored by the Federal Housing Administration in 1968 and proposed that the limiting deflection ratio be L/360, where the term L was the length of the slab in inches. The American Concrete Institute, in their standard ACI-318, required that concrete slabs be designed and constructed to limit their deflection ratio to L/480, which is more stringent. The Post-Tensioning Institute has recommended the use of the L/360 standard. In our opinion, deflections between L/180 to L/360, when accompanied by foundation induced damage, may be applied in the assessment of foundation distress, particularly for a building whose age is 10 years or less. The application of such standards has been defined by Lenert[6], which was presented at the Soil-Structure Interaction Seminar of 1996.

[5] "Criteria for Selection and Design of Residential Slabs-On-ground" by the Building Research and Advisory Board, Publication 1571, dated 1968

[6] Lenert, Donald: "Foundation Distress Evaluation and Assessment for Residential Structures." Soil Structure Interaction Seminar, Foundation Performance Committee, July 25,1996

4.1 ALLOWABLE DEFLECTIONS

As previously discussed, a single deflection value may not be an appropriate criterion in the assessment of performance. Various deflection limits have been described by Meyer[7] and in ACI 435.3R-68[8] Figure 3 from the Meyer report is shown on Page 26 while Table 1 of the Meyer report is contained in Appendix A and Table 3.1 of ACI 435.3R-68 is contained in Appendix B, herein.

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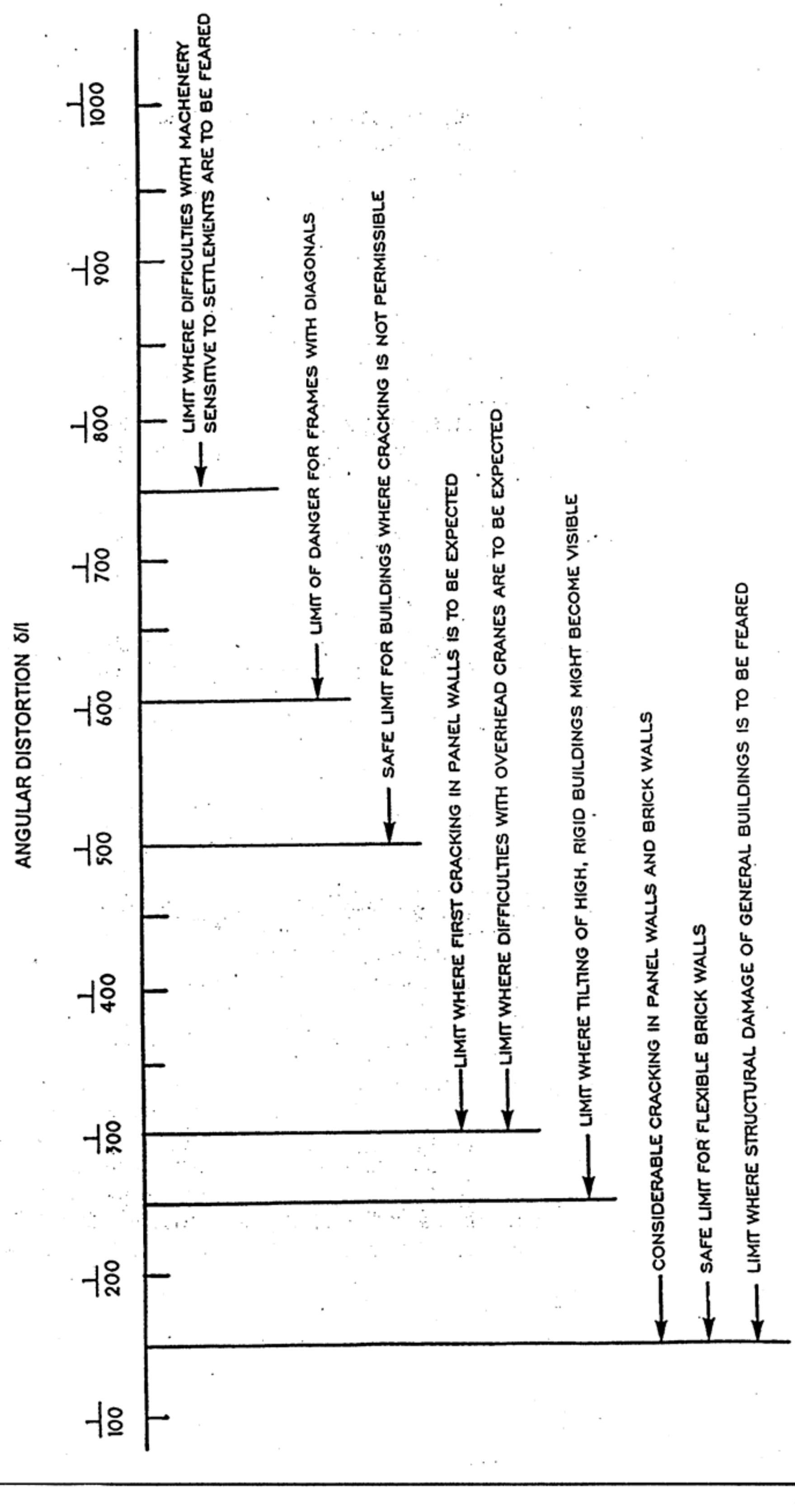
[7] Meyer, Kirby, PE: 'Defining Foundation Failure," Presented at the Fall Meeting of the Texas Section of the American Society of Civil Engineers, 1991

