COMMENTARY ON GEOTECHNICAL PRACTICES

OVER-EXCAVATION FOR

EXPANSIVE SOIL AND BEDROCK MITIGATION

IN COLORADO'S FRONT RANGE

COLORADO ASSOCIATION

OF GEOTECHNICAL ENGINEERS

CAGE

PREFACE AND SUMMARY

This Commentary was developed by the Colorado Association of Geotechnical Engineers (CAGE) based on inquiry and discussion among CAGE's membership regarding their experience with over-excavation techniques for expansive soil and bedrock mitigation in Colorado's Front Range. This Commentary was then presented to and recognized by a vote of CAGE's Professional Members as representing a consensus of geotechnical practices of CAGE members as of that date. The practices described in this document may evolve over time as experience is accumulated in the processes of over-excavation and swell mitigation, in general.

The **Front Range Urban Corridor (Front Range)** is a region of urban population located along the eastern slope of the Southern Rocky Mountain Range, encompassing 18 counties in the states of Colorado and Wyoming. The corridor derives its name from the Front Range, the mountain range that defines the western boundary of the corridor which serves as a gateway to the Rocky Mountains. The Front Range Urban Corridor stretches from Pueblo, Colorado, north along Interstate 25 to Cheyenne, Wyoming. In Colorado and for purposes of this paper, it includes the metropolitan statistical areas of Pueblo, Denver-Aurora-Lakewood, Broomfield, Castle Rock, Colorado Springs, Boulder, Fort Collins, Greeley, and the micropolitan statistical areas of Canon City.

In the context of this document, CAGE members understand mitigation to imply a reduction in adverse effects and does not imply perfection, nor does it imply elimination of the effects of the condition being mitigated. It instead implies net benefit or improvement, or a reduction in harmful effects. The information gathered by the CAGE Over-Excavation Task Force, coupled with CAGE member approval of this Commentary, substantiate that over-excavation is an effective mitigation method for expansive soil and bedrock that are prevalent in the Front Range of Colorado.

HISTORY AND BACKGROUND

Construction of engineered fills is a common practice throughout the world and has been since ancient times. The development of modern earth moving equipment has made the construction of larger and deeper fills more practical and common. Today's equipment can excavate, move, process, and place large volumes of earth more efficiently and economically than in the past.

Engineered fills, often tens of feet in thickness, are routinely used to support improvements such as dams, roadways, airfield pavements, and various structures, including small to large buildings and residential subdivisions.

For many applications, the need for fills is driven by topography. The fill is constructed to raise grade to an acceptable or useful level, so that the improvement constructed on the fill is more functional. In other applications, fill is used to improve or replace subsurface conditions that are less favorable for support of improvements.

The development and evolution of geotechnical practice has enabled engineers to identify ground conditions that are unfavorable for construction, and multiple ground improvement methods have been developed to treat a wide variety of unfavorable ground support conditions.

Over-excavation is one of the more common methods of ground improvement which can be used to treat various types of problematic ground conditions. Over-excavation commonly includes excavation of the on-site material, mechanical processing to add and mix water (and sometimes chemical admixtures) into the material, then placing and compacting the moisture conditioned material back into the excavation. In some cases, the quality or condition of the existing on-site material might merit chemical treatment or replacement with imported soils. A few of the conditions that are commonly encountered in Colorado and elsewhere where over-excavation is utilized are discussed below.

- Expansive soils and bedrock can experience a volume increase when wetted (depending on confining pressure and other factors), which can result in upward movement (i.e., heaving) of the ground surface and ground-supported structures and infrastructure. This phenomenon can cause damage to roadway pavements, flatwork, slab-on-grade (SOG) floors, foundations, and structures. Various methods have been used to mitigate the effects of expansive soils and bedrock, including over-excavation.

- Soft or loose soils can be subject to excessive settlement, whether due to their own weight or loading from structures that bear upon them. Soft or loose soils may also have limited bearing capacity. Deep foundations of various types can be used to transfer structure loads to more competent, deeper strata. Alternatively, over-excavation can be, and often is employed to mitigate the effects of soft or loose soils to allow construction of shallow foundations. This method is particularly useful when the soft or loose soil has a well-defined and measurable depth, so that the over-excavation geometry can be designed with greater confidence. Over-excavation is commonly used for roadway construction in areas of soft ground or when existing undocumented fill or fill of poor quality is present. Over-excavation in this application may include re-compaction of on-site materials or may require replacement of the excavated material with a more suitable imported fill.

- Some building sites include non-uniform foundation support. One common example in Colorado occurs when shallow, non-expansive bedrock is present under a portion of a proposed structure but is significantly deeper under the remaining portion of the structure. The concern is that the portions of the structure bearing on this bedrock may experience small settlement under the imposed loading, but other parts of the structure, bearing on softer materials, may be subject to more settlement, creating an increased risk of differential movement across the structure. Over-excavation of the bedrock and replacement with compacted fill is a common method of providing a more uniform bearing condition, thereby mitigating this risk.

- Collapsible, hydro-compactive, or hydro-compressible soils can experience compression when subject to water infiltration or wetting. This can result in dramatic and damaging settlements of overlying structures and infrastructure. Over-excavation is a common method of treatment to mitigate the collapse or compression potential and enable shallow foundations to be constructed on these soils (White and Greenman).

