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SOILS AND FOUNDATION INVESTIGATION
RALSTON TERRACE TOWNHOMES, PHASE 2
10555 WEST 63RD PLACE
ARVADA, COLORADO

Prepared for:

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Project No. DN50,360.001-120-R1

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TABLE OF CONTENTS

SCOPE 1
SUMMARY 1
SITE CONDITIONS 2
PROPOSED CONSTRUCTION 3
PREVIOUS INVESTIGATION 3
INVESTIGATION 4
SUBSURFACE CONDITIONS 5
    Groundwater 6
GEOLOGIC HAZARDS 6
SITE PREPARATION 7
    Excavation 7
    Fill and Backfill 8
POTENTIAL HEAVE 9
FOUNDATIONS 10
SLAB PERFORMANCE RISK 11
FLOOR SYSTEMS AND SLABS-ON-GRADE 12
    Structurally Supported Floors 12
    Porches, Decks and Patios 13
    Garage Floors and Exterior Flatwork 13
BELOW-GRADE WALLS 14
BACKFILL COMPACTION 15
SUBSURFACE DRAINS AND SURFACE DRAINAGE 16
PAVEMENTS 17
CONCRETE 19
CONSTRUCTION OBSERVATIONS 19
GEOTECHNICAL RISK 20
LIMITATIONS 20

EXHIBIT A – SLAB PERFORMANCE RISK EVALUATION, INSTALLATION AND MAINTENANCE

EXHIBIT B – SURFACE DRAINAGE, IRRIGATION AND MAINTENANCE

EXHIBIT C – EXAMPLE BACKFILL COMPACTION ALTERNATIVES

FIG. 1 – LOCATIONS OF EXPLORATORY BORINGS

FIGS. 2 AND 3 – SUMMARY LOGS OF EXPLORATORY BORINGS

FIGS. 4 AND 5 – FOUNDATION WALL DRAIN DETAILS

APPENDIX A – LABORATORY TEST RESULTS AND TABLE A-I

APPENDIX B – FLEXIBLE AND RIGID PAVEMENT MATERIALS, CONSTRUCTION, AND MAINTENANCE GUIDELINES

SCOPE

This report presents the results of our Soils and Foundation Investigation for Phase 2 of Ralston Terrace townhomes located at 10555 West 63rd Place in Arvada, Colorado (Fig. 1). The purpose of our investigation was to evaluate the subsurface conditions and provide geotechnical design and construction recommendations for the townhome buildings. The scope was described in a Proposal (DN 20-0434-CM1) dated January 25, 2021.

The report is based on conditions found in our exploratory borings, results of field and laboratory tests, engineering analysis of field and laboratory data, previous investigation, and our experience with similar conditions and projects. It includes our opinions and recommendations for design criteria and construction details for foundations and floor systems, slabs-on-grade, lateral earth loads, and drainage precautions. The report was prepared for the exclusive use of Ralston Terrace, LLC and your team in design and construction of the referenced townhome buildings. Other types of construction may require revision of this report and the recommended design criteria. A brief summary of our conclusions and recommendations follows, with more detailed discussion and design criteria provided within the report.

SUMMARY

1. Strata encountered in our borings consisted of 4 to 22 feet of sandy clay underlain by sandstone and claystone bedrock. Testing indicates the clay and claystone is predominantly low swelling. We judge the sandstone is non-expansive.

2. Water was measured in one boring at a depth of about 26 feet. Groundwater should not affect construction. Groundwater may fluctuate seasonally and rise in response to precipitation and landscape irrigation.

3. The presence of expansive soils and bedrock constitutes a geologic hazard. There is risk that slabs-on-grade and foundations will experience heave and damage. We believe the recommendations presented in this report will help to control risk of damage; they will not eliminate that risk.

Slabs-on-grade and, in some instances, foundations may be damaged by heave or settlement of the soils.

4. Our investigation revealed predominantly low swelling clay and non-expansive sandstone at depths likely to influence performance of footing foundations. We estimate potential ground heave may range from less than 0.5-inch to 2.2 inches at proposed grades with normal post-construction wetting. We judge footing foundations can be used with relatively low risk of damage. Design and construction criteria are presented in the report.

5. The main floor of each building should be structurally supported. Basements are not planned for these homes. We judge there is low risk of poor performance of ground-supported slabs. Slab-on-grade driveways, garage floors, and exterior flatwork may experience movement and cracking.

6. Surface drainage should be designed, constructed, and maintained to provide rapid removal of surface runoff away from structures off pavements and flatwork. The site soils are moisture-sensitive. Conservative irrigation practices should be followed to avoid excessive wetting.

7. The design and construction criteria for foundations and floor system alternatives in this report were compiled with the expectation that all other recommendations will be incorporated into the project and that townhome owners and the HOA will maintain the structures, use prudent irrigation practices and maintain surface drainage. It is critical that all recommendations in this report are followed.

SITE CONDITIONS

Ralston Terrace, Phase 2 is located at 10555 West 63rd Place in Arvada, Colorado (Fig. 1 and Photo 1). The site was formerly used as a miniature golf course. The former structures and miniature golf course have been demolished and removed. The site is bordered by a gas station on the east, existing residential development on the south, and future Phase 1 of Ralston Terrace Townhomes on the west. Final site grades are expected to be near existing. The ground surface slopes gently to the north towards West 64th Avenue.

Photo 1 – Google Earth© Aerial Site Photo, October 2019. Approximate site outline is in red.

PROPOSED CONSTRUCTION

Plans indicate the development will consist of 12 townhome residences in 3 buildings. The buildings will be serviced by buried utilities and paved roadways/access drives (Fig. 1). The townhome buildings will each have two to six units and be two or three-story, wood-framed structures with no below-grade levels. The residences may have partial brick or stone exterior veneer. Foundation loads are expected to vary between 1,000 and 3,000 pounds per lineal foot of foundation wall, with individual column loads of 45 kips or less. We anticipate excavations up to 3 feet will be required for foundation construction. Final grading and landscaping may result in slightly greater depth of backfill.

PREVIOUS INVESTIGATION

We performed a Preliminary Geotechnical Investigation under our Project No. DN50,360.001-115 (report dated October 26, 2020). We drilled and sampled three

exploratory borings (TH-1, TH-2, and TH-3) across the site and identified expansive soil and bedrock as the primary geotechnical concern for the development. Bedrock was encountered at a shallow depth in the northwestern corner of the parcel. At this location, sandstone was encountered at 4 feet in one boring (TH-1). The depth to bedrock dropped off precipitously on the southern and eastern reaches of the site. The southern boring (TH-2) encountered bedrock at 33 feet and the eastern boring (TH-3) did not encounter bedrock to a maximum explored depth of 25 feet. Groundwater was encountered at 18 and 23 feet in two borings. The data and recommendations presented in this report were compiled using data from our current and previous investigations. Locations of exploratory borings from this and the previous investigation are shown on Figure 1. Summary logs of all of our exploratory borings are included in Figure 3.

INVESTIGATION

We investigated subsurface conditions on February 4, 2021 by drilling and sampling three additional exploratory borings at the approximate locations shown on Fig. 1. We determined boring locations and elevations using a Leica GS18 GPS unit referencing the North American Vertical Datum of 1988 (NAVD88). Prior to drilling, we contacted the Utility Notification Center of Colorado and local sewer and water districts to identify locations of buried utilities. The borings were drilled to depths of 20 to 30 feet below existing grades using 4-inch diameter, continuous-flight, solid-stem auger and a truck-mounted CME-45 drill rig. We obtained samples at approximate 5-foot intervals using a 2.5-inch diameter (O.D.) modified California barrel sampler driven by blows from an automatic 140-pound hammer falling 30 inches. A bulk sample of auger cuttings from the upper 5 feet was obtained in one boring. Our field representatives were present to observe drilling operations, log the strata encountered, and obtain samples. Upon completion of drilling, hand-slotted PVC pipe was installed in the holes to allow delayed groundwater level measurements. The pipe was removed, and the holes were filled following the final groundwater measurements. Graphical logs of the borings, including results of field penetration resistance tests and some laboratory test data, are presented on the Summary Logs of Exploratory Borings in Figures 2 and 3.

Samples were returned to our laboratory where they were examined, and tests were assigned. Laboratory tests included moisture content, dry density, percent silt and clay-sized particles (passing No. 200 sieve), Atterberg limits, swell-consolidation, soil suction and water-soluble sulfate concentration. Swell-consolidation tests were performed by wetting the samples under approximate overburden pressure (the weight of the overlying soils). Load-back analysis was performed on select samples to estimate swelling pressure. Results of laboratory tests are presented in Appendix A and summarized in Table A-I.

SUBSURFACE CONDITIONS

Strata encountered in our exploratory borings generally consisted of about 4 to 22 feet of sandy clay underlain by sandstone and claystone bedrock to the maximum explored depth of 30 feet. Some pertinent engineering characteristics of the soil and bedrock are described in the following paragraphs.

The sandy clay was medium stiff to very stiff based on the results of field penetration resistance tests. One clay sample compressed 0.1 percent and three swelled 1.2 to 2.8 percent when wetted. Three samples developed load-back swelling pressures of approximately 3,300 to 4,000 psf, and four samples had soil suction values of 3.84 to 4.07 pF. One sample contained 63 percent silt and clay-sized particles and showed moderate plasticity with a liquid limit of 37 and plasticity index of 24.