[8] Allowable Deflections, American Concrete Institute, ACI 435.3R

TABLE 1



FROM MEYER, FALL MEETING, TEXAS SECTION, ASCE

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The most widely used reference with regard to the deflection criterion in a concrete foundation is the American Concrete Institute AC1-318[9], which in Table 9.5(b) specifies:

a) L/180 for flat roofs not supporting or attached to non-structural elements likely to be damaged by large deflections.
b) L/360 for floors not supporting or attached to non-structural elements likely to be damaged by large deflections.
c) L/480 for roof or floor construction supporting or attached to non-structural elements likely to be damaged by large deflections.
d) L/240 for roof or floor construction supporting or attached to non-structural elements not likely to be damaged by large deflections.

Case c) applies to brick, stucco or drywall (which in a veneer state is a non-structural element) which is likely to be damaged by large deflections, while b) or d) applies to cabinets, wood paneling and similar related items. The Foundation Performance Association membership has generally accepted that drywall will not crack as readily as modern clay brick, and has given it a 50% increase for the allowable deflection. Thus, an analysis of foundation performance may be interpreted to include the following (also refer to the flow chart in Appendix C):

e) The maximum slope throughout an average residential foundation should not be greater than 3 inches between any two points. Otherwise, the foundation may be suspected to have failed its intended function (i.e., to maintain the interaction between the soils and the foundation structure such that the amount of damages caused by soil pressure variations is limited). *See Chapter 7 for notes on additional research.*
f) If the slope in the foundation exceeds 3 inches, and there is extensive foundation induced damage, then some of the structural elements may be considered to have failed.

   NOTE: the 3 inch maximum is an arbitrary limit based on experience which shows that large cracks are usually present when a 3 inch slope exists. There is no limit for the distance being considered, since we may reasonably assume that no responsible contractor would build a slab 3" out of level. Therefore, the 3" may be considered, at least in part, as a post-construction <u>movement</u>. The original construction may be assumed to be _" out of level. Brick or drywall cracks greater than _" usually indicate a problem regardless of slope.

g) If the differential elevation in the foundation exceeds 3 inches, but there is a scarcity of foundation induced damage, then individual structural members may be analyzed against the limits for differential deflection prescribed in the Uniform Building Code.
h) If the differential elevation in the foundation does <u>not</u> exceed 3 inches (but has exceeded the L/240 or L/360 criteria), and the foundation induced damage is extensive, then the deflection criteria should be examined to see if a performance failure has occurred in the foundation.
i) If the differential elevation in the foundation does <u>not</u> exceed 3 inches (but has exceeded the L/240 or /360 criteria), and the foundation induced damage is <u>not</u> extensive, then the deflection criteria should be examined to see if the foundation has *tilted* instead of *deflected*. The possibility that the foundation was not built level should also be considered.