Over-excavation can be used in many conditions. Its success in reducing heave and differential heave of expansive soils and bedrock that are prevalent in Colorado's Front Range has led geologists, engineers, and governmental agencies to recommend over-excavation to reduce the potential for damage related to heave. Expansive soils and bedrock have been a known geologic hazard in the area for many years. The Colorado Geological Survey (CGS) published documents as early as 1972 ([1]Hamilton and Owens) implicating expansive soils as the cause of significant foundation problems.

Heave mitigation strategies have been studied extensively, and over-excavation and re-compaction became a standard mitigation method in Colorado in the late 1950s and 1960s as noted in a 1966 memo ([2]Bower) from the Colorado Department of Highways, now known as the Colorado Department of Transportation (CDOT). In this memo, CDOT outlined over-excavation depths based on soil properties. This memo discussed the moisture treatment and re-use of on-site soils when practical and was cited in a 1992 CDOT report ([3]Ardani) entitled *Expansive Soil Treatment Methods in Colorado*. Ardani indicated that over-excavation and re-compaction was the predominant method being used in all regions of Colorado for mitigation of expansive soil and bedrock beneath roadways. These same methods were incorporated into the CDOT Pavement Design Manual ([4]CDOT) and are still in use today. Several local jurisdictions followed suit and over-excavation remains a standard treatment for expansive pavement subgrade soils.

Historically, deep foundations, primarily drilled straight shaft piers extending through the depth of wetting, zone of seasonal moisture change, or "active zone," have commonly been used to mitigate the impacts of expansive soil and bedrock to structures ([1]Hamilton and Owens).

Residential basement floors were traditionally SOG and constructed directly on clay or claystone bedrock subgrades in most areas. By the 1970s, SOG basement floors were still common, but some ground improvement beneath SOG floors was usually considered to reduce potential heave, especially when highly expansive soils or bedrock were encountered ([5]Hart). This included over-excavation and re-compaction of on-site soils or replacement with imported soils that possessed no or lower swell potential. Structurally supported basement floors were the exception and not often used during this era. Residential structures without basements were often constructed with structurally supported floors over crawl spaces to isolate floors from the underlying expansive soils or bedrock. Flatwork and pavements were commonly constructed directly on clay subgrades with little effort to mitigate expansive soil behavior.

As development increased, an increasing number of basement floor slabs were experiencing movements that were not acceptable to the end users and there was also an increase in the number of drilled straight shaft pier and grade beam foundations that were experiencing unacceptable movement. As a result, by the late 1980s and early 1990s, structurally supported basement floors became more prevalent and drilled shaft lengths increased, particularly in areas where highly expansive soils/bedrock were present and where claystone bedrock was shallow.

At the same time, large portions of residential and commercial developments in portions of Jefferson and Douglas Counties in the area now known as the steeply dipping bedrock zone were experiencing severe differential movements in foundations, basement walls, floor slabs, and pavements. A task force that included the CGS was formed in 1994 under the auspices of Jefferson County, resulting in new Land Development Regulations (LDR) ([6]Jefferson County). Douglas County also retained the CGS to provide guidance for development in areas of steeply dipping bedrock located within Douglas County ([7]Noe and Dodson).

Research on the performance of residential subdivisions in Jefferson County found that areas of poor foundation and basement floor slab performance tended to occur in areas where existing grades were lowered (i.e., cut areas) and/or where the underlying expansive claystone bedrock was near the final ground surface. Better performance of foundations and slabs occurred in areas where overburden soils with low to moderate swell potential were relatively thick or where engineered fills were constructed that created a separation or buffer zone between the bottom of foundations/floor slabs and underlying expansive bedrock. The Jefferson County LDR that were subsequently developed require at least 10 feet of fill or overburden soil between the deepest part of any foundation element and the top of the underlying bedrock. Where basements are provided, this typically requires 16 to 20 feet of suitable overburden or fill from finished grade, depending upon the height of the basement. Where this depth of native overburden material is not present, or where it has high expansion potential, over-excavation can be performed to provide a suitable thickness of material between the bottom of foundations and basement floor slabs and the top of the expansive bedrock. The process of creating this buffer zone of material between the bottom of foundations and the top of bedrock as required by the Jeffco LDR was coined deep over-excavation.

Douglas County follows guidelines presented by the CGS, which are similar to those promulgated by Jefferson County. Because overburden soils in the steeply dipping bedrock zone commonly exhibit moderate to very high expansive potential and are frequently not thick enough to meet requirements of the LDR, deep over-excavation emerged as a standard technique used for entire subdivisions (i.e., beneath residential structures and, in some cases, driveways, sidewalks, streets, and utilities) in these areas.

The practice of deep over-excavation was found to be most cost effective when performed as a large-scale, earthmoving operation across structure areas within subdivisions or development properties. The cost of the earthmoving operation was offset in part by the ability to use shallow foundation systems and SOG basement floors. Additional benefits were also recognized in the improved performance of flatwork, pavements, and utilities, decreased issues with lateral movement of basement walls, and a reduction of moisture management/ventilation challenges in the space below the structural basement floors as these spaces were eliminated when SOG basement floors could be used.

Based on successful use of deep over-excavation in the steeply dipping bedrock zone, geotechnical engineers began to consider that deep over-excavation might also benefit development on other sites where expansive soils and more flat lying bedrock were prevalent outside the dipping bedrock zone.