Sandstone with lesser amounts of claystone bedrock was found in all borings at depths of about 4 to 22 feet. The bedrock was hard to very hard. One sandstone sample did not swell, and one claystone sample swelled 0.3 percent when wetted. Four sandstone samples contained 20 to 44 percent silt and clay-sized particles. One sandstone sample had a soil suction value of 2.56 pF. The claystone is judged to be expansive, but at depths unlikely to influence the planned construction.

Groundwater

Groundwater was not encountered during drilling. When the holes were checked four days after drilling on February 8, 2021, groundwater was encountered in one boring at a depth of 26 feet. We do not expect groundwater will affect surface construction. Water levels may fluctuate seasonally and rise in response to precipitation and landscape irrigation.

GEOLOGIC HAZARDS

Colorado is a challenging location to practice geotechnical engineering. The climate is relatively dry and the near-surface soils are typically dry and comparatively stiff. These soils and related sedimentary bedrock formations tend to react to changes in moisture conditions. Some of the soils swell as they increase in moisture and are referred to as expansive soils. Other soils can compress significantly upon wetting and are identified as compressible soils. Most of the land available for development east of the Front Range is underlain by expansive clay or claystone bedrock near the surface. The soils that exhibit compressible behavior are more likely west of the Continental Divide; however, both types of soils occur throughout the state.

Covering the ground with buildings, streets, driveways, patios, etc., coupled with lawn irrigation and changing drainage patterns, leads to an increase in subsurface moisture conditions. As a result, some soil movement due to heave or settlement is inevitable.

The presence of expansive soil and bedrock constitutes a geologic hazard. There is risk that slabs-on-grade and, in some instances, foundations may be damaged by movement of the swelling soils. Based on our investigation, the soil is predominantly low swelling and the risk is relatively low. The risk of foundation and slab movements can be mitigated, but not eliminated, by careful design, construction and maintenance procedures. We believe the recommendations in this letter will help control risk of

foundation and slab damage; they will not eliminate that risk. The builder and homebuyers should understand that slabs-on-grade and, in some instances, foundations may be affected by movement of the subsoils. Homeowner maintenance will be required to control risk. We recommend the builder provide a booklet to homebuyers that describes swelling soils and includes recommendations for care and maintenance of homes constructed on expansive soils. Colorado Geological Survey Special Publication 43[1] was designed to provide this information.

SITE PREPARATION

Excavation

Excavations should be sloped to comply with Occupational Safety and Health Administration (OSHA) standards. We anticipate the clay and sandstone will likely classify as Type B soil, which require maximum side slope inclinations of 1:1 (horizontal:vertical) for temporary excavations in dry conditions. Flatter slopes will be required if seepage is present. Excavation slopes specified by OSHA are dependent upon soil types and seepage conditions exposed. Contractors should identify the soils encountered in the excavations and refer to OSHA standards to determine appropriate slopes. Excavations made at this site, including those for foundations and utilities, may be governed by local, state, or federal guidelines or regulations. Subcontractors should be familiar with these regulations and take whatever precautions they deem necessary to comply with the requirements and thereby protect the safety of their employees and that of the general public. Permanent un-retained slopes should be designed no steeper than about 3:1 and should be re-vegetated as soon as practical to control erosion; use of 4:1 maximum slopes are preferable.

If loose or soft soils are encountered in foundation excavations during construction, they should be removed and replaced with compacted fill as recommended above or stabilized. Stabilization can likely be accomplished by crowding 1.5-inch to 3-inch

[1]"A Guide to Swelling Soils for Colorado Homebuyers and Homeowners," Second Edition Revised and Updated by David C. Noe, Colorado Geological Survey, Department of Natural Resources, Denver, Colorado, 2007.

nominal size crushed rock into the soft subsoils until the base of the excavation does not deform more than about 1 inch when compactive effort (a full-sized loader with full load) is applied.

Fill and Backfill

The on-site soils are generally suitable for reuse as new fill, provided they are substantially free of debris, organics, and other deleterious material. Soil particles larger than about 3 inches in diameter should not be used for fill. If imported fill is necessary, we recommend the import material to contain less than 60 percent silt and clay-sized particles, a liquid limit less than 40, and a plasticity index less than 20. Potential fill materials should be submitted to our office for approval prior to importing to the site.

Prior to fill placement, debris, organic matter, and deleterious material should be substantially removed from areas to receive fill. The excavation surface should be scarified to a depth of at least 8 inches, moisture conditioned, and compacted to the criteria below. Subsequent fill should be placed in thin (8 inches or less) loose lifts, moisture conditioned between optimum and 4 percent over optimum moisture content for clay and within 2 percent of optimum moisture content for sand, and compacted to at least 95 percent of standard Proctor maximum dry density (ASTM D 698).

Water and sewer lines are often constructed beneath slabs and pavements. Compaction of utility trench backfill can have a significant effect on the life and service-ability of floor slabs, pavements and exterior flatwork. We recommend utility trench backfill be placed and compacted as outlined above. Our experience indicates use of self-propelled compactors results in more reliable performance compared to fill compacted by a sheepsfoot wheel attachment on a backhoe or trackhoe. The upper portion of the trenches should be widened to allow the use of a self-propelled compactor. The placement and compaction of utility trench backfill should be observed and tested by a representative of our firm during construction.

Our experience indicates fill and backfill can settle, even if properly compacted to criteria provide above. Factors that influence the amount of settlement are depth of fill, material type, degree of compaction, amount of wetting and time. The degree of compression of fill under its own weight will likely range from low for granular soils (½ percent or less), to moderate for clay mixtures (1 to 2 percent).

POTENTIAL HEAVE

Our investigation indicates predominantly low swelling clay and non-expansive sandstone is present at depths likely to influence performance of shallow foundations. Based on a 24-foot depth of wetting, we estimate total potential ground heave may range from less than 0.5-inch to 2.2 inches at proposed grades. Research by Walsh, Colby, Houston and Houston[2] indicates there is a 90 percent probability that the wetting depth will not exceed 24 feet for this region, suggesting that the risk of ground heave exceeding the estimated values is low. This study was conducted on irrigated residential sites with basements. Considering the townhome buildings will not have basements, the depth of wetting may be less. We judge total potential movements will likely be 2 inches or less. Our heave calculations are presented in the table below.

ESTIMATED POTENTIAL HEAVE AT PROPOSED GRADE BASED ON 24-FOOT DEPTH OF WETTING

Boring	Estimated Potential Heave at Proposed Grade (inches)	Estimated Risk Due to Expansive Soil/Bedrock
TH-101	<0.5	LOW
TH-102	<0.5	LOW
TH-103	2.2	LOW
TH-1*	1.4	LOW
TH-2*	<0.5	LOW
TH-3*	0.5	LOW

*From previous investigation

[2]"Method for Evaluation of Depth of Wetting in Residential Areas" by Walsh, Colby, Houston and Houston, Journal of Geotechnical and Geoenvironmental Engineering, ASCE February 2009.

FOUNDATIONS

Our investigation indicates predominantly low swelling clay and non-expansive sandstone is present at depths likely to influence performance of shallow foundations. We judge footing foundations designed to maintain a minimum deadload pressure can be used with comparatively low risk of damaging movements for all buildings. Footings may experience settlement if soft or loose soils are present or if excessive wetting and softening occurs.

Design criteria for footing foundations are presented below. These criteria are developed from analysis of field and laboratory data and our experience. The builder and structural engineer should also consider design and construction details established by the structural warrantor (if any) that may impose additional design and installation requirements.

The upper 8 inches of foundation subgrade should be scarified, moisture-conditioned and compacted to the criteria presented in Fill and Backfill. If soft/loose soils are exposed in footing excavations, they should be removed and recompacted as recommended in **SITE PREPARATION**.

1. Footings should be designed for a maximum allowable soil pressure of 2,500 psf and a minimum deadload pressure of 800 psf. The maximum pressure can be determined using deadload plus ½-live load.

2. If interrupted footings are necessary to maintain deadload, a minimum 4-inch thick continuous void should be constructed below grade beams or foundation walls, between the pads.

3. Footings should have a minimum width of 16 inches. Foundations for isolated columns should have minimum dimensions of 18 inches by 18 inches. Larger sizes may be required depending upon the loads and structural system used.

4. Foundation walls should be well-reinforced. We recommend reinforcement sufficient to span an unsupported distance of at least 10 feet. Reinforcement should be designed by the structural engineer considering lateral earth pressure and the effects of large openings on wall performance.

5. Exterior footings must be protected from frost action. Normally, 3 feet of frost cover is assumed in the area.

6. The completed foundation excavation should be observed by a representative of our firm to confirm subsurface conditions are as anticipated from our borings.

7. Excessive wetting of foundation soils during and after construction can cause heave or softening and settlement of foundation soils and result in footing movements. Proper surface drainage around the residences and between lots is critical to control wetting. The foundation drain and utility service trenches should be braced or adequately sloped away from the footing to reduce the risk of undermining the footings. Sump pit construction should avoid undermining the footings. The voids around the sump pit excavation should be backfilled with compacted on-site soils, squeegee or "flowable fill" to reduce settlements.