[9] <u>Building Code Requirements for Reinforced Concrete</u>, American Concrete Institute, ACI-318

4.2 DISCUSSION OF FOUNDATION FAILURES

Building Codes are designed for NEW construction. According to the Texas Residential Construction Liability Act (RCLA) a builder retains responsibility for the quality of workmanship of a residential building for ten (10) years[10]. For the purpose of this criterion, we will consider that to be *new* construction. Building codes do not address *old* or *existing* construction. We recommend that the applicable Building Codes be used as a basis for establishing whether deflections are excessive in any given residential or commercial project. Structural Building Codes nation-wide, including the Uniform Building Code[11], the BOCA National Building Code[12], the SBCI Standard Building Code[13], the American Concrete Institute standard ACI-318[14] and the International Building Code[15], in general, recommend the allowable deflection criteria for new construction.

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[10] William Little & Stephen Paxon: "The Implied Warranties of Good Workmanship and Habitability and the Builder's Statute of Repose," The Houston Lawyer, 1991

[11] Uniform Building Code, International Conference of Building Officials

[12] BOCA National Building Code, Building Officials and Code Administrators International, Inc.

[13] Standard Building Code, Southern Building Code Conference International

[14] Building Code Requirements for Reinforced Concrete, American Concrete Institute, ACI-318

[15] The International Building Code was adopted by most Texas cites.

4.3 BUILDINGS UNDER 10 YEARS OF AGE

There is a concept within the engineering inspection discipline that recognizes that there are two specific types of failures that generally occur: ***short-term failures*** and **long-term** ***failures***. Although foundation failures do not occur with the same repeatability as mechanical failures, the analogy still applies. Although there are other reasons, *short-term failures* are often the result of a basic defect in the design/construction of a foundation and generally occur within the early life of a residence, most often within the first 10 years. Since the RCLA[16] holds a builder responsible for the foundation through this time period, failures within this period of time often are considered to be the result of a design and/or construction failure.

4.4 BUILDINGS OVER 10 YEARS OF AGE

Where the building age is in excess of 10 years, the foregoing standards may not apply and one must then consider the possibility of *long-term failures*. In such cases, the rigid L/360 criterion may not be applicable and other factors must be considered. The "applicable community standard" test, as an example, must give weight to location since foundation problems may be more prevalent in one subdivision as opposed to another. The age of the individual building is also a factor that must certainly be considered. If the standards were rigorously applied without such considerations, one might then be faced with the dilemma that every home within the boundaries of one subdivision would be in a distressed state and need to be repaired or that the worst case on a subdivision could not be considered to have distressed since it is better than the average of another.

Also, it is a well-known fact that the homes in some subdivisions were not as well constructed as they were in others. It is also well known that such a factor has little bearing on the value of such homes. In some subdivisions, the occurrence of damaging foundation deflections is very common; yet, their real estate values remain consistently high. These problems are intensified when a foundation has undergone underpinning since foundation repair firms seldom lift a repaired foundation to a level position. In such cases, an inspector can only carefully inspect the property and properly convey the results to the client. Standards for conducting such inspections have been defined by Peverley in his paper titled, “Foundation Distress Measurement and Evaluation”[17], which was also presented at the Soil-Structure Interaction Seminar of 1996. We recommend that the engineer consider all the foregoing factors in his assessment of the performance of the foundation.

[16] William Little & Stephen Paxon: "The Implied Warranties of Good Workmanship and Habitability and the Builder's Statute of Repose," The Houston Lawyer, 1991

[17] Soil Structure Interaction Seminar, Foundation Performance Committee, July 25,1996

5.0 PREPARATION AND PUBLICATION OF THE ANALYSIS REPORT

After all of the data have been acquired, the results should be put into writing so they can be used to the benefit of the client and the affected general public, as well. Although all parts are of equal importance, we must emphasize the absolute need for any investigator to give the proper attention to this vital part of the investigative process. A poorly prepared report can totally negate the results of an otherwise thorough investigation.

The report must be clear, concise, complete and technically accurate. The report must be understandable to one of your contemporaries, as well as your client, who may not have the benefit of a technical background. Although some reports are specifically written to be used in a court of law, every author of a foundation investigation report must recognize that any report he prepares may end up in front of a jury after it has been torn asunder by an opposing attorney. A format that has been found in many foundation performance assessment reports is shown in Table 2, below.