Geotechnical engineers recognize that the fill soils and underlying strata present after the over-excavation process may still have some heave or settlement potential. However, the moisture treated on-site or imported fill materials greatly reduce the potential total and differential heave at the site and, if compacted to a sufficient degree at a suitable moisture content, can keep the potential for post-construction settlement low as well. With the reduced movement potential, structures can often be successfully supported on spread footings, and SOG floors can be used. The performance of these foundations is more predictable and more uniform with lower potential for differential movement (whether settlement or heave) between adjacent foundations, SOG floors, flatwork, pavements, and utilities. In addition, the process has been found to mitigate the effects of differential movement between deep foundations and other shallow supported improvements.

Beginning in the 1990's and continuing to the present, over-excavation has emerged as a viable and in many cases preferred ground improvement method for many residential and commercial building construction projects throughout the Front Range Urban corridor. It can be used to treat most expansive soil and bedrock sites to allow use of footings and SOG floors with expected movements within levels that are reasonable and tolerable for most stakeholders. In addition, the process, when performed sitewide during site grading, can reduce lateral swell pressures on basement foundation walls, and can mitigate the risk of movement in other appurtenant areas of the development. In addition to improving performance, deep over-excavation is often more economical than other options of mitigation such as deep foundations and structural floors.

- When over-excavation is selected by the owner/developer of a residential subdivision, design-level studies are typically performed on each lot after completion of over-excavation and site grading to evaluate the characteristics of the fill. If these characteristics are judged to be acceptable, design recommendations for shallow foundations are typically provided in the design-level report.

- For other types of projects, the design-level study may occur prior to site grading and possible over-excavation, and additional studies after fill placement may not be performed.

CAGE OVER-EXCAVATION TASK FORCE ACTION ITEMS

The CAGE Over-Excavation Task Force (Task Force) considered the practice of over-excavation to mitigate the expansion potential of native soils and bedrock. Although there are situations where over-excavation is performed to mitigate settlement conditions, the Task Force found through discussion among members that within the Front Range area of Colorado, it is most commonly performed to mitigate impacts of expansive soils and bedrock on buildings and infrastructure.

To better understand the state of the practice, the Task Force set out to gather information about how often over-excavation was being utilized, the methods used to evaluate when over-excavation was appropriate, the criteria used to develop an over-excavation depth, and if there were any conditions where over-excavation was not considered practical. The goal was to collect anonymous information from CAGE members and provide the membership with an understanding of current industry practices related to over-excavation.

Additionally, the Task Force wanted to learn what field and laboratory testing was being performed to evaluate the viability of over-excavation and the recommended over-excavation depth.

The Task Force also wanted to explore the current practice relating to construction quality assurance during the over-excavation process, i.e., what field observations and testing were performed to evaluate the fill materials.

The Task Force wanted to understand the experience of CAGE members in terms of the general performance of structures and site features constructed on over-excavated fills. With the understanding that over-excavation was being used to mitigate, but not eliminate, impacts from expansive soil and bedrock, was the process effective in meeting its goals? Were there situations when the process was not effective and if so, how often? In those cases, what other alternatives were being considered?

Finally, the Task Force wanted this commentary to be a reference document for the CAGE membership to summarize current practices for mitigation of expansive soils and bedrock. Accordingly, this paper is intended to provide qualitative information about the current state of practice, rather than prescriptive or quantitative design guidance.

OVER-EXCAVATION SURVEY

The Task Force developed a survey that was sent to all CAGE members in September 2020. A copy is contained in Appendix A. The anonymous survey was completed via SurveyMonkey and the Task Force requested that responses be limited to one response per firm (CAGE members are individuals). The main questions considered in the survey included the following:

- **Firm Demographics –**The first portion of the survey included questions related to each firm's geographic area of practice, types of projects, quantity of projects, and number of professional CAGE members represented by the responses.

- **Expansive Soil and Bedrock Experience –** The survey included questions related to how many projects completed by the responding firm were underlain by expansive soil and bedrock, and how often the responding firm included over-excavation in their recommendations. Respondents were also asked about criteria their firms considered when recommending over-excavation.

- **Over-excavation Methodology and Experience –** The survey requested that respondents indicate some of the more specific criteria they used in their evaluations, including: common laboratory testing, standards such as the 1996 CAGE Guideline for Slab Performance Risk Evaluation ([8]CAGE), and/or county or municipal design requirements, quality-control methods, and experience with similar projects. The survey included questions relating to field testing and sampling performed as part of quality assurance of the fill and subsequent laboratory testing performed on the field samples, both the types of testing and frequency.

Summary of Survey Respondents – Survey results included responses from firms representing the majority of the voting membership of CAGE.

Respondent Project Locations – The survey included questions to help understand each respondent's locale, types of projects (i.e., residential, commercial, industrial, infrastructure, etc.). In general, responses were from firms primarily working in Colorado's Front Range. Responding firms reported that, on average, 89 percent of their projects were in the Front Range, with the majority of the projects located in the Denver-Boulder region. Some key takeaways are summarized below:

- Most of the respondents perform most of their services in the Front Range area.

- A handful of responding firms reported that more than 10 percent of their projects were located outside the Front Range; even so, those firms reported that deep over-excavation was commonly recommended in other areas of the state as well (Western Slope, farther into the eastern plains, etc.).

Respondent Project Types – The survey included questions relating to each respondent's types of projects (i.e., residential, commercial, industrial, infrastructure, etc.). Respondents were asked to summarize the number of single-family residences (SFR), multi-family residential units (MFR), and commercial buildings for which they provided services, both over the last year and the preceding five years. Key project-type data is summarized in the tables below.