SLAB PERFORMANCE RISK

We conducted swell tests to provide a basis to calculate potential heave of the on-site soils. Based on these test results and our experience, we estimated total potential ground heave may range from less than 0.5-inch to 2.2 inches at proposed grades. A depth of wetting of 24 feet was considered for the evaluation. Slabs may experience settlement if loose or soft soils are present or if excessive wetting and softening of subsoils occurs.

The results of the laboratory testing, subsoil profiles, heave estimates and our experience with residential construction and performance were used to provide an evaluation of slab performance risk. Slab performance risk evaluation is an engineering judgment that is used as a predictor of the general magnitude of potential slab-on-grade heave and the risk of poor slab-on-grade performance. We judge there is low risk of poor slab-on-grade performance. A more detailed discussion of this evaluation is provided in Exhibit A.

FLOOR SYSTEMS AND SLABS-ON-GRADE

No basements are planned for these residences. We understand structurally supported floors are planned for finished living areas, and slab-on-grade floors will be used in garages. Our experience indicates slab-on-grade floor performance has generally been satisfactory on low risk sites. Slab heave and/or settlement of 1 to 3 inches is considered “normal” for these sites. In unusual cases, movements can exceed these ranges. Where slabs-on-grade are provided, we recommend the precautions for slab-on-grade construction that are included in Exhibit A.

Structurally Supported Floors

A structural floor is supported by the foundation system. We understand you will likely use a slab-on-void system for living areas. We recommend the void form be at least 4 inches high. Void form should be chosen that will not retain substantial strength after the concrete hardens. For example, polystyrene foam is not suitable void material. Wax-coated cardboard that will break down in long term contact with moist soils is suitable. The minimum void space should be maintained between any point on the underside of the floor system and the soils.

Where structurally supported floors are used, utility connections including water, gas, air duct, and exhaust stack connections to floor supported appliances should be capable of absorbing some deflection of the floor. Plumbing that passes through the floor should ideally be hung from the underside of the structural floor and not lain on the bottom of the excavation. This configuration may not be achievable for some parts of the installation. It is prudent to maintain the minimum clear space below all plumbing lines. If trenching below the lines is necessary, we recommend sloping these trenches so they discharge to the foundation drain (if a drain is necessary).

Porches, Decks and Patios

Porches, patios and decks with roofs that are integral with a residence should be constructed with the same foundation type as the residence when movement would damage the residence. These foundations should be designed by a structural engineer. For simple decks that are not integral with the residence and can tolerate some movement, the use of short pier or footing foundations bottomed at least 3 feet below grade can be considered, as long as the foundations are located outside foundation wall backfill. The deck foundations should bottom below foundation wall backfill to reduce risk of settlement. The inner edge of a deck may be supported on joist hangers nailed to the rim joist or haunches or steel angles bolted to the foundation walls and detailed such that movement of the deck foundation will not cause distress to the residence. We suggest use of adjustable bracket-type connections or other details between foundations and deck posts so the posts can be adjusted if movement occurs.

Porches, patio slabs, and other exterior flatwork should be isolated from the structures. Porch slabs can be constructed to reduce the likelihood that settlement or heave will affect the slabs. One approach (for smaller porches located over backfill zones) is to place loose backfill under a structurally supported slab. This fill will more likely compress than swell, and can thus accommodate some heave of the underlying soils. A lower risk approach is to construct a structural porch slab over void-forming materials. Conditions should allow the void-forming materials to deteriorate and soften quickly after construction to reduce the risk of transmitting ground heave to the porch slab. Plastic-coated void boxes should not be used unless measures are taken to allow moisture penetration and softening.

Garage Floors and Exterior Flatwork

Garage floors, driveways and sidewalks are normally constructed as slab-on-grade. Performance of conventional slabs on expansive/compressible soil is erratic. Various properties of the soils and environmental conditions influence magnitude of

movement and other performance. Increases in the moisture content in these soils will cause heaving or settlement and may result in cracking of slabs-on-grade. Backfill below slabs should be moisture conditioned and compacted to reduce settlement, as discussed in **BACKFILL COMPACTION**. Slabs constructed on the backfill may settle and crack if the backfill is not properly moisture treated and compacted.

BELOW-GRADE WALLS

Foundation walls and grade beams that extend below grade should be designed to resist lateral earth pressures where backfill is not present to about the same extent on both sides of the wall. Many factors affect the value of the design lateral earth pressure. These factors include, but are not limited to, the type, compaction, slope and drainage of the backfill, and the rigidity of the wall against rotation and deflection. For a very rigid wall where negligible or very little deflection will occur, an “at-rest” lateral earth pressure should be used in design. For walls that can deflect or rotate 0.5 to 1 percent of the wall height (depending upon the backfill types), lower “active” lateral earth pressures are appropriate. Our experience indicates walls can deflect or rotate slightly under normal design loads, and that this deflection typically does not affect the structural integrity of the walls. Thus, the earth pressure on the walls will likely be between the “active” and “at-rest” conditions.

If on-site soils are used as backfill and the backfill is not saturated, we recommend design of foundation walls and grade beams using an equivalent fluid density of at least 60 pounds per cubic foot (pcf). The value assumes deflection; some minor cracking may occur. If very little wall deflection is desired, a higher design value is appropriate. The structural engineer should also consider site-specific grade restrictions.

BACKFILL COMPACTION

Settlement of foundation wall and utility trench backfill can cause damage to concrete flatwork and/or result in poor drainage conditions. Compaction of backfill can reduce settlement. Attempts to compact backfill near foundations to a high degree can cause damage to foundation walls and window wells and may increase lateral pressures on the foundation walls. The potential for cracking of a foundation wall can vary widely based on many factors including the degree of compaction achieved, the weight and type of compaction equipment utilized, the structural design of the wall, the strength of the concrete at the time of backfill compaction, and the presence of temporary or permanent bracing.

Proper moisture conditioning of backfill is as important as compaction because settlement commonly occurs in response to wetting. The addition of water complicates the backfill process, especially during cold weather. Frozen soils are not considered suitable for use as backfill because excessive settlement can result when the frozen materials thaw. Exhibit C describes four alternative methods to place, moisture condition, and compact backfill along with a range of possible settlement, and advantages and disadvantages of each approach, based upon our experience. These are just a few of the possible techniques, and represent a range for your evaluation. We recommend Alternative C or D if you wish to control settlement.

Precautions should be taken when backfilling against a foundation wall or grade beam. Waiting at least seven days after the walls are placed to allow the concrete to gain strength can reduce the risk of damage. Compaction of fill placed beneath and next to counterforts (if any) may be difficult to achieve without damaging these building elements. Proper moisture conditioning of the fill prior to placement in these areas will help reduce potential settlement.

Ideally, drainage swales should not be located over the backfill zone (including excavation ramps), as this can increase the amount of water infiltration into the backfill

and cause excessive settlement. Swales should be a minimum of 5 feet from the foundation to help reduce water infiltration. Irrigated vegetation, sump pump discharge pipes, sprinkler valve boxes, and roof downspout terminations should also be about 5 feet from the foundation.

SUBSURFACE DRAINS AND SURFACE DRAINAGE

Water from surface irrigation of lawns and landscaping frequently flows through relatively permeable backfill placed adjacent to a residence and collects on the surface of less permeable soils occurring at the bottom of foundation excavations. This process can cause wet or moist conditions in crawl spaces after construction. Moist conditions can develop in crawl space areas, resulting in isolated instances of damp soils, musty smells and, in rare cases, standing water. Crawl spaces, if used should be well ventilated. For slab-on-void floors where the subgrade is at or above exterior ground grade, drains are not normally necessary.

Where crawl spaces are constructed without basements, a drain should be installed around crawl space areas. We recommend provision of a foundation drain around the entire crawl space perimeter of each building to reduce the likelihood water pressure will develop outside foundation walls and the risk of accumulation of water at crawl space level. The provision of a drain will not eliminate slab movement or prevent moist conditions in crawl spaces. The drain should consist of a 4-inch diameter, perforated or slotted pipe encased in free-draining gravel. The drain should lead to a positive gravity outlet, such as a subdrain located beneath the sewer, or to a sump where water can be removed by pumping. Sump pumps must be maintained by home owners. Typical foundation drain details for crawl space construction are presented on Figs. 4 and 5.

For interior crawl space foundation drains and footing foundations, “tunneling” under the footing or installation of short segments of void form in the footings and is recommended to provide a flow path for water from the outside of the crawl space walls

to the interior foundation drain (Fig. 4). The structural engineer should consider the impact of this detail on footing foundation design.

Proper design, construction, and maintenance of surface drainage are critical to the satisfactory performance of foundations, slabs-on-grade, and other improvements. Landscaping and irrigation practices will also affect performance. Exhibit B contains our recommendations for surface drainage, irrigation, and maintenance.

PAVEMENTS

Pavement areas will be used for automobile parking, access drives and truck/fire lanes. Our investigation indicates pavement subgrade will likely consist of moderate plasticity clay material, which is considered to be relatively poor subgrade. Pavements can experience heave due to expansive clay, or settlement due to compression of clay or utility trench backfill. We typically recommend the pavement subgrade be proof-rolled to disclose soft areas. Soft areas should be stabilized. Subgrade areas that pass proof-roll should be stable enough to pave.

We provided pavement alternatives for full-depth asphalt and portland cement concrete and composite section consisting of asphalt over aggregate base course below. The sections assume compacted subgrade with similar engineering characteristics to the soils we tested.