5.1 SUGGESTED REPORT FORMAT

	Transmittal Letter	Establishes the report as an entity and identifies its distribution.
	Report Summary	Provides the author with an opportunity to emphasize the important points and for those who do not wish to read the entire report.
	Table of Contents	An essential organizational tool for any report.
1	Introduction	What is the purpose of the report and what are the limitations in the investigation process that could affect the outcome.
2	Project Description	Describe the project & identify the configuration of the structure.
3	Investigation Results	Describe in detail the type of investigation conducted and the results thereof.
4	Data Analysis	What is the meaning of the data results and what are its limitations.
5	Conclusions	What is the conclusion that can be derived from the investigation and what should be done.
6	Certification	For a PE, a certification statement is desirable, since the property may eventually change owners. A professional engineering seal is mandatory.
7	References	All references should be listed.
	Illustrations	All drawings and sketches should be included.
	Appendices	This is a good place for detailed technical data/discussions in which only another engineer or an attorney may be interested.

The report must address all of those factors that are pertinent to the objectives of the client and/or are contributory to any condition cited in the report as being a deviation from anticipated foundation performance. Every affecting condition should be addressed and author should justify his or her opinions that such conditions did not adversely affect performance of the foundation.

6.0 ADDITIONAL RESEARCH

Recently completed studies[18] of over 400 residential structures over a period of 12 years came to the following general conclusions:

Residential slab-on-grade foundation systems do not behave as rigid bodies such as a “mat foundation” might. Rather, the slabs behave as flexible members and deflect relatively non-uniformly, resulting in tension or compression forces that develop, depending on the type of soil movement to which the foundation/slab system is being subjected. A study was also made of the initial degree of unlevelness present just after construction of slabs. The results indicated that all of the homes were constructed within 1” of level. The average elevation difference measured was _” and the range was 5/8” to 1”. The findings suggested that a slab of normal proportions can be constructed well within 1” of level, and more likely within _” of level.

Low levels of damage became noticeable at angular distortions of about 1/280 for homes being affected by expansive soil. For homes that were affected by settlement, higher levels of angular distortion were required before the homes experiences low levels of damage, approximately 1/230. This is because settlement tends to cause more tilting rather than bending resulting in lower level distress.

Cracking observed in post-tensioned slabs occurred as a series of fine cracks as opposed to one large crack (in conventionally reinforced slabs). The damage categories were divided into:

1) Homes affected by expansive soil influence. Low levels of damage occurred at angular distortions of about 1/300 or 1.1”.
2) Homes affected by slope influence. Low levels of damage occurred at angular distortions of about 1/330 or 1.1”.
3) Homes affected by settlement. Low levels of damage occurred at angular distortions of about 1/230 or 1.5”.

The studies concluded that cracking alone was not sufficient to determine the level of damage. It was equally important to consider patterns of tilt and distress when trying to quantify the level of damage. The patterns of foundation movement, angular distortion and manifestation of damage to the slab/foundation system must be considered when characterizing the level of damage. Presentation of levels of damage, effects on various structures and ranges of crack widths in different types of foundation systems were itemized in table 4 (see Table 4 on the following page).

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[18] Damage and Distortion Criteria for Residential slab-on-grade Structures, ASCE Journal of Performance of Constructed Facilities, August 1999, by Edred T. Marsh and Scott A. Thoeny.

"*Guidelines for the Evaluation and Repair of Residential Foundations*" [19] by the ASCE (Texas Section) contains a detailed discussion on Levels A, B & C inspection and report formats. Their "deflection ratio" is identical to the FPA "slope-distance" term. Their discussion on evaluation criteria also includes an excellent presentation on structural integrity.