- ***Single-family Residential (SFR)*** – Most respondents reported providing services for residential projects. Most of these did a mix of both single-family and multi-family residential projects, though one respondent reported very rarely working on single-family residential projects. The data was clear that a majority of the SFR projects were performed by a small number of respondents. Respondents reported completing geotechnical reports for 76,415 single-family homes over the last five years, with 92 percent of these being done by a few firms.

- ***Multi-Family Residential (MFR)*** – Similarly, a small number of respondents reported providing services for a substantial number of MFR projects, completing reports for about 70 percent of the MFR units reported by all respondents over the last five years.

- ***Commercial*** – All respondents reported providing services for commercial projects. However, a few respondents reported completing fewer than 100 commercial projects over the last 5 years. At the other end of the spectrum, a small number of respondents completed over 70 percent of the commercial projects reported.

Expansive Soils and Bedrock Responses – The survey included several questions regarding the prevalence of expansive soils and bedrock and common mitigation recommendations. The following items were of significance among the responses:

- Among the firms reporting the most projects completed, expansive soils and bedrock were reported to be most prevalent (more than 75 percent of the sites) in the greater Denver metro area, less prevalent but still substantial in the NoCO region, and less so in the Colorado Springs (COS) region.

- The frequency of inclusion of over-excavation in geotechnical recommendations followed much the same pattern as the prevalence of expansive soils and bedrock: the use of deep foundations and structurally supported floors is included as one recommendation on sites underlain by expansive soils and bedrock. However, respondents were likely to also include over-excavation as an alternative for mitigating expansive soils and bedrock.

- Respondents reported that over-excavation is rarely provided as a "stand alone" recommendation in preliminary studies, but rather as an alternative means to mitigate structural movement.

- When over-excavation is proposed as a possible alternative, it typically is recommended when the client has expressed a desire to have alternatives such as shallow foundations and SOG floors, and where applicable for residential projects, SOG basement floors.

Key Over-Excavation Considerations and Goals – The survey included questions relating to the key project aspects and considerations used when recommending over-excavation. Specific response items of note include:

- When asked to rank common considerations related to over-excavation recommendations, respondents indicated the most important factors were site geology and laboratory test results.

- The tolerance to movement and the type of project were the second and third highest ranked criteria.

- When asked to provide other criteria that were not included in the survey options, some respondents indicated that the depth to (or presence of) groundwater was another key criterion.

- When asked to rank the goals of over-excavation, reducing vertical movement and differential movement of foundations and floor slabs was the most important goal (when considered against reducing lateral movement, reducing movement of other infrastructure, or reducing construction difficulties). When asked about other potential goals, responses were few but varied.

Specific Over-Excavation Responses

- **Determining the Depth of Over-excavation –** The survey included questions regarding the information and methods firms used to develop over-excavation recommendations.

  Of the respondents, a large majority indicated that they relied on the results of oedometer tests (also referred to as "swell/consolidation" or "swell/settlement" or "response to wetting" tests) to estimate potential heave and help develop a recommended over-excavation depth.

  Most respondents indicated that past experience on nearby projects was also a major consideration, indicating test results on other projects also has a heavy influence among respondents.

  Soil suction testing was listed by a few of the responding firms as a criterion they considered.

  A small number of respondents indicated they rely on index testing such as moisture content, dry density, and other soil classification tests.

- **Confirmation of Over-Excavation Effectiveness** – Most of the respondents indicated that heave estimates were used to evaluate and forecast foundation and floor slab movement.

  A small number of respondents indicated they almost always (90 and 95 percent of the time) perform swell testing on laboratory re-compacted samples as part of their evaluation of over-excavation. Several other respondents indicated they commonly use this technique (30 percent or more of the time).

  Some of the respondents indicated that more than 50 percent of the time, they also recommend mitigation above and beyond moisture conditioning and re-compaction of on-site soils. In these cases, it appears that replacement of the on-site soils with imported, non- to low expansive structural fill, or chemical treatment of the on-site soils was prevalent. It is important to note that these respondents did a substantial amount of their projects in the Colorado Springs region or on the Western Slope of Colorado.

  When moisture conditioning and re-compaction, alone, is determined not to be an effective alternative, in most cases the respondents recommend importing non-expansive fill or only recommend deep foundations and structural floors.

However, a fair number (though not a majority) of respondents indicated that chemical treatment (either during compaction or using injection methods) was an alternative they sometimes consider.

- **Field Testing and Quality Assurance (QA or QC)** – A large majority of respondents indicated that they perform quality assurance (QA) or quality control (QC) observations and testing on over-excavation projects. Most firms reported that they provide QA or QC on sites where they provided the over-excavation recommendations. The firms responsible for a majority of SFRs said they are retained for QA or QC for almost 90% of their projects and on these projects, QA or QC is frequently done on a nearly "full-time" (as interpreted by the respondents) basis.

  It is presumed that the other responding firms simply do not provide these services. For example, one of these firms indicated that on their projects, another firm "always" does QA or QC testing.

  Of the responding firms, a large majority reported they collect hand drive samples during QA or QC to evaluate measured swell of the resulting fill.

  Most of the firms also complete additional geotechnical exploration, sampling and testing as part of their QA or QC program. In some cases, another firm might complete additional geotechnical borings. Respondents indicated that this is most common for residential subdivisions.

- **Other General Comments and Experience –** Respondents were offered an open-ended question at the end of the survey to share their experience with over-excavation and/or their current practices. Several of the responses are presented below:

  - "Based on extensive testing after fill placement and interaction with clients, we are confident that over-excavation is an appropriate means to address most expansive soil sites. Damaging movements occur more frequently for areas near limits of excavation such as corners of the excavations. Often, these instances also include excessive wetting during or after grading and construction."