SUMMARY OF MINIMUM RECOMMENDED PAVEMENT ALTERNATIVES

Anticipated Traffic Type	Hot-Mix Asphalt (HMA)	Hot-Mix Asphalt + Aggregate Base Course (HMA +ABC)	Portland Cement Concrete (PCC)
Automobile Parking	6” HMA	4” HMA + 8” ABC	6” PCC
Access Drives and Fire/Truck Lanes	7” HMA	4” HMA + 10” ABC or 4.5” HMA + 8” ABC	6” PCC

The design of a pavement system is as much a function of paving materials as support characteristics of the subgrade. If the pavement system is constructed of inferi-

or material, then the life and serviceability of the pavement will be substantially reduced. Materials and placement methods should conform to the requirements of the City of Arvada. All materials planned for construction should be tested to confirm their compliance with project specifications.

Control joints should separate concrete pavements into panels with patterns and spacing as recommended by ACI. No de-icing salts should be used on paving concrete for at least one year after placement. Routine maintenance, such as sealing and repair of cracks and overlays at 5 to 7-year intervals, are necessary to achieve long-term performance of an asphalt system. We recommend application of a rejuvenating sealant such as fog seal after the first year. Deferring maintenance usually results in accelerated deterioration of pavements leading to higher future maintenance costs.

A primary cause of early pavement deterioration is water infiltration into the pavement system. The addition of moisture usually results in softening of the subgrade and eventual failure of the pavement. We recommend drainage be designed for rapid removal of surface runoff. Curb and gutter should be backfilled and the backfill compacted to reduce ponding adjacent to the pavements. Final grading of the subgrade should be carefully controlled so that design cross-slope is maintained and low spots in the subgrade which could trap water are eliminated. A seal should be provided between curb and pavement and at all joints to reduce moisture infiltration. Landscaped areas and detention ponds in pavements should be avoided.

Recommended material properties and construction criteria for pavements are provided in Appendix B. These criteria were developed from analysis of the field and laboratory data and our experience. If the materials cannot meet these recommendations, then the pavement design should be re-evaluated based upon available materials. All material and construction requirements of the City of Arvada should be followed. All materials planned for construction should be submitted and the applicable laboratory tests performed to verify compliance with the specifications.

CONCRETE

Concrete in contact with soil can be subject to sulfate attack. We measured water-soluble sulfate concentrations of less than 0.01 percent in two samples from the two investigations on this site. For this level of sulfate concentration, there are no special requirements for sulfate resistance.

Superficial damage may occur to the exposed surfaces of highly permeable concrete, even though sulfate levels are relatively low. To control this risk and to resist freeze-thaw deterioration, the water-to-cementitious materials ratio should not exceed 0.50 for concrete in contact with soils that are likely to stay moist due to surface drainage or high-water tables. Concrete should have a total air content of 6 percent +/-1.5 percent. We advocate all below-grade walls in contact with subsoils be damp-proofed.

CONSTRUCTION OBSERVATIONS

This report has been prepared for the exclusive use of Ralston Terrace, LLC and your team for the purpose of providing geotechnical design and construction criteria for the planned townhome residences. The information, conclusions, and recommendations presented herein are based upon consideration of many factors including, but not limited to, the type of structures proposed, the geologic setting, and the subsurface conditions encountered. The conclusions and recommendations are not valid for use by others. Standards of practice evolve in the area of geotechnical engineering. The recommendations provided are appropriate for about three years. If the proposed residences are not constructed within about three years, we should be contacted to determine if we should update this report.

We recommend that CTL | Thompson, Inc. provide construction observation services to allow us the opportunity to confirm whether soil conditions are consistent with those found during this investigation. If others perform these observations, they must

accept responsibility to judge whether the recommendations in this report remain appropriate.

GEOTECHNICAL RISK

The concept of risk is an important aspect with any geotechnical evaluation, primarily because the methods used to develop geotechnical recommendations do not comprise an exact science. We never have complete knowledge of subsurface conditions. Our analysis must be tempered with engineering judgment and experience. Therefore, the recommendations presented in any geotechnical evaluation should not be considered risk-free. Our recommendations represent our judgment of those measures that are necessary to increase the chances that the structures will perform satisfactorily. It is critical that all recommendations in this report are followed during construction. Homeowners must assume responsibility for maintaining the structures and use appropriate practices regarding drainage and landscaping. Improvements performed by the homeowners after construction, such as construction of an addition, retaining wall, deck, porch, patio, landscaping, and exterior flatwork should be completed in accordance with recommendations provided in this report and may require additional soil investigation and consultation.

LIMITATIONS

Our borings were spaced to obtain a reasonably accurate indication of foundation soil conditions beneath the proposed townhome buildings. Variations in the subsoil conditions not indicated by our borings are possible. A representative of our firm should observe foundation excavations and footing construction. Our representative should also test moisture and density of fill placed below foundations and foundation wall backfill during construction.

We believe this investigation was conducted with that level of skill and care ordinarily used by geotechnical engineers practicing in this area under similar conditions.

No warranty, express or implied, is made. If we can be of further service in discussing the contents of this report or in the analysis of the influence of subsoil conditions on design of the structures, please call.

CTL | THOMPSON, INC.

Samuel J. Rumel, E.I.T.
Staff Engineer

Reviewed by:

David Allen Glater
Mar 5 2021 11:14 AM

David A. Glater, P.E., C.P.G.
Senior Principal Geological Engineer

SJR:DAG/nn

Via e-mail: dcerniglia@creeksidecommunities.com
ssundberg@creeksidecommunities.com

EXHIBIT A

SLAB PERFORMANCE RISK EVALUATION,
INSTALLATION AND MAINTENANCE

As part of our evaluation of the subsoils and bedrock, samples were tested in the laboratory using a swell test. In the test procedure, a relatively undisturbed sample obtained during drilling is first loaded and then flooded with water and allowed to swell. The pressure applied prior to wetting can approximate the weight of soil above the sample depth or be some standard load. The measured percent swell is not the sole criteria in assessing potential movement of slabs-on-grade and the risk of poor slab performance. The results of a swell test on an individual lot are tempered with data from surrounding lots, depth of tests, depth of excavation, soil profile, and other tests. This judgment has been described by the Colorado Association of Geotechnical Engineers[3] (CAGE, 1996) as it relates to basement slab-on-grade floors. It can also be used to help judge performance risk for other slabs-on-grade such as garage floors, driveways, and sidewalks. CTL Thompson also performs potential heave calculations to aid in our judgment. The risk evaluation is considered when we evaluate appropriate foundation systems for a given site. In general, more conservative foundation designs are used for higher risk sites to control the likelihood of excessive foundation movement.

As a result of the Slab Performance Risk Evaluation, sites are categorized as low, moderate, high, or very high risk. This is a judgment of the swelling characteristics of the soils and bedrock likely to influence slab performance.

REPRESENTATIVE MEASURED SWELL
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	$\geq$ 8	$\geq$ 6

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

The rating of slab performance risk on a site as low or high is not absolute. Rather, this rating represents a judgment. Movement of slabs may occur with time in low, moderate, high, and very high risk areas as the expansive soils respond to increases in moisture content. Overall, the severity and frequency of slab damage usually is greater in high and very high rated areas. Heave of slabs-on-grade of 3 to 5 inches is not uncommon in areas rated as high or very high risk. On low and moderate risk sites, slab heave of 1 to 2 inches is considered normal and we believe in the majority of instances, movements of this magnitude constitute reasonable slab performance; more heave can occur. Slabs can be affected on all sites. On lots rated as high or very high risk, there is more likelihood of need to repair, maintain or replace main level and garage floors and exterior flatwork.

[4]"Guideline for Slab Performance Risk Evaluation and Residential Basement Floor System Recommendations", Colorado Association of Geotechnical Engineers, December 1996.

The home buyer should be advised slabs-on-grade may move and crack due to heave or settlement and that there may be maintenance costs associated during and after the builder warranty period. Heave or settlement may require maintenance of finish details to control damage. Our experience suggests that soil moisture increases below residence sites due to covering the ground with the house and exterior flatwork, coupled with the introduction of landscape irrigation. In most cases, slab movements (if any) resulting from this change occur within three to five years.

For portions of the houses where conventional slabs-on-grade are used, we recommend the following precautions. These measures will not keep slabs-on-grade from heaving; they tend to mitigate damages due to slab heave.

1. Slab-on-grade floor construction should be limited to areas where slab movement and cracking are acceptable to the builder and home buyer.

2. The International Residential Code (IRC R506) states that a 4-inch base course layer consisting of clean graded sand, gravel, crushed stone or crushed blast furnace slag shall be placed beneath below slab-on-grade floors (unless the underlying soils are free-draining), along with a vapor retarder. Installation of the base course and vapor retarder is not common in this area. Historically, there has been some concern that installation of clean base course could allow wetting of expansive soils to spread from an isolated source.