[19] http://www.texasce.organization/ER.htm

TABLE 4. Damage Characterization

Level of damage (1)	Effect on structure (2)	Typical range of interior or exterior wall crack width (mm), (in.) (3)	Maximum Slab Crack Width Range (in.): A1 & B1 structures (4)	Maximum Slab Crack Width Range (in.): A2 & B2 structures (5)	Maximum Slab Crack Width Range (in.): A3 & B3 structures (6)	Overall Differential Δ (in.): Expansive soil influence (7)	Overall Differential Δ (in.): Settlement (8)	Overall Differential Δ (in.): Slope influence (9)	Angular Distortion δ/l: Expansive soil influence (10)	Angular Distortion δ/l: Settlement (11)	Angular Distortion δ/l: Slope influence (12)
Negligible	None	≤0.25, 1/100 (h/l)	h/l	h/l	h/l	<1.00	<1.10	<1.00	1/350–1/330	1/340–1/320	1/480–1/460
Slight or low	Aesthetic damage, some doors and windows may stick. Cosmetic repairs are most likely necessary.	0.25–1 (1/100–1/25) or number of cracks ~0.5 mm (1/50 in.)	1/32–1/8	1/32–1/12	h/l–1/40	0.75–1.25	1.00–1.75	0.75–1.25	1/290–1/270	1/240–1/220	1/340–1/320
Low to moderate	More pronounced aesthetic damage. Some doors and windows may stick. Accelerated weathering to external features. Cosmetic repairs necessary and slab and foundation repair often needed.	0.55–2 (1/50–1/13) or number of cracks ≥1–2 mm (1/16 in.)	1/8–3/8	1/12–1/4	1/40–1/16	1.10–1.50	1.50–2.50	1.00–1.75	1/240–1/220	1/180–1/160	1/240–1/220
Moderate	Distinct patterns of interior and exterior distress appearing. Window and door frames are sometimes distorted. Pervasive cracking may be present. Tilt in floor is usually perceivable. Repairs to home, slab, and foundation are usually necessary.	1.5–4 (1/16–1/6) or number of cracks ≥2–3 mm (1/10 in.)	3/8–3/4	1/4–1/2	1/16–1/8	1.40–1.90	2.50–4.00	1.75–2.50	1/190–1/170	1/130–1/110	1/170–1/150
Moderate to severe	Distinct patterns of distress exist. Window and door frames are distorted and there is perceivable tilt in floor. Serviceability of building is affected. Repairs to home, slab, and foundation are necessary.	3–13 (1/8–1/2) or number of cracks ≥5–10 mm (1/4 in.)	3/4–1 1/2	1/2–1.1	1/8–1/5	1.75–2.50	3.75–6.00	2.50–3.50	1/160–1/140	1/100–1/80	1/130–1/110
Severe	Large pervasive cracks throughout and doors and window frames are severely distorted. Wall frames noticeably leaning. Repairs to home, slab, and foundation are necessary and are often extensive.	10–25 (1/2–1) or number of cracks ≥15–20 mm (3/4 in.)	1 1/2–3	1.1–1.75	1/5–1/3	2.50–4.00	6.00–10.00	3.50–5.00	1/130–1/110	1/70–1/50	1/90–1/70
Very severe	Increasing risk of structure becoming dangerous. Requires major repair and often requires removal of structure.	>25 (1 in.) or number of cracks varying in width with several generally greater than 1 in.	>3	>1.75	>1/3	—*	>10.00	>5.00	1/110–1/90	1/50–1/30	1/70–1/50

*None of homes reviewed being affected by expansive soil influence could be characterized as having very severe levels of damage.

A = Single family detached home
B = Attached townhome/condominium unit

1 = Nonreinforced
2 = Lightly reinforced
3 = post-tensioned

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A	**=**	**Single family detached home**	**1**	**=**	**Non-reinforced**
B	**=**	**Attached townhome/condominium unit**	**2**	**=**	**Lightly reinforced**
			3	**=**	**post-tensioned**

A	**=**	**Single family detached home**	**1**	**=**	**Non-reinforced**
B	**=**	**Attached townhome/condominium unit**	**2**	**=**	**Lightly reinforced**
			3	**=**	**post-tensioned**

A	**=**	**Single family detached home**	**1**	**=**	**Non-reinforced**
B	**=**	**Attached townhome/condominium unit**	**2**	**=**	**Lightly reinforced**
			3	**=**	**post-tensioned**

APPENDIX "A"

(Table 3.1 of ACI 435-3R-68)

