GUIDELINE FOR SLAB PERFORMANCE RISK EVALUATION AND RESIDENTIAL BASEMENT FLOOR SYSTEM RECOMMENDATIONS (Denver Metropolitan Area)

PLUS

GUIDELINE COMMENTARY

Colorado
Association of
Geotechnical
Engineers

PREFACE

The enclosed "Guideline for Slab Performance Risk Evaluation and Residential Basement Floor System Recommendations" and the associated "Commentary…" were developed by the Colorado Association of Geotechnical Engineers (CAGE), Professional Practice Committee and approved by vote of the members of the organization. The "Guideline…" was formally adopted at the CAGE meeting of December 11, 1996 and represents a consensus of geotechnical practice in the Denver metropolitan area as of that date. It should not be construed to represent practice prior to December 1996, or the practice in areas other than metropolitan Denver. This practice will likely evolve over time. As more is learned about floor slab and structurally supported floor performance, change to the "Guideline…" may be merited.

Colorado
Association of
Geotechnical
Engineers

Guideline 1
December 1996

GUIDELINE FOR SLAB PERFORMANCE RISK EVALUATION AND RESIDENTIAL BASEMENT FLOOR SYSTEM RECOMMENDATIONS (Denver Metropolitan Area)

PURPOSE:

This document presents a guideline for slab performance risk evaluation and recommendations regarding residential basement floor systems based upon a consensus opinion of what CAGE members believe is the state of practice in the Denver metropolitan area at this time. This practice will likely evolve over time. As more is learned about floor slab and structurally supported floor performance, changes to this guideline may be merited.

PROPOSED GUIDELINE:

I. Field Investigation

The first step in a proper slab performance risk evaluation for a residential site should be consideration of geologic conditions in the area of the site. Site geology can significantly influence the approach to field investigation, particularly in areas of geologic hazards, regardless of laboratory test results.

In areas of expansive soils, field investigation of subsoil, bedrock and ground water conditions should be designed to evaluate swell potential on a site-specific basis. Current practice in areas of expansive soils involves drilling each residential lot. When investigating isolated lots, at least two borings should be drilled on each lot, generally at opposite corners of the proposed structure. Where more than two adjacent lots are being investigated, at least one boring should be drilled near the center of each building footprint. The geotechnical engineer should adjust the drilling location within the specific lot where site conditions indicate information gained from the alternative location is desirable.

In a situation where a previous report is available, the geotechnical engineer should use this information to determine exploration requirements to develop a thorough understanding of site conditions.

Boring depths should be established to evaluate the materials which exist within the anticipated zone of moisture increase below foundation excavation depths and those materials which will likely influence structure performance. Borings 15 to 25 feet deep below anticipated final exterior grade are generally acceptable. Drilling refusal can limit practical exploration depths. Deeper borings should be drilled in proposed cut areas based upon engineering judgment. Where two borings are drilled on each lot, at least one of the borings should be at least 25 feet deep. Where adjacent lots are drilled, the depth of borings on successive lots may vary, so that conditions can be assessed reasonably.

Ground water can affect foundation installation and performance of residences. Ground water levels should be checked and reported at the time of drilling and one day or more after drilling.

During drilling, relatively undisturbed samples should be obtained. It is common practice in the Denver area to use a sampling procedure similar to the Standard Penetration Test (ASTM D1586), except that a modified California-type sampler with a 2.5-inch O.D. and 2.0-inch I.D. is used. These samplers are commonly driven 12 inches or less in residential applications. Borings performed for the purposes of providing foundation and/or interior floor support recommendations are sampled using either of the following procedures:

Method 1: Sample every boring at intervals throughout the total depth. Sampling intervals should have a maximum spacing of 5 to 10 feet and should include the zone at or near the anticipated foundation levels (i.e. basement, garage, or crawl space). Where more than one boring is drilled on the lot, sampling should be designed to obtain samples which represent the soil profile.

Method 2: When drilling multiple borings on groups of adjacent lots, borings may be sampled using a pattern technique. The pattern used should be designed to provide multiple samples of representative materials over the entire site. Samples should be distributed throughout the zone of interest beneath foundations and slabs, throughout the site. An example of such a pattern is provided on Table I.