   IRC states that the vapor retarder can be omitted where approved by the building official. The merits of installation of a vapor retarder below floor slabs depend on the sensitivity of floor coverings and building use to moisture. A properly installed vapor retarder is more beneficial below concrete slab-on-grade floors where floor coverings, painted floor surfaces, or products stored on the floor will be sensitive to moisture. The vapor retarder is most effective when concrete is placed directly on top of it, rather than placing a sand or gravel leveling course between the vapor retarder and the floor slab. Placement of concrete on the vapor retarder may increase the risk of shrinkage cracking and curling. Use of concrete with reduced shrinkage characteristics including minimized water content, maximized coarse aggregate content, and reasonably low slump will reduce the risk of shrinkage cracking and curling. Considerations and recommendations for the installation of vapor retarders below concrete slabs are outlined in Section 3.2.3 of the 2006 American Concrete Institute (ACI) Committee 302, “Guide for Concrete Floor and Slab Construction (ACI 302.R-96)”.

3. Conventional slabs should be separated from exterior walls and interior bearing members with a slip joint that allows free vertical movement of the slabs. These joints must be maintained by the home buyer to avoid transfer of movement.

4. Underslab plumbing (if any) should be thoroughly pressure tested during construction for leaks and be provided with flexible couplings. Gas and waterlines leading to slab-supported appliances should be constructed with flexibility. The homebuyer must maintain these connections.

5. Use of slab bearing partitions (if any) should be minimized. Where such partitions are necessary, a slip joint (or float) allowing at least 3 inches of free vertical slab movement should be used. Doorways should also be designed to allow vertical

movement of slabs. To limit damage in the event of movement, sheetrock should not extend to the floor. The home buyer should monitor partition voids and other connections and re-establish the voids before they close to less than ½-inch.

6. Plumbing and utilities that pass through slabs (if any) should be isolated from the slabs. Heating and air conditioning systems constructed on slabs should be provided with flexible connections capable of at least 3 inches of vertical movement so slab movement is not transmitted to the ductwork. These connections must be maintained by the home buyer.

7. Roofs that overhang a patio or porch should be constructed on the same foundation as the residence. Isolated piers or pads may be installed beneath a roof overhang provided the slab is independent of the foundation elements. Patio or porch roof columns may be positioned on the slab, directly above the foundation system, provided the slab is structural and supported by the foundation system. Structural porch or patio slabs should be constructed to reduce the likelihood that settlement or heave will affect the slab by placing loose backfill under the structurally supported slab or constructing the slab over void-forming materials.

8. Patio and porch slabs without roofs and other exterior flatwork should be isolated from the foundation. Movements of slabs should not be transmitted to the foundation. Decks are more flexible and more easily adjusted in the event of movement.

9. Frequent control joints should be provided in conventional slabs-on-grade to reduce problems associated with shrinkage cracking and curling. Panels that are approximately square generally perform better than rectangular areas. We suggest an additional joint about 3 feet away from and parallel to foundation walls.

EXHIBIT B

SURFACE DRAINAGE,
IRRIGATION AND MAINTENANCE

Performance of foundations and concrete flatwork is influenced by the moisture conditions existing within the foundation soils. Surface drainage should be designed to provide rapid runoff of surface water away from proposed residences. Proper surface drainage and irrigation practices can help control the amount of surface water that penetrates to foundation levels and contributes to settlement or heave of soils and bedrock that support foundations and slabs-on-grade. Positive drainage away from the foundation and avoidance of irrigation near the foundation also help to avoid excessive wetting of backfill soils, which can lead to increased backfill settlement and possibly to higher lateral earth pressures, due to increased weight and reduced strength of the backfill. CTL | Thompson, Inc. recommends the following precautions. The home buyer should maintain surface drainage and, if an irrigation system is installed, it should substantially conform to these recommendations.

1. Wetting or drying of the open foundation, utility and earthwork excavations should be avoided.

2. The ground surface surrounding the exterior of each residence should be sloped to drain away from the building in all directions. For non-basement residences, we recommend a minimum constructed slope of at least 6 inches in the first 10 feet (5 percent) in landscaped areas around each residence, where practical.

   Between houses that are separated by a distance of less than 10 feet, the constructed slope should generally be at least 5 percent to the swale used to convey water out of this area.

3. Swales used to convey water across yards and between houses should be sloped so that water moves quickly and does not pond for extended periods of time. We suggest minimum slopes of about 2 to 2.5 percent in grassed areas and about 2 percent where landscaping rock or other materials are present. If slopes less than about 2 percent are necessary, concrete-lined channels or plastic pipe should be used.

4. Backfill around the foundation walls should be moistened and compacted.

5. Roof downspouts and drains should discharge well beyond the limits of all backfill. Splash blocks and/or extensions should be provided at all downspouts so water discharges onto the ground beyond the backfill. We generally recommend against burial of downspout discharge. Where it is necessary to bury downspout discharge, solid, rigid pipe should be used and it should slope to an open gravity outlet. Downspout extensions, splash blocks and buried outlets must be maintained by the home owner.

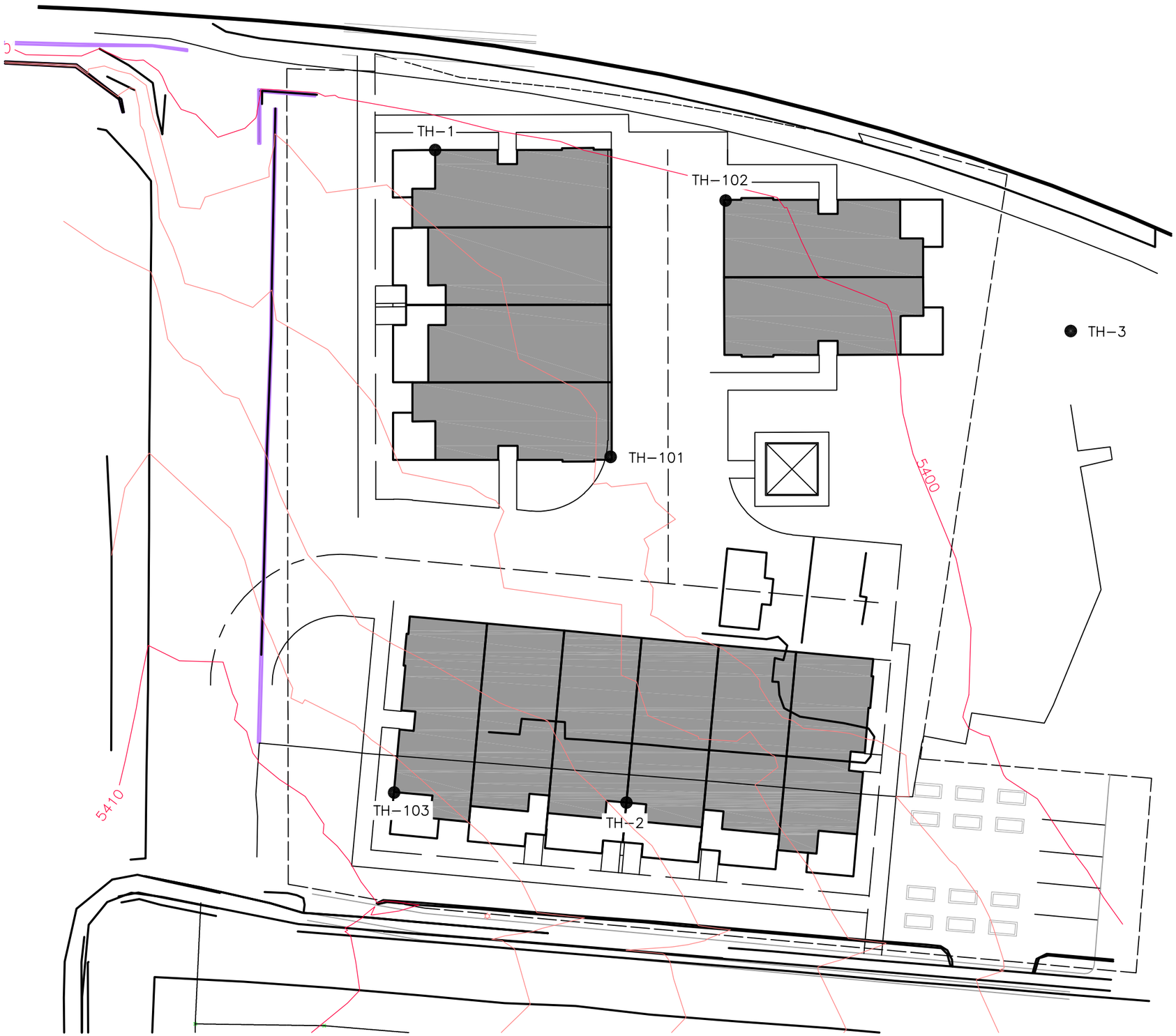
6. The importance of proper irrigation practices cannot be over-emphasized. Irrigation should be limited to the minimum amount sufficient to maintain vegetation; application of more water will increase likelihood of slab and foundation movements. Landscaping should be carefully designed and maintained to minimize irrigation. Plants placed close to foundation walls should be limited to those with

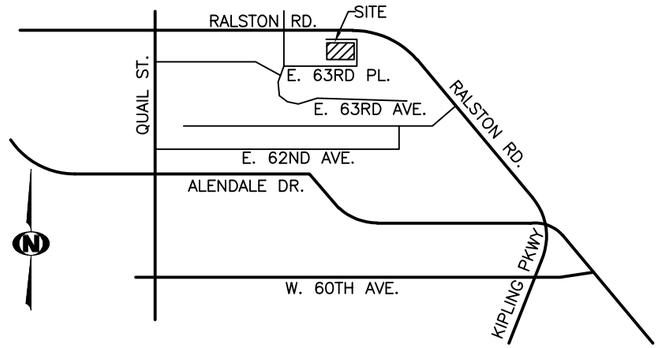
low moisture requirements. Irrigated grass should not be located within 5 feet of the foundation. Sprinklers should not discharge within 5 feet of foundations. Plastic sheeting should not be placed beneath landscaped areas adjacent to foundation walls or grade beams. Geotextile fabric will inhibit weed growth yet still allow natural evaporation to occur.