TABLE 3.1 – DEFLECTION LIMITATIONS FOR VARIOUS EXAMPLES

Reasons for limiting deflections	**Examples**	**Deflection limitation[a]**	**Portion of total deflection on which the deflection limitation is based**
1. Sensory acceptability			
1.1 Visual	Droopy cantilevers and sag in long span beams	By personal preference[b]	Total deflection[c]
1.2 Tactile	Vibrations of floors that can be felt Lateral building vibrations	L/360[d] No recommendation[e]	Full live load Gust portion of wind
1.3 Auditory	Vibrations producing audible noise	Not permitted	
2. Serviceability of structure			
2.1 Surfaces which should drain water	Roofs, outdoor decks	L/240[f]	Total deflection
2.2 Floors which should remain plane	Gymnasia and bowling alleys	L/360 + or cambers[g,h] or L/600[h]	Total deflection Incremental deflections after floor is installed[i]
2.3 Members Supporting sensitive equipment	Printing presses and certain building mechanical equipment	Manufacturer's recommendations	Incremental deflections after equipment is leveled [j]
3. Effect on nonstructural elements			
3.1 Walls	3.1.1 masonry and plaster 3.1.2 metal movable partitions and other temporary partitions 3.1.3 lateral building movement 3.1.4 vertical thermal movements	L/600 or 0.30 in. (7.6 mm) maximum[k,h] or ϕ = 0.00167 rad. [l] L/240 or 1 in. (25.4 mm) max[h] 0.15 in. (3.8 mm) offset[m] per story 0.002 _ (height) See Fig. 3.1 L/300 or 0.60 (15.2 mm) max.[n]	Incremental deflections after walls are constructed[j] Incremental deflections after walls are constructed[j] Five min sustained wind load Full temperature differential movement
3.2 Ceilings	3.2.1 plaster 3.2.2 unit ceilings such as acoustic tile	L/360 [h,p] L/180 [h,p]	Incremental deflections after ceiling is built[j]
3.3 Adjacent building elements supported by other members	Windows, walls and folding partitions on un-yielding supports below the element in question	Absolute deflection limited by tolerances built into the element in question	Incremental deflection after building element in question is constructed[j]
4. Effect on structural elements			
4.1 Deflections causing instability of primary structure	Arches and shells Long columns	Effect of deflections on the stresses and stability of the structure should be taken into account in the structural design of the element	
4.2 Deflections causing different force system or change in stresses in some other element	Beam bearing rotation on masonry wall	Effect of deflections on the stresses and stability of the structure should be taken into account in the structural design of the element	
4.3 Deflections causing dynamic effects	Resonant vibrations which increase static deflections and stresses such as those produced by wind, dancing, moving loads and machinery	Dynamic deflections should be added to the static deflections and the total should be less than the limitations imposed for other reasons	

FOOTNOTES

[a] Deflection limitations are given for members supported at both ends and for cantilevers, except as noted. It is assumed that the supports do not move.

[b] For excessive deflections, correct total deflection by camber. Overcorrectlon by camber is desirable

[c] Total deflection is the sum of all individual computed deflections due to all loadings plus those due to time dependent effects.

[d] Noticeable floor vibrations depend upon the frequency as well as the amplitude. In addition, the damping efficiency is importance since vibrations that die out within a few cycles will be felt only as a single movement, if at all.

[e] Limitations may be based on the lateral acceleration (or deceleration) of the building. Secondary vibrations caused by the wind sway might also be a problem and require limitation in some manner. More research in this area is necessary.

[f] Surfaces should be sloped or total deflections corrected by camber to prevent ponding of water

[g] The deflection of floors that should remain plane may be partially compensated by camber so that any possible incremental deflection as well as the camber itself does not produce a floor that deviates from plane by more than *L/360* either upward or downward.

[h] The span L should be considered either parallel to or perpendicular to the direction of stress, whichever is shorter.

[j] Incremental deflection is the change in elastic deflection over a period of time produced by the addition of new loads or subtraction of existing loads during that time, plus the change in deflection produced by creep and shrinkage during that time.

[k] This limitation assumes that the deflection computation does not give credit to composite action between the member and the wall, or what is commonly called "arching action." If composite action is computed, the deflection limitation should be considerably less than that tabulated. The tabulated limits might still allow some visible damage to weak fragile walls and walls which cannot act compositely with the structural member (e.g. walls with large openings in the span.)

[l] Rotation of any member supporting a wall at the point of support of the wall. This is equivalent to a limitation of 1/600th of the height of the wall.