TABLE I
EXAMPLE SAMPLING PATTERN

Boring 1	Boring 2	Boring 3	Boring 4
2'	-	2'	-
-	4'	-	4'
6'	-	6'	-
-	9'	-	9'
14'	-	14'	-
-	19'	-	19
24'	-	24'	-

NOTE: The engineer may use alternative patterns which provide sufficient samples to judge conditions on a given site.

II. Laboratory Investigation

The type and number of laboratory tests should be selected by the geotechnical engineer to evaluate pertinent engineering properties of the subsoils and bedrock. All lab tests should be performed by technicians trained in the specific test procedure, in a soils laboratory equipped to perform the tests. All tests should be performed in substantial conformance with ASTM or other accepted laboratory standards. The following tests may be considered for design.

A. **Atterberg Limits:** Atterberg limits are helpful in assessing how in-situ moisture conditions compare with soil behavior at different moisture contents, and to understand soil properties. Random testing of representative materials is suggested.

B. **Moisture Content and Dry Density:** Sample moisture content and dry density should be measured in conjunction with other laboratory testing. The geotechnical engineer should consider performing moisture content and dry density determinations for representative soil and bedrock profiles as part of the design-level investigation.

C. **Swell Testing:** Typical swell-consolidation tests as commonly used in the Denver Metro area substantially conform with ASTM D4546 and are considered an indicator test for evaluating swell potential. The use of 500 and 1000 pounds per square foot surcharge pressures prior to wetting is common in these indicator tests. At the engineers option, use of surcharge pressures which approximate overburden pressures may be used.

Where swelling soils are found, swell tests should be performed on a sufficient number of samples to judge the swell potential throughout the site. As a general guideline approximately 50 percent of the samples tested should be from the zone of expansive soils or bedrock anticipated to influence basement floor performance. The remaining tests should include samples from the full depth of expansive soils and/or bedrock encountered and may include additional tests at or near basement level.

D. **Suction Testing:** Soil suction testing provides another method to evaluate potential movement of swelling soils and bedrock. At this time, use of suction testing is not common in design-level investigations, but it is considered an equivalent to swell testing and may be substituted for swell testing.

E. **Compression Test:** Compression tests may be used in conjunction with penetration resistance tests to evaluate the strength properties of cohesive soils; usually the unconfined compression test is used. Extensive laboratory testing for strength is not common for residential projects in the Denver Metro area.

F. **Type and Amount of Clay:** Identification, classification, and hydrometer analysis may be performed on soil samples recommended by the engineer. Such testing is not common for residential projects.

G. For post-tensioned slab-on-grade foundations, various information available from the Post Tensioning Institute should be reviewed.

III. Slab Performance Risk Evaluation

The use of swell tests and/or suction tests alone cannot and should not be used as the sole criteria in assessing the risk that slab-on-grade movement will occur, the potential amount of slab movement, and whether the potential movement will result in unacceptable performance. Such assessment is necessarily subjective, and therefore requires considerable experience and judgment on the part of the geotechnical engineer. Factors affecting a slab performance risk evaluation include the following:

- Geologic Structure
- Soil and Bedrock Profile and Profile Variability
- Material Types Below the Slab
- Engineering Properties of Materials Below the Slab

- Swell Tests and/or Suction Tests on a Given Lot and Nearby Lots
- Depth and Magnitude of Moisture Increase
- Existing Ground Water Conditions
- Anticipated Ground Water Conditions
- Presence and Location of Nearby Surface Water Sources
- Type of Basement
- Tolerable Movement for Intended Use
- Performance History and Experience in the Area
- Surface Topography
- Previous and Future Grading
- Surface and Subsurface Drainage
- Site Landscaping, Irrigation and Vegetation

To provide some uniformity in terminology between geotechnical engineers and provide a relative correlation of slab performance risk to measured swell, CAGE recommends use of the descriptions shown on Table II.

TABLE II
RECOMMENDED REPRESENTATIVE SWELL POTENTIAL DESCRIPTIONS AND CORRESPONDING SLAB PERFORMANCE RISK CATEGORIES

Slab Performance Risk Category	Representative* Percent Swell (500 psf Surcharge)	Representative* Percent Swell (1000 psf Surcharge)
Low	0 to <3	0 to <2
Moderate	3 to <5	2 to <4
High	5 to <8	4 to <6
Very High	≥8	≥6

*NOTE: The representative percent swell values presented are not necessarily measured values; rather, they are a judgement of the swell of the soil and bedrock profile likely to influence slab performance.