7. The design and construction criteria for foundations and floor system alternatives were compiled with the expectation that all other recommendations presented in this report related to surface and subsurface drainage, landscaping irrigation, backfill compaction, etc. will be incorporated into the project. It is critical that all recommendations in this report are followed.

EXHIBIT C
EXAMPLE BACKFILL COMPACTION ALTERNATIVES

Alt.	Description	Possible Settlement	Pros (+) / Cons (-)
A	Place in 18 to 24-inch lifts, without moisture conditioning. Compact lift surface to about 85 percent of maximum standard Proctor (ASTM D698) dry density.	5 to 15% of depth (for 8 feet of backfill, 5 to 15 inches)	+ Fast + Water not required - Excessive Settlement - Highest water penetration - Highest probability of warranty repair
B	Moisture condition within 2% of optimum, place in 12 to 18-inch lifts. Compact lift surface to about 85 to 90 percent.	5 to 10 percent of depth	+ Relatively Fast - Moderate water penetration - Excessive settlement - Need for water during fill compaction - Warranty repairs probable
C	Moisture condition to within 2 percent of optimum and place in 8 to 12-inch lifts. Compact lift surface to 90 to 95 percent.	2 to 5 percent of depth	+ Reduced warranty + Reduced water infiltration + Reduced settlement - Possible higher lateral pressure - Slower - Need for water during fill compaction - Potential damage to walls
D	Moisture condition and place as in C. Compact lift surface to at least 95 percent.	1 to 2 percent of depth	+ Reduced warranty + Reduced water infiltration + Lowest comparative settlement - Possible higher lateral pressure - Slower - Need for water during fill compaction - Potential damage to walls





VICINITY MAP
NOT TO SCALE

LEGEND:

- TH–101 ● APPROXIMATE LOCATION OF EXPLORATORY BORING
- TH–1 ○ APPROXIMATE LOCATION OF EXPLORATORY BORING FROM PREVIOUS INVESTIGATION (REPORT DATED; OCTOBER 26, 2020)
- INDICATES PROPOSED GROUND SURFACE (FEET)

N

0 15 30

SCALE: 1" = 30'

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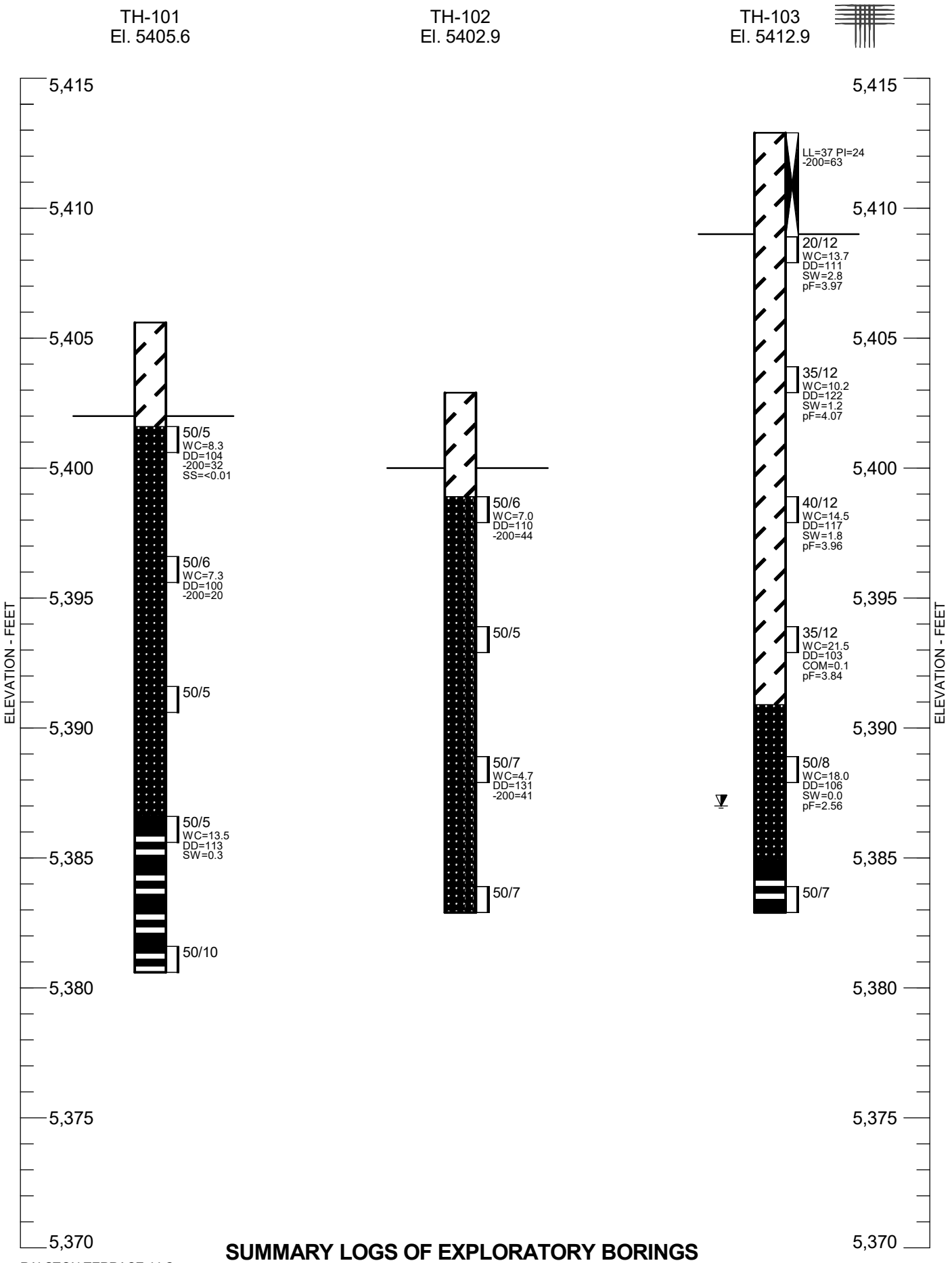
CTL|T Project No. DN50,360.001-120-R1

Locations of Exploratory Borings

Fig. 1



SUMMARY LOGS OF EXPLORATORY BORINGS

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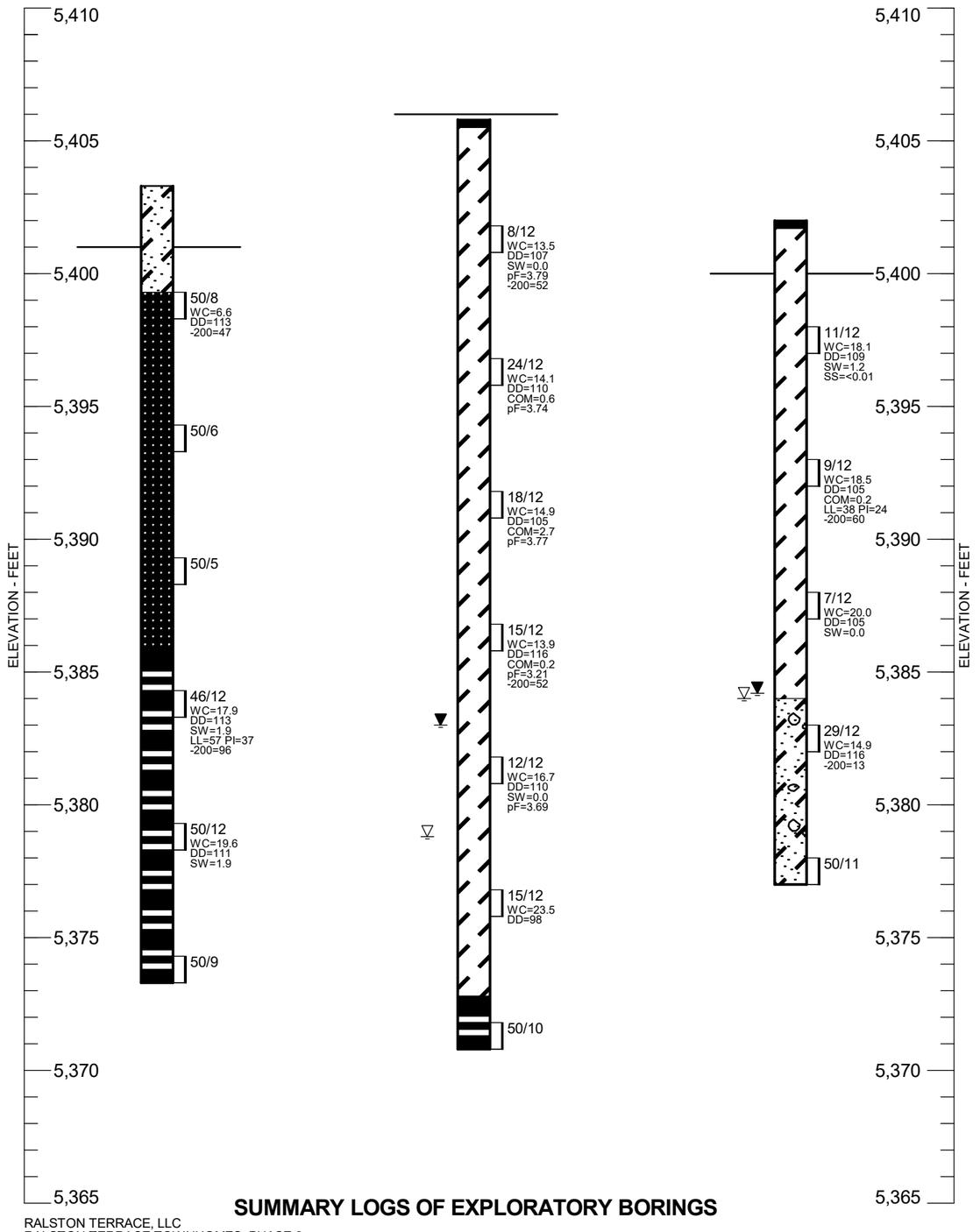
CTL|T PROJECT NO. DN50,360.001-120-R1

