Using Slab-on-Ground Elevation Measurements in Residential Foundation Engineering Performance Evaluations

Introduction – A Critical Focus on Limitations

- Review of Historical Basis
- Review of Published Criticisms
- Geometry of Deformation Issues
- Construction Practices
- Code Requirements
- Evaluation Protocols Using Surface Elevation Measurements
- Forensic (Causation) Studies
- Real Estate Transactions
- Summary and Conclusions

Where Did This Idea Come From?

- Studies of Visually Apparent Building Response to Foundation Movement (Skempton and MacDonald, 1956)
  - Foundations were true structural foundations
  - Angular Distortion and Maximum Differential Settlement
  - Purpose was to develop threshold damage criteria to use in foundation design
- Studies of Residential Building Response to Foundation Movement (Day 1990)
  - Foundations were slab-on-ground foundations, not structural foundations
  - Purpose was to develop threshold damage criteria to use in foundation performance evaluations
  - What is the purpose of a damage criteria for performance evaluations?

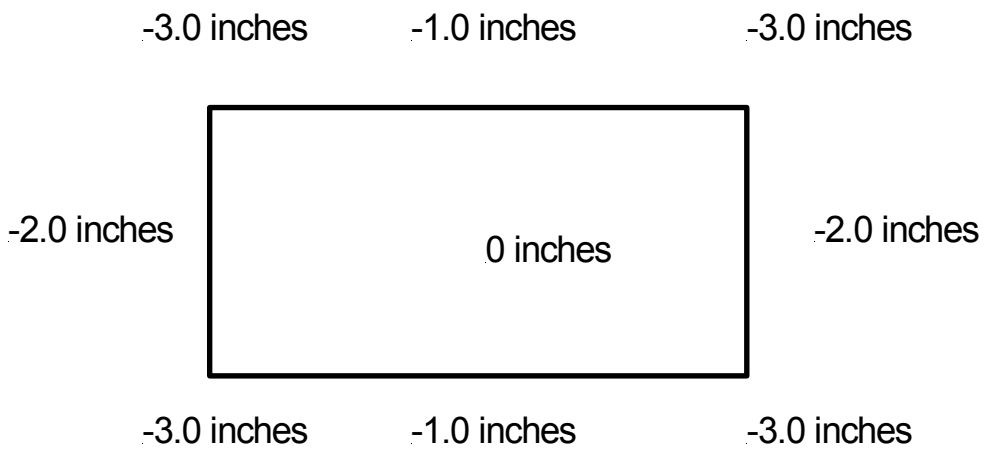
Published Criticisms of the Levelness Approach

- Karl Terzaghi (1956)
  - Insufficient data for a statistical approach
  - Feared this approach would preclude new ideas
- F. H. Chen (1988)
  - Single elevation surveys should never be used
  - Engineers should use at least two surveys with a stable benchmark
- Robert Brown, P.E. ((1997)
  - Single elevation surveys may be misleading
  - Engineers should use two surveys
- Ken Bondy (2000)
  - Analysis of elevation survey data must take account of construction tolerances

Published Criticisms of the Levelness Approach - continued

- Walsh, Bashford and Mason (2001)
  - Statistical analysis of new slab-on-ground foundations indicate that use of surface elevation data is not reliable for forensic evaluations
- R. Michael Gray, P.E. (2002)
  - Surface slope and maximum elevation difference are overly general and simple parameters for use in foundation performance evaluation
- Walsh and Miguel (2003)
  - Statistical analysis of new slab-on-ground foundations indicate current foundation surface elevation data analysis techniques are not repeatable or reliable for forensic evaluations

Foundation Deformation Geometry - Deflection Surface



plan view of a 30-foot by 60-foot slab-on-ground foundation distorted in both directions l/360

Foundation Deformation Geometry

- Curvature is not related mathematically to maximum elevation difference or to angular distortion
- Maximum elevation difference is related to the deflection ratio and the foundation geometry
- Maximum angular distortion is not related to the deflection ratio but the average slope is so related for a specific deflection curve shape