Slab performance risk evaluation is an engineering judgment which is used as a predictor of the general magnitude of potential slab-on-grade heave, and the risk of poor slab-on-grade performance. Although measured swell percentage for individual samples is an important consideration, the variability of soil and bedrock conditions and other factors as outlined above must also be considered. Representative swell can be thought of as the range of swell percentage which, in the opinion of the engineer, best represents the swelling characteristics of the soils and bedrock within the anticipated zone of wetting below foundation excavation depths when considering all of these factors. A current design assumption for the depth of wetting below basement slabs-on-grade is approximately 7 to 10 feet. In unusual circumstances, wetting can exceed these depths. The engineer should evaluate potential wetting depths based upon geologic conditions and the site specific soil profile.

IV. Use of Structurally Supported Basement Floors

Structurally supported basement floors, also known as structural floors, are generally considered the most effective way to reduce the likelihood of basement floor movement due to soil heave. There are other design issues associated with structural floors, such as ventilation and increased lateral loads, which must be considered. Structural floors do not constitute a perfect option and in many cases are not the best option. Based upon our experience at this time, the Colorado Association of Geotechnical Engineers believes engineers in the Denver area should recommend structurally supported basement floors on sites where the slab performance risk is judged to be high or very high. We also believe that builders and original home owners, where possible, should be given the option of using a structural floor or concrete slab-on-grade where the slab performance risk is judged to be low or moderate.

Builders and home owners must be informed of the potential risks of constructing concrete slabs on sites with expansive soils. They must also understand that the evaluation of swell potential is subjective and is based upon the experience and judgment of the design engineer and, therefore, is not a guarantee that the soil and structure will interact as designed or intended. Builders and original home owners, where possible, may then elect to use slab-on-grade or structural floors on a particular site provided they understand and accept the risk that slab performance may not be reasonable on some sites. Builders and all home buyers should be advised that slab-on-grade floors on most sites will heave and crack to some degree. CAGE member experience suggests the result may be up to 3 inches of differential slab elevation in some cases on low and moderate swell potential sites. In unusual instances, the degree of movement may exceed this range.

Colorado Association of Geotechnical Engineers

COMMENTARY ON PROPOSED GUIDELINE FOR SLAB PERFORMANCE RISK EVALUATION AND RESIDENTIAL BASEMENT FLOOR SYSTEM RECOMMENDATIONS (Denver Metropolitan Area)

PURPOSE:

This commentary describes the historical development of the current state of practice for slab performance risk evaluation as it relates to residential slab-on-grade basement floors. It was prepared to provide a general understanding of how local geotechnical practice has evolved to its current state. Based upon this practice, a guideline for slab risk performance evaluation and recommendations for use of structurally supported basement floors has been prepared by the Professional Practice Committee for CAGE as a separate document. The proposed guideline represents a consensus opinion of CAGE members.

DISCUSSION:

The soils and bedrock in the Denver Metropolitan area of Colorado include expansive materials which swell when they are wetted. These conditions result in risk of movement and cracking to slabs-on-grade and foundations. For years, geotechnical engineers practicing in the area have identified use of structurally supported basement floors, also known as structural floors, as the most effective way to reduce the likelihood of basement floor movement due to soil heave. There are other design issues associated with structural floors, such as ventilation and increased lateral loads, which must be considered. Structural floors do not constitute a perfect option and in many cases are not the best option. Builders and home owners continued to utilize slab-on-grade floors under nearly all conditions through the 1980's. In the majority of instances, these floors performed reasonably well. When they did not, forensic studies often showed unusual damage occurred on sites with high or very high swelling soils or bedrock near the basement floor.