FIG. 2



SUMMARY LOGS OF EXPLORATORY BORINGS

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CTL|T PROJECT NO. DN50,360.001-120-R1

LEGEND:

- ASPHALT.
- CLAY, SANDY, MEDIUM STIFF TO VERY STIFF, MOIST, BROWN, TAN, BLACK (CL).
- SAND, CLAYEY, MEDIUM DENSE, SLIGHTLY MOIST, BROWN, TAN (SC).
- SAND, GRAVEL, CLAYEY, MEDIUM DENSE TO DENSE, MOIST TO WET, BROWN, TAN, RED, GRAY (SC-GC).
- BEDROCK, CLAYSTONE, MEDIUM HARD TO VERY HARD, MOIST, OLIVE, GRAY, RUST.
- BEDROCK, SANDSTONE, HARD TO VERY HARD, MOIST, BROWN, TAN.
- DRIVE SAMPLE. THE SYMBOL 50/5 INDICATES 50 BLOWS OF AN AUTOMATIC 140-POUND HAMMER FALLING 30 INCHES WERE REQUIRED TO DRIVE A 2.5-INCH O.D. SAMPLER 5 INCHES.
- BULK SAMPLE COLLECTED FROM AUGER CUTTINGS.
- WATER LEVEL MEASURED AT TIME OF DRILLING.
- WATER LEVEL MEASURED AFTER DRILLING ON OCTOBER 9, 2020.
- WATER LEVEL MEASURED AFTER DRILLING ON FEBRUARY 8, 2021.
- INDICATES PROPOSED GRADE.

NOTES:

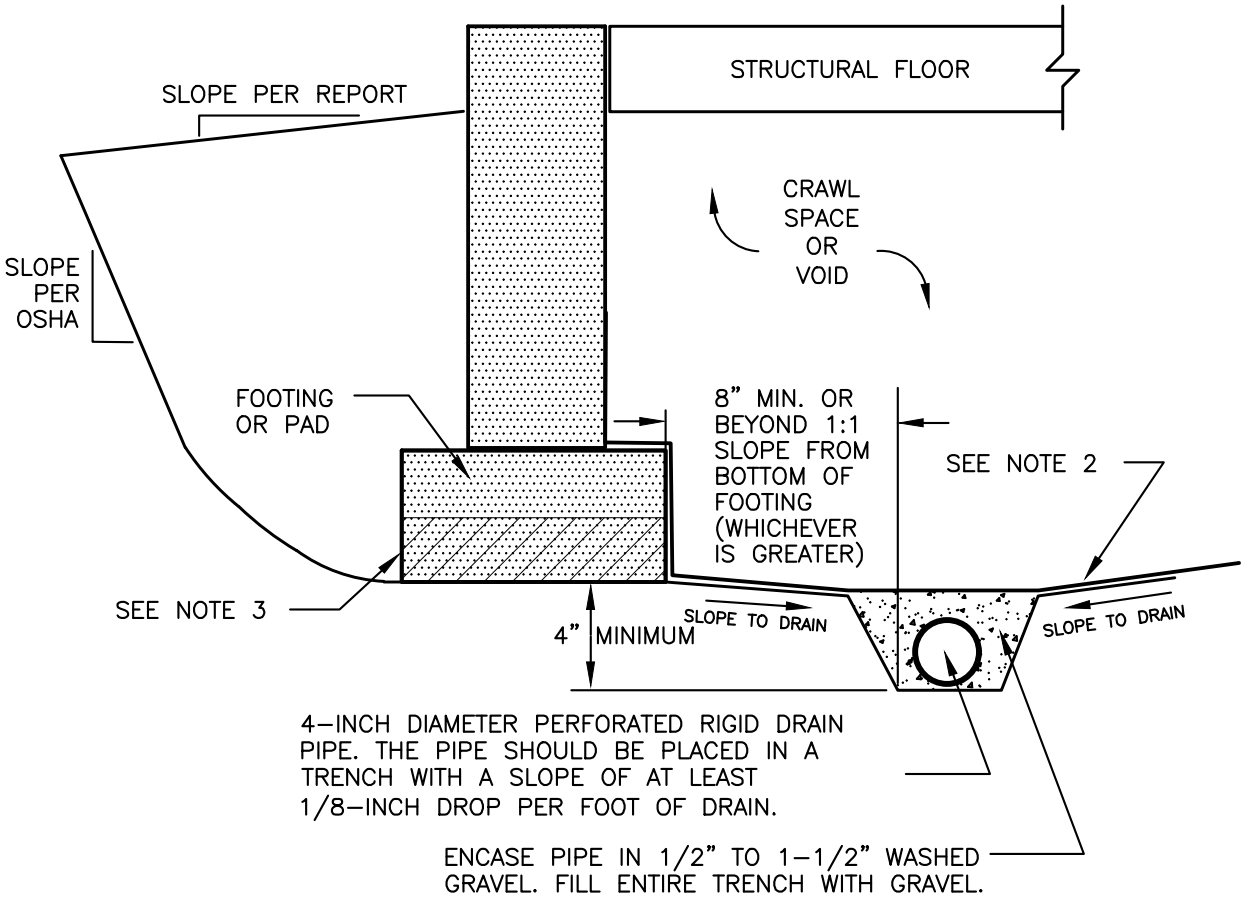
1. THE BORINGS WERE DRILLED ON OCTOBER 1, 2020 AND FEBRUARY 4, 2021 USING 4-INCH DIAMETER, CONTINUOUS-FLIGHT SOLID-STEM AUGER AND TRUCK-MOUNTED CME-45 DRILL RIGS.

2. BORING LOCATIONS AND ELEVATIONS ARE APPROXIMATE AND WERE SURVEYED BY A REPRESENTATIVE OF OUR FIRM USING A LEICA GS18 GPS UNIT REFERENCING THE NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD 88).

3. WC - INDICATES MOISTURE CONTENT (%).
   DD - INDICATES DRY DENSITY (PCF).
   SW - INDICATES SWELL WHEN WETTED UNDER APPLIED PRESSURE (%).
   COM - INDICATES COMPRESSION WHEN WETTED UNDER APPLIED PRESSURE (%).
   LL - INDICATES LIQUID LIMIT.
   PI - INDICATES PLASTICITY INDEX.
   -200 - INDICATES PASSING NO. 200 SIEVE (%).
   SS - INDICATES WATER-SOLUBLE SULFATE CONTENT (%).
   pF - INDICATES SOIL SUCTION VALUE (pF).

4. THESE LOGS ARE SUBJECT TO THE EXPLANATIONS, LIMITATIONS AND CONCLUSIONS CONTAINED IN THIS REPORT.

01-FTG-INT-STF-01



NOTES:

1) THE BOTTOM OF THE DRAIN SHOULD BE AT LEAST 4 INCHES BELOW BOTTOM OF FOOTING AT THE HIGHEST POINT AND SLOPE DOWNWARD TO A POSITIVE GRAVITY OUTLET OR TO A SUMP WHERE WATER CAN BE REMOVED BY PUMPING.

2) TO HELP CONTROL THE HUMIDITY IN THE CRAWL SPACE, A MINIMUM 6-MIL POLYETHYLENE VAPOR RETARDER SHOULD BE PLACED OVER THE CRAWL SPACE SOILS. THE RETARDER SHOULD BE ATTACHED TO CONCRETE FOUNDATION ELEMENTS AND EXTEND UP FOUNDATION WALLS AT LEAST 8 INCHES ABOVE TOP OF FOOTING. OVERLAP JOINTS 3 FEET AND SEAL.

3) FOR FOOTINGS, WE RECOMMEND PLACING A 4-INCH THICK, 8-INCH WIDE SECTION OF VOID FORM PERPENDICULAR TO FOOTING ABOUT EVERY 10 TO 15 FEET TO ALLOW WATER IN WALL BACKFILL TO PASS BENEATH THE FOOTING INTO THE INTERIOR DRAIN. THIS CAN ALSO BE ACCOMPLISHED BY "TUNNELING" UNDER FOOTINGS AT THE TIME OF DRAIN INSTALLATION. THIS DETAIL SHOULD BE REVIEWED BY THE STRUCTURAL ENGINEER DURING FOUNDATION DESIGN AND INCORPORATED INTO THE FOUNDATION PLAN. ALTERNATIVELY, AN EXTERIOR FOUNDATION DRAIN CAN BE USED.