[m] This limitation applies to the lateral deflection between adjacent floors caused by the story wind shear but does not include the deflection caused by axial lengthening and shortening of the columns. It also applies to the vertical offset deflection between two shear walls in the same plane.

[n] L is the distance between the exterior column and the first interior column.

[p] Deflection of cantilevers may be twice as high as the tabulated ratios.

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Ibid No. 9

Policy Advisory Guidelines Regarding Design, Evaluation and Repair of Residential Foundations” (1998)
www.tbpe.state.tx.us/

Texas Society of Civil Engineers “Guidelines for the Evaluation and Repair of Residential Foundations”
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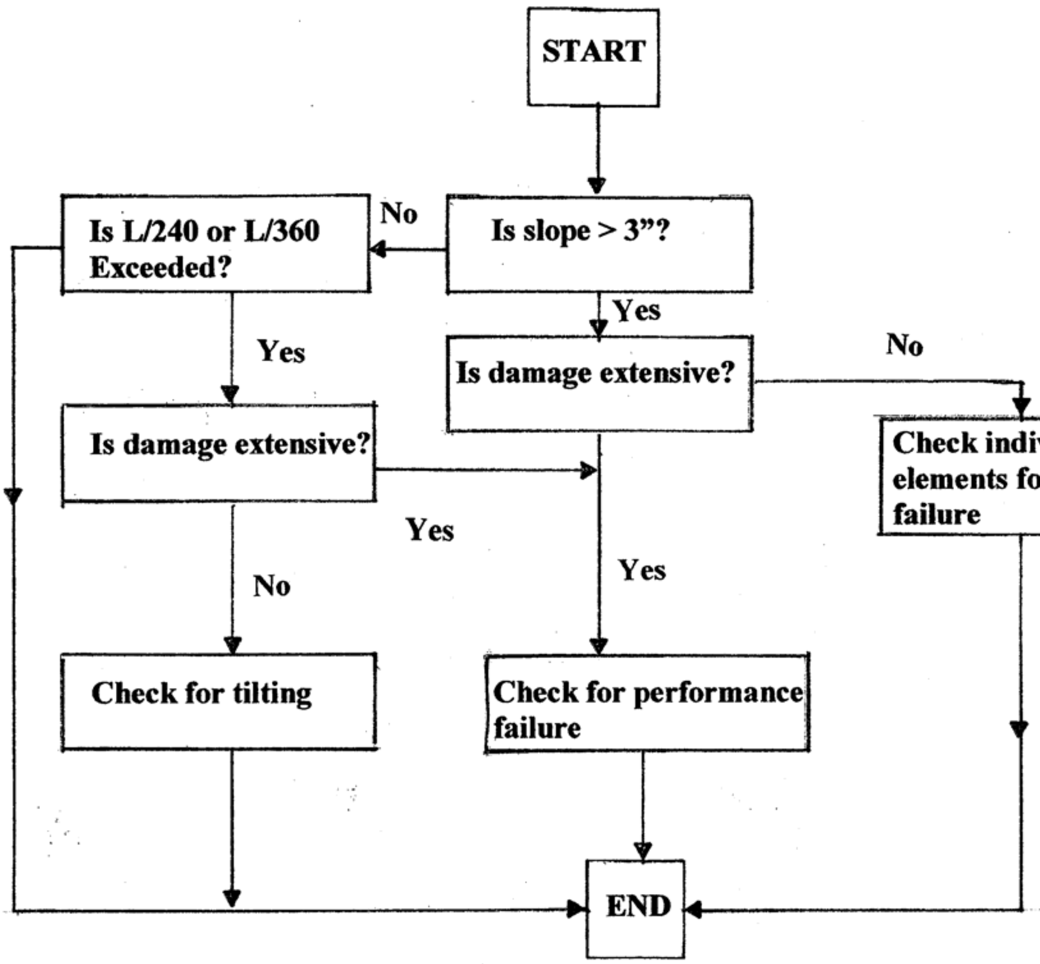
APPENDIX "B"

(Flow Chart for determining causes of foundation movement)

FLOW CHART

(See pages 27 & 28)



APPENDIX "C"

"Distress Phenomena Often Mistaken for Foundation Movement" (FPA-SC-03-0)

see http://www.foundationperformance.org/