  - "We feel that sub-excavation provides a reliable alternative for mitigating expansive soils and bedrock. However, we stress that quality control during earthwork construction is critical to the success of the method and reducing future problems."

  - "Generally very effective when combined with properly constructed surface and subsurface drainage measures and when backfill zone properly placed."

  - A firm whose work was primarily done in the COS area reported "Our firm has decades of practice using over-excavation, generally the recommendation is based on testing from test boring samples. We primarily use the consol/swell test. On some projects we will use the FHA swell test. The majority of the over-excavation on residential projects involves remove and replace with suitable granular materials. A minimum over-excavation for expansive sols [sic] is typically 3 feet with 4 feet being more common today."

  - "We use over-excavation as a regular solution to expansive soil issues since the Colorado's High Plains area does not always have good bedrock for embedment of piers."

ANALYSIS OF SURVEY RESULTS

Based on the survey responses, over-excavation is a very common recommendation to mitigate expansive soil and bedrock, and to enable the use of shallow foundation systems and SOG floors. The responses clearly indicate that over-excavation has been successful in mitigating expansive soils and bedrock materials in Colorado's Front Range area and other areas in the state where expansive materials are present.

Although replacement of the excavated materials with select imported fill material is sometimes performed, the general practice among respondents is to recommend excavating, processing, and moisture-conditioning the existing onsite soil and bedrock materials. These materials are then placed back into the excavation and compacted. If imported fill material with a significantly higher permeability than the native soil is used, it is often necessary to include a drain system at the base of the more permeable fill prism to mitigate additional heave due to the infiltration of surface water through the fill and into the underlying expansive soils. This is discussed in both CDOT Memo #323 and the 1992 CDOT document that discourages replacement with granular fill due to ponding of water in the granular fill when underlain by expansive subgrade.

Residential Construction – As discussed previously, survey respondents indicated over-excavation is very commonly used for residential projects. The data showed that the respondents performing the great majority of the residential work in the survey also reported a majority of their projects were located in Colorado's Front Range.

In order to further evaluate how representative the survey responses were, residential construction permit data was obtained from the website http://www.census.gov for the major metropolitan areas of Colorado and for the entire state. While the data was not expected to correlate exactly to the number of units investigated by survey respondents, the permit data seems to indicate that the survey respondents are representative of most residential projects in the Front Range (at least 65 percent of the single-family homes and multi-family residential units developed over the last 5 years).

The task force identified the following additional key trends among the data:

- Over-excavation, moisture conditioning, and re-compaction of expansive soil and bedrock is a commonly used practice to mitigate expansive soils and reduce the risk of excessive post-construction movement and differential movement of structures in the state of Colorado. In the Front Range, over-excavation is presented as at least one alternative for swell mitigation on the majority of sites where expansive soils or bedrock are identified.

- Depth of over-excavation for foundations and floor slabs in the Front Range area may extend as much as 20 feet below the ground surface, and deeper in some circumstances. Based on the responses, over-excavation does not typically extend to the full design depth of wetting. Respondents report effective mitigation of the impacts of swelling material at the design depths of over-excavation. Over-excavation, moisture conditioning, and re-compaction of expansive soil and bedrock is most common when the process is expected to result in a fill mass with predominantly low swell potential.

- There are currently numerous methods used by member firms to estimate potential heave of expansive materials and develop a recommended over-excavation depth. These include the use of laboratory tests such as oedometer (swell/consolidation) and suction tests, index tests such as Atterberg Limits and sieve analyses, reliance on jurisdictional requirements, consideration of regional geologic conditions, and previous experience with projects in the area. In most cases, a variety of methods and information are considered by the respondents. Most respondents consider the overburden confinement pressures in determining the depth of over-excavation.

- One-dimensional oedometer test results (also known as swell/consolidation tests) are frequently performed in Colorado and can be used to estimate heave when considering a depth of future wetting (active zone). As such, they are widely used to help evaluate the recommended depth of over-excavation.

- Soil suction is another method used to estimate potential future heave, though based on responses to the survey, suction testing appears to be less common. This test method involves the measurement of the free energy of the pore-water or tension stress exerted by the pore-water on the soil matrix by using filter paper or other methods. Once a suction profile is established, it can be compared to an estimate of the final suction profile to estimate potential swell or consolidation of the considered zone.

Settlement Considerations – The geotechnical community recognizes settlement of deep fills occurs. This settlement usually occurs during or shortly after fill placement, and typically does not yield damaging differential structural movement. Such movement is more likely to occur if the fill is placed in an uncontrolled or improper manner. Geotechnical engineers sometimes provide different compaction recommendations for the portion of fill deeper than 20 or 25 feet. The general practice of moisture conditioning above optimum and compaction in thin lifts is to maintain the fill at moisture and density levels that result in partially saturated fills that undergo some primary consolidation during the process of fill placement, limiting future settlement. The survey did not include questions in specific regard to settlement; however, in response to open-ended questions about their general experience, survey respondents did not indicate that long-term settlement was a major issue. However, respondents indicated that good performance of the fill zones was dependent on consistent performance of the contractors' processes, and reinforced by adequate QA/QC testing.

Regional Trends – Regional geology is an important consideration in the evaluation of the risk of damaging foundation movement. The steeply dipping bedrock area along the Front Range is one example. Communities affected by this hazard have implemented over-excavation guidelines to help reduce the risk of damage. Although both a minimum over-excavation depth and alternative considerations are presented within the guidelines, it appears that the minimum over-excavation depths are commonly used for projects within designated hazard zones. In some instances, over-excavation depths greater than the minimum are recommended.