Prior to about 1984, site specific information regarding soil and bedrock swelling characteristics in subdivisions was limited. Drilling and laboratory investigation practices typically did not involve sampling and testing for each lot. In 1984, the adoption of Senate Bill 13 (C.R.S. 6-6.5-1-1) spurred changes in soil investigation methods. After this legislation was adopted, practices evolved to include more site-specific drilling, sampling and laboratory testing. This resulted in more data being obtained regarding soil properties in subdivisions. By 1986-1988, some of the data from these studies could be related to basement slab performance. After about 1989 it became clear that basement slab movement and associated damage were significantly greater in areas of high and very high swell potential, as described in the attached guideline, than on sites where low or moderate swelling soils were present below floors. In response, some geotechnical engineers practicing in the Denver Metropolitan area strongly recommended use of structurally supported basement floors on sites judged to have high and very high swelling soils, whether basements were finished or unfinished at the time of initial construction This change in engineering practices, and the resulting building methods, evolved gradually from about 1989 through 1992, and especially from 1991-1992.

The changes in industry practices regarding use of structurally supported basement floors which occurred in the late 1980's and early 1990's were based upon evaluation of performance of many floors, both by geotechnical engineers practicing in this area and by home owners, builders and structural warranty companies. The evaluations included development of criteria for reasonable slab-on-grade performance. It should be noted that in many basements where slab performance was considered reasonable by the builder, home owner, structural warrantor and geotechnical engineer, slab-on-grade heave which resulted in 1 to 3 inches of differential slab elevation was often evident. Other criteria, such as the magnitude and extent of cracking, movement of pipe columns and utility lines, and the condition of partition voids, were also considered. In 1993, the Federal Housing Administration (FHA) adopted standards of 3/8-inch crack width or height, and a floor levelness standard of 2 inches in 10 feet, as guidelines for unacceptable basement floor slab performance. The FHA standards were not well disseminated through the industry.

The Colorado Association of Geotechnical Engineers (CAGE) believes the current state of building practice in the Denver Metro area is to use structurally supported basement floors when the slab performance risk is judged to be high or very high. However, the rating of a residential site as having low or high risk relative to basement slab performance is not absolute; rather, this represents a judgment. The risks associated with swelling soils and bedrock can be mitigated, but not eliminated, by careful design and construction procedures. There remains some potential for movement of foundations and slabs-on-grade even in areas judged to have low to moderate risk as the soils respond to increases in moisture content following development.

CAGE believes that it is prudent to perform a slab performance risk evaluation for each residential site, and to use this evaluation to identify sites where the use of structural floors provides the greatest benefit. Builders, and home buyers must accept the fact that there are inherent risks associated with homes built in areas of expansive soils that cannot be entirely eliminated. Geotechnical engineers should evaluate the risk of poor basement slab performance and inform their clients of the comparative risk so that clients can assess the risks that must be assumed, and have the means to communicate the risks to a subsequent home buyer(s).

The approach described above may now be changed by a marketing response from builders rather than through well researched engineering analysis based upon experience. This response has the potential to force changes in the housing industry which will likely result in increased cost to the consumer, very often with little increased benefit. The use of overly conservative criteria for the selection of structural floors disregards years of practical experience and engineering judgment.

Geotechnical engineers serving the home building industry in the Denver metropolitan area have contributed to an evolution of design and construction procedures which has reduced the frequency of foundation and basement floor distress over the past 10 to 15 years. Each step toward more conservative design procedures, such as use of structurally supported basement floors, has reduced the frequency of problems. However, the reduction grows smaller with every design change. In the long term, the home building industry and public officials must educate the home buying public that it is not effective to adopt design procedures which attempt to eliminate all problems. The industry should instead adopt those practices which reduce the frequency of failures as low as economically practical, and provide other mechanisms to address problems that may occur. Concrete slabs-on-grade will heave and crack. Occasionally, repair of damage due to foundation movement will be required. CAGE encourages the industry to develop standards which represent reasonable construction and performance tolerances, and to communicate these standards to home buyers.

The practices of geotechnical engineers, and home builders, have evolved over the past 20 to 30 years. CAGE supports continued evolution in investigation and design practices, as well as performance monitoring. The slab performance risk evaluation represents a significant advancement of the profession, and is considered a milestone in the evolution of local practice. CAGE encourages geotechnical engineers to continue advancement in understanding the performance of residential structures on expansive soils. Specifically, CAGE promotes continued evaluation of methods to predict movement through swell and suction tests, and performance monitoring to assess those predictions.