Construction Practices

- Face Numbers
- $F = 12.5/(3\sigma+Z)$
- If F= 13, 3σ = .962 inches
- Maximum Elevation Difference is given by 6σ or 1.924 inches
- If F= 10, Z= 1.25 inches and maximum elevation difference equals 1.25 + .962 inches or 2.12 inches
- Maximum slope is 1.25/120 or .010 or 1.88/180

Building Codes

- ACI 318
  - Elevated Structures versus Ground-Supported Structures
  - Computed design deflection criteria are not intended to be used as performance criteria for existing structures
- International Residential Code
  - Foundation must resist soil volume changes
  - No structural damage to the supported structure
  - Deflection and racking must not interfere with the usability and serviceability of the supported structure

Misconceptions Concerning Use of Design Deflection Criteria

- Load-deflection behavior of concrete beams is not consistent and predictable
  - Cannot predict load-deflection behavior with a single deflection ratio
  - Deflection calculations are approximations only
  - If the deflection is within realistic expectations cannot be called a failure
- Purpose of Design Calculations is not to predict structural behavior
  - Provides a basis for comparing designs and making better engineering judgments

Foundation Performance Evaluation Protocols

- PTI Bondy
  - The levelness of the foundation surface cannot be explained with reference to Face Numbers plus normal distortion
  - Visible damage to the supported structure near the location of excessive soil/foundation movement
  - The overall shape of the slab surface must be consistent with recognized patterns of foundation distortion

Foundation Performance Evaluation Protocols

- Criticism of Bondy
  - Foundation levelness is not a construction control
  - Slabs can be within ACI levelness criteria and be suffering from excessive deflection
  - The distorted foundation surface may not conform to an center lift or a edge lift distortion mode

Foundation Performance Evaluation Protocols

- Robert W. Day
  - Uses maximum angular distortion and maximum elevation difference
  - Elevations are taken 15-feet apart to minimize influence of anomalies in the foundation surface
  - Maximum angular distortion of 1/300 for cosmetic damage and 1/100 for structural damage

Foundation Performance Evaluation Protocols

- Criticism of Day
  - There is no evidence that a 15-foot grid solves the construction tolerance issue
  - Day's damage criteria are less than construction tolerances
  - Day's damage criteria do not address foundation repair

Foundation Performance Evaluation Protocols

- KESCORP Foundation Repair Protocol
  - The average slope of a deflection curve distorted to 1/360 is taken as a foundation repair criteria
  - Average slope is 1/180

Foundation Performance Evaluation Protocols

- Criticism of KESCORP Foundation Repair Protocol
  - Based on a one-way bending model that understates the average slope by 41%
  - Curvature is related to the rate of change in the slope, not to the slope itself
  - A slope of 1/180 is less than the maximum expected as-constructed slope of 1.88/180
  - Can easily mislead a homeowner into believing foundation repair is necessary

Foundation Performance Evaluation Protocols

- Finish Floor Profile Deflection Ratio Approach – Texas Section ASCE
  - Use elevation numbers to create a profile of the finish floor surface across the length and width of the slab-on-ground foundation
  - Make adjustments to accommodate construction tolerances
  - Compare the adjusted deflection ratio of the profile with 1/360

Forensic (Causation) Studies

- Assumed as-constructed foundation surface geometry is subjective and cannot be verified
- Survey methodology does not allow for calculating the error of closure
- Analysis of elevation data is not reliable or repeatable
- Expert testimony must be supported by adequate modeling or analysis

Real Estate Transactions

- Significance of time constraints
  - 7 to 10 day option period
  - Appointment to report delivery can be 24-hours or less

Real Estate Transactions

- The Evaluation Addresses Different Questions than a Forensic (Causation) Evaluation
  - Opinion Concerning the Performance of the Foundation
  - Is Foundation Repair Needed?
    - The question of foundation repair is usually subjective

Summary and Conclusions

- No mathematical relation between foundation or maximum elevation difference and deflection surface curvature
- Levelness is neither a design nor a construction control
- Inadequate data for a statistical approach
- No standard measurement or analysis methodology
- No logical or empirical relation to foundation repair capabilities
- Subjective nature of elevation survey approach
- Propensity to Mislead
- An elevation measurement approach in causation studies may not be effective
- Elevation measurement approaches may not be the best way to address the pertinent questions for a real estate transaction