Other Considerations – The data obtained through field and laboratory tests is used to assist in the development of recommended over-excavation depths. In general, the goal of over-excavation is to provide a construction option with lower potential movement and differential movement. Increased over-excavation depths may reduce the risk of potential swell, but will add project cost, and could introduce an increased risk for potential settlement. Engineering judgment and consideration of the risks acceptable to the client/owner are almost always factors considered when recommending over-excavation depths. Depending on the subsurface conditions and the type of fill used in the over-excavation zone, the use of a drain system at the base of over-excavation may be used to limit development of perched groundwater in the basin created by over-excavation.

A consideration that most respondents rely on is previous local experience. This is often, if not always, paired with other methods of analysis. Knowledge of local subsurface conditions and previous projects is a commonly used method to help evaluate the potential for foundation movement.

Methods for QA/QC – In most cases, the soil and bedrock excavated during over-excavation are processed to a soil-like consistency and moisture conditioned to above optimum moisture content before compaction. The processed fill soils are then placed in relatively thin lifts and compacted to a minimum of 95 percent of standard Proctor maximum dry density below structural areas. The survey responses indicated that monitoring of this process is key to good performance.

Surveyed firms indicated that in most cases, they are also retained to observe excavations and perform testing of newly placed fill. Only one respondent indicated that they do not perform compaction testing during the process, but they indicated that another firm is usually retained by the developer or client. Most of the respondents reported performing QA/QC testing on a nearly full-time basis for most residential over-excavation projects.

Based on the survey responses, it is common for a firm's field representative to collect relatively undisturbed samples (hand drives) for additional laboratory swell/consolidation tests during the fill placement. Some respondents indicated that they may collect hand drives daily to confirm moisture content, density, and that the measured swell of the fill samples is typically less than about 1 to 2 percent (under a surcharge of 500 to 1,000 pounds per square foot (psf)).

Some respondents indicated they also drill additional borings after the completion of fill placement on residential projects to evaluate whether the potential swell of the over-excavated fill and underlying materials are suitable for the intended construction of shallow foundations. These borings are also used to provide geotechnical design-recommendations.

CONCLUSIONS

Survey responses received as part of this study indicate there is a consensus among CAGE members engaged in geotechnical consulting for new residential and commercial development. CAGE members believe current practices for over-excavation are appropriate and can be effective in mitigating the harmful effects of expansive soil and bedrock.

Based on the survey responses, over-excavation can effectively mitigate total and differential vertical movement, whether expansion or settlement, under buildings. CAGE members commonly recommend the use of deep over-excavation for mitigation of expansive soils in the Front Range. Performance of over-excavation fill is similar to the performance of fills used successfully for decades in highway construction.

Every survey respondent indicated that they frequently provide over-excavation as an alternative recommendation, and in some cases, as the preferred alternative. This extensive use indicates that member firms believe that over-excavation is an effective mitigation practice for expansive soil or bedrock.

As with many aspects of construction, and in geotechnical practice in particular, over-excavation is not without its challenges. The performance relies heavily on the contractor to produce a well-processed fill. Nonetheless, CAGE members consider use of over-excavation to mitigate the harmful effects of expansive soil and bedrock to be consistent with the state of practice in the geotechnical profession.

SOURCES CITED

1 Hamilton, Judith L. and Owens, Willard G., 1972, ***Geologic Aspects, Soils and Related Foundation Problems, Denver Metropolitan Area, Colorado***, Colorado Geological Survey, Environmental Geology No. 1

2 Bower, L.C., Deputy Chief Engineer, January 5, 1966, ***Memo #323 (Construction) Swelling Soils***, Department of Highways, State of Colorado

3 Ardani, Ahmad, March 1992, ***Expansive Soil Treatment Methods in Colorado***, Colorado Department of Transportation, Report No. CDOT-DTD-R-92-2

4 _____, 2021, ***M-E Pavement Design Manual***, Colorado Department of Transportation

5 Hart, Stephen S., 1974, ***Potentially Swelling Soil and Rock in the Front Range Urban Corridor, Colorado***, Colorado Geological Survey, Environmental Geology 7

6 _____, 1995, **Land Development Regulations**, Jefferson County, Colorado

7 Noe, David C. and Dodson, Marilyn D., 1999, ***Heaving-Bedrock Hazards Associated with Expansive, Steeply Dipping Bedrock in Douglas County, Colorado***, Colorado Geologic Survey, Special Publication 42

8 _____, December 1996, ***Guideline For Slab Performance Risk Evaluation and Residential Basement Floor System Recommendations (Denver Metropolitan Area)***, Colorado Association of Geotechnical Engineers, Guideline 1

9 Chen, Fu Hua. 1988. Foundations on Expansive Soils. Elsevier Scientific Publishing Company. New York, NY.

10 Hart, T., Thompson, R.W., and McOmber, R.M. 2008. "Ground Modification by Sub-Excavation for Subdivisions on Expansive Soils." Proceedings GEO-Velopment. Denver, CO. November 7. pp. 22-37.

11 Jones, D. Earl, Jr. and Jones, Karen A. 1988. "Options for Building on Expansive Clays." Proceedings Up & Down Soils Technical Seminar. ASCE. Colorado Section. University of Colorado at Boulder. March 31. 35 pp.