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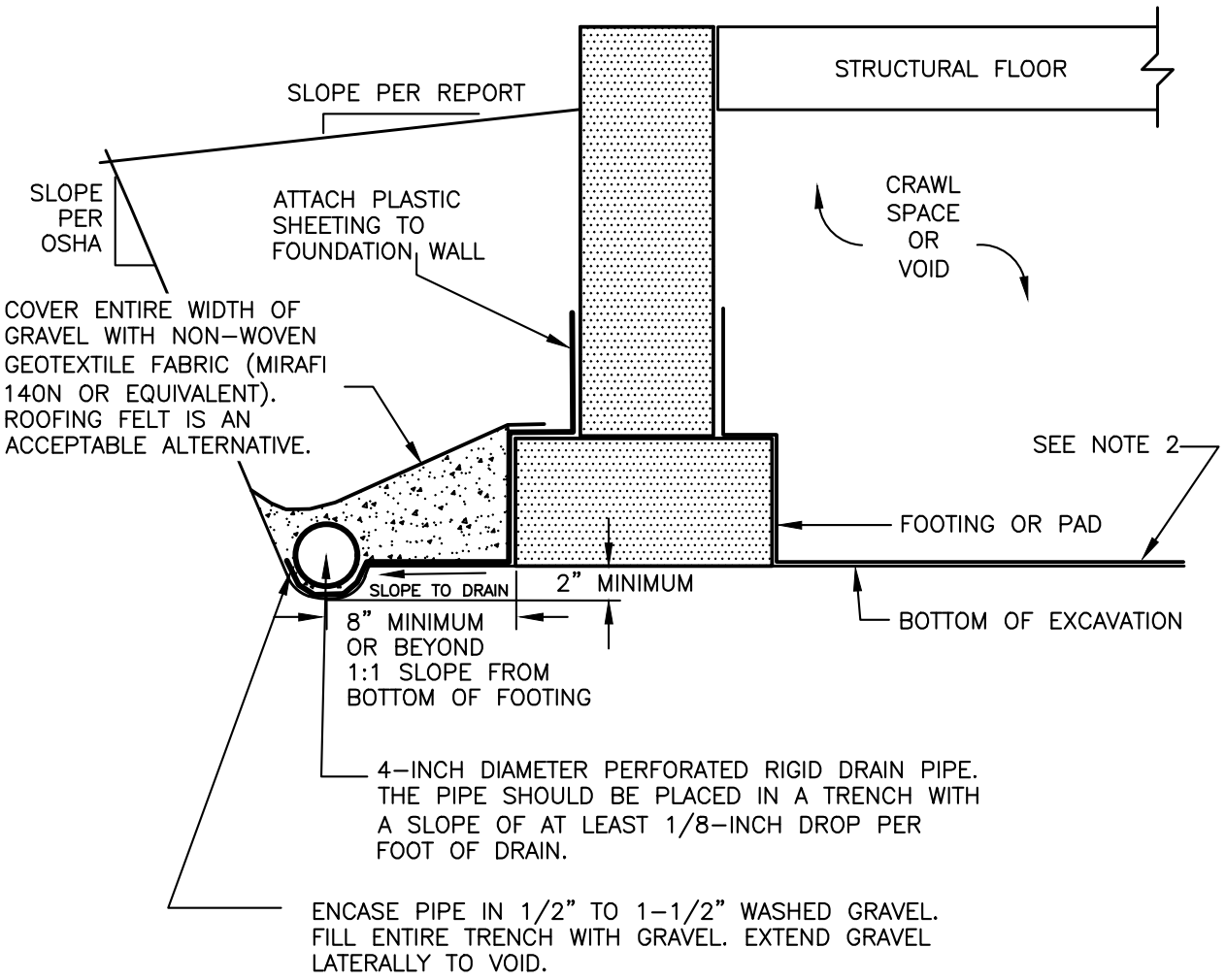
Interior Foundation Wall Drain

Fig. 4

01-FTG-XTR-STF-02



NOTES:

1) THE BOTTOM OF THE DRAIN SHOULD BE AT LEAST 2 INCHES BELOW BOTTOM OF FOOTING AT THE HIGHEST POINT AND SLOPE DOWNWARD TO A POSITIVE GRAVITY OUTLET OR TO A SUMP WHERE WATER CAN BE REMOVED BY PUMPING.
2) TO HELP CONTROL THE HUMIDITY IN THE CRAWL SPACE, A MINIMUM 6-MIL POLYETHYLENE VAPOR RETARDER SHOULD BE PLACED OVER THE CRAWL SPACE SOILS. THE RETARDER SHOULD BE ATTACHED TO CONCRETE FOUNDATION ELEMENTS AND EXTEND UP FOUNDATION WALLS AT LEAST 8 INCHES ABOVE TOP OF FOOTING. OVERLAP JOINTS 3 FEET AND SEAL.

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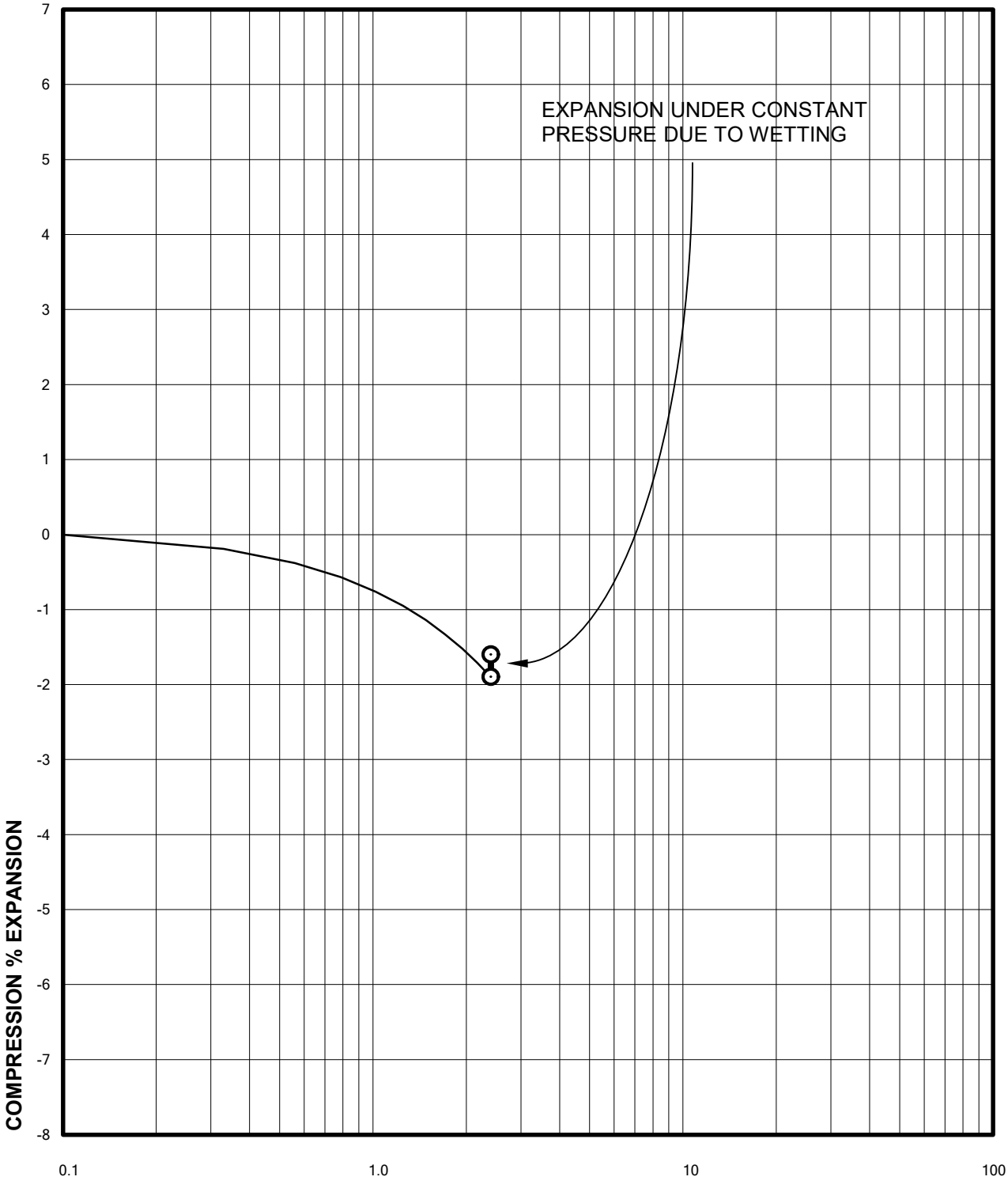
Exterior Foundation Wall Drain

Fig. 5

APPENDIX A
LABORATORY TEST RESULTS AND TABLE A-I



Sample of CLAYSTONE
From TH-101 AT 19 FEET

DRY UNIT WEIGHT= 113 PCF
MOISTURE CONTENT= 13.5 %

Swell Consolidation Test Results

FIG. A-1

RALSTON TERRACE, LLC
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