12 Likos, William J., Lu, Ning, and Sharkey, Kevin J. 2005. "Laboratory Characterization of Steeply Dipping Expansive Bedrock in the Rocky Mountain Front Range." Journal of Geotechnical and Geoenvironmental Engineering. ASCE. Vol. 131. No. 9. September. pp. 1162-1171.

13 Nelson, John D. and Miller, Debora J. 1992. Expansive Soils – Problems and Practice in Foundation and Pavement Engineering. John Wiley & Sons, Inc. New York, NY.

14 Noe, David C. 2003. "Case History of Damage to a School Caused by Differentially Heaving Bedrock." Journal of Performance of Constructed Facilities. ASCE. Vol. 17. Issue 2. May. pp. 97-105.

15 Noe, David C. 2005. "Geologic Controls of Subdivision Damage near Denver, Colorado." Journal of Geotechnical and Geoenvironmental Engineering. ASCE. Vol. 131. No. 9. September. pp. 1080-1096.

16 White, Jonathan L. and Greenman, Celia. 2008. "Collapsible Soils in Colorado". Colorado Geologic Survey Engineering Geology 14.

APPENDIX: OVER-EXCAVATION SURVEY

CAGE Overexcavation Survey

Overexcavation for Swell Mitigation
A Survey of CAGE Professional Members

Background

Overexcavation (also known as sub-excavation) has become a common method to mitigate the potential swell of expansive soils and bedrock along Colorado's Front Range.

The basic process seems to have originated in the Colorado Springs area in the early 1960s and overexcavation to 10 feet or more below foundation elements followed by processing and recompaction was developed in the early to mid-1990s as a method for mitigation of the highly variable subsurface conditions found along the eastern face of the foothills (steeply dipping, expansive bedrock).

Today, overexcavation is common for residential and commercial developments underlain by expansive soils and bedrock.

Survey Purpose

The goal of this study is to collect and compile information from the CAGE membership regarding the current state of the practice for overexcavation, specifically:

- History
- Geographical distribution
- Frequency of use
- Purpose or goal
- Methodology and criteria for evaluating and recommending depth of overexcavation
- Field evaluation and quality control during construction

Participation Requirements

Response to this survey shall be by professional members experienced with overexcavation as a method of swell mitigation in Colorado's Front Range or other areas of the state.

This survey is being distributed to all active CAGE Professional Members. Recognizing that more than one CAGE Professional Member may work at the same geotechnical firm, the intent is that one response be provided per firm that represents the practice or range of practice within the responding firm. The final response should include the number of CAGE Professional Members represented by the response. Responses will be anonymous.

Deadline

Please complete and return via email all survey responses to CAGE no later than **September 18, 2020**. Thank you for your willingness to share your experience. Together we are better!

1. Please indicate how much of your new-build residential and commercial building project work is performed in the following regions (by percentage, the sum of which should be 100%)

Greater Denver area (Arapahoe, Douglas, Jefferson, Adams, Boulder, Broomfield, and Denver Counties) [ ]

Larimer and Weld Counties (Loveland, Fort Collins, Greeley, etc.) [ ]

Greater Colorado Springs area (El-Paso County, Larkspur, Monument, etc.) [ ]

Eastern Plains [ ]

Mountains (Summit, Grand, Eagle Counties, etc.) [ ]

Western Slope and Four Corners (Glenwood, Grand Junction Durango, etc.) [ ]

2. Considering the last 5 years, please estimate the average annual number of new-build residential and commercial building projects for which your firm completes geotechnical reports (a residential subdivision would count as one project):

	Greater Denver-Metro	Greater Colorado Springs	Greater Fort Collins/Greeley
less than 25	☐	☐	☐
26 to 50	☐	☐	☐
51 to 100	☐	☐	☐
101 to 150	☐	☐	☐
151 to 200	☐	☐	☐
201 to 250	☐	☐	☐
over 250	☐	☐	☐

3. Over the last year, estimate the number of a) detached single family homes and b) the number of multi-family units for which your firm has provided geotechnical foundation design recommendations.

a. detached single family homes [ ]

b. multi-family units [ ]

4. Over the last five years, estimate the number of a) detached single family homes and b) the number of multi-family units for which your firm has provided geotechnical foundation design recommendations.

a. detached single family homes [ ]

b. multi-family units [ ]

5. Over the last year, estimate the number of commercial (i.e. non-residential) buildings for which your firm has provided geotechnical foundation design recommendations.

[ ]

6. Over the last five years, estimate the number of commercial (i.e. non-residential) buildings for which your firm as provided geotechnical foundation design recommendations.

[ ]

7. What percentage of the above projects represented in Question 2 are underlain by expansive soils?

	Greater Denver-Metro	Greater Colorado Springs	Greater Fort Collins/Greeley
Less than 10%	☐	☐	☐
11 to 25%	☐	☐	☐
26 to 50%	☐	☐	☐
51 to 75%	☐	☐	☐
More than 75%	☐	☐	☐

Comments:

[ ]

8. On average, on what percentage of the above projects represented in Question 2 has your firm recommend overexcavation as an alternative for swell mitigation?

	Greater Denver-Metro	Greater Colorado Springs	Greater Fort Collins/Greeley
Less than 10%	☐	☐	☐
11 to 25%	☐	☐	☐
26 to 50%	☐	☐	☐
51 to 75%	☐	☐	☐
More than 75%	☐	☐	☐

Comments:

[ ]

When considering only those projects where expansive soils and bedrock are present, please answer the following:

9. How often does your firm recommend the following?

	1 (never)	2	3	4	5	6	7	8	9	10 (always)
deep foundations and/or suspended, structural floors	○	○	○	○	○	○	○	○	○	○
overexcavation to enable use of shallow foundations (i.e. spread footings, rigid mats, or post-tensioned slab-on-grade foundations)	○	○	○	○	○	○	○	○	○	○
overexcavation to enable use of interior slab-on-grade floors in conjunction with deep foundations	○	○	○	○	○	○	○	○	○	○

Comments

10. How often do you or your firm present overexcavation as an alternative to the use of deep foundations versus being presented as a "stand-alone" or preferred alternative?

	1 (never)	2	3	4	5	6	7	8	9	10 (always)
Alternative	○	○	○	○	○	○	○	○	○	○
Preferred (Stand Alone) recommendation	○	○	○	○	○	○	○	○	○	○
Alternative for interior slab-on-grade floors only	○	○	○	○	○	○	○	○	○	○

Comments

11. When considering whether to recommend overexcavation, please rank the following criteria from 7 being the most important to 1 being the least important, using each value only once:

- Experience in the project vicinity
- Geologic setting and lab data
- Type of project, i.e. residential vs. commercial, structural loading, etc.
- Estimated long-term effectiveness (or probability of meeting the project goals)
- Client's tolerance for post-construction movement
- End-user's tolerance for post-construction movement
- Expectation that firm will perform construction observation and testing

12. Are there other critical criteria when considering whether to recommend overexcavation? If so, please describe in the space provided.

13. When considering the goals of overexcavation, please rank the following criteria from 6 being the most important to 1 being the least important, using each value only once:

- Reduce potential vertical foundation movement
- Reduce potential lateral foundation movement
- Reduce potential interior floor slab movement
- Reduce potential movement/distress of other infrastructure (utilities, etc.)
- Eliminate construction issues associated with deep foundations and structural floors

14. Are there other critical criteria when considering the goals of overexcavation? If so, please describe in the space provided.

15. Which of the following methods are used (by you or your firm) to determine the recommended depth of overexcavation (select all that apply)?

- ☐ Oedometer Methods: Swell/Consolidation tests are used to model the subsurface materials in order to calculate an estimated heave within the anticipated depth of wetting should significant wetting occur.
- ☐ Oedometer Methods: Swell/Consolidation tests are used as index values to provide an estimate of the relative risk and magnitude of heave should significant wetting occur.
- ☐ Suction Methods: Soil Suction tests are used to model the subsurface materials to calculate the estimated heave within the anticipated depth of wetting should significant wetting occur.
- ☐ Potential Vertical Rise is calculated using natural and recompacted soil/bedrock properties and estimated active zone
- ☐ Mandated by local agency (such as in the Steeply Dipping Bedrock Area)
- ☐ Experience on nearby sites

Please provide a brief explanation of any other methods used:

16. What are the criteria you or your firm use to determine what depth of overexcavation is adequate to enable the use of shallow foundations and slab-on-grade floors?

- ☐ Heave estimate
- ☐ Jurisdictional criteria (e.g. 10 feet below base of foundation)

Please provide a brief explanation of any other criteria used:

17. Please provide percentages for the following:

Where overexcavation is considered, how often (by percentage of projects) is your firm performing laboratory remolded swell testing at the time of the report to evaluate whether the swell potential can be satisfactorily mitigated?

18. Any comments to Question 17

19. Of the projects where overexcavation is considered, what percentage require some other means of mitigation, i.e., where mitigation by moisture conditioning alone is not sufficient to meet project goals?

0 100

20. Any comments to Question 19

21. Of the projects requiring some other method of mitigation, which other methods has your firm used?

- [ ] None, deep foundations and/or suspended floors were recommended
- [ ] Exporting on-site soils bedrock and importing low-expansive fill (either entirely or partially replacing on-site materials)
- [ ] Chemical treatment of on-site soils/bedrock (lime, potassium chloride, Clayset, etc.)

Please provide a brief explanation of any other methods used:

22. Provide an estimated percentage of the projects for which your firm has recommended overexcavation (as a preferred mitigation method or an alternative), **AND** is also retained to provide construction observations and testing.

0 100

23. Any comments to Question 22

CAGE Overexcavation Survey

Questions 21-27 relate to situations when your firm provides construction observation and testing services on overexcavation projects. Please indicate the general methods and procedures your firm utilizes to evaluate the effectiveness of the overexcavation process (select yes to all that apply, and describe the acceptance criteria used in the space provided):

24. Full-time observation

- Yes
- No

If yes, what % of projects

25. Part-time observation

- Yes
- No

26. Minimum moisture-compaction testing frequency (tests/lot, tests per lift, tests per 5,000 cy, etc.)

- ◯ Yes
- ◯ No

If yes, what frequency?

27. Field moisture confirmation, via other methods

- ◯ Yes
- ◯ No

If yes, what moisture criteria and what frequency?

28. Hand-drive samples for laboratory swell testing

- ◯ Yes
- ◯ No

If yes, define swell criteria (what percent at what surcharge pressure) and frequency:

29. Geotechnical borings and sampling

- ◯ Yes
- ◯ No

Acceptance criteria:

30. Please provide a brief explanation of any other methods/procedures used:

31. Please provide brief comments regarding your (your firm's) experience with projects where over-excavation was used. Please consider sharing current practices regarding geotechnical exploration, and construction observation and testing.

32. How many CAGE professional members from your firm participated or are represented in the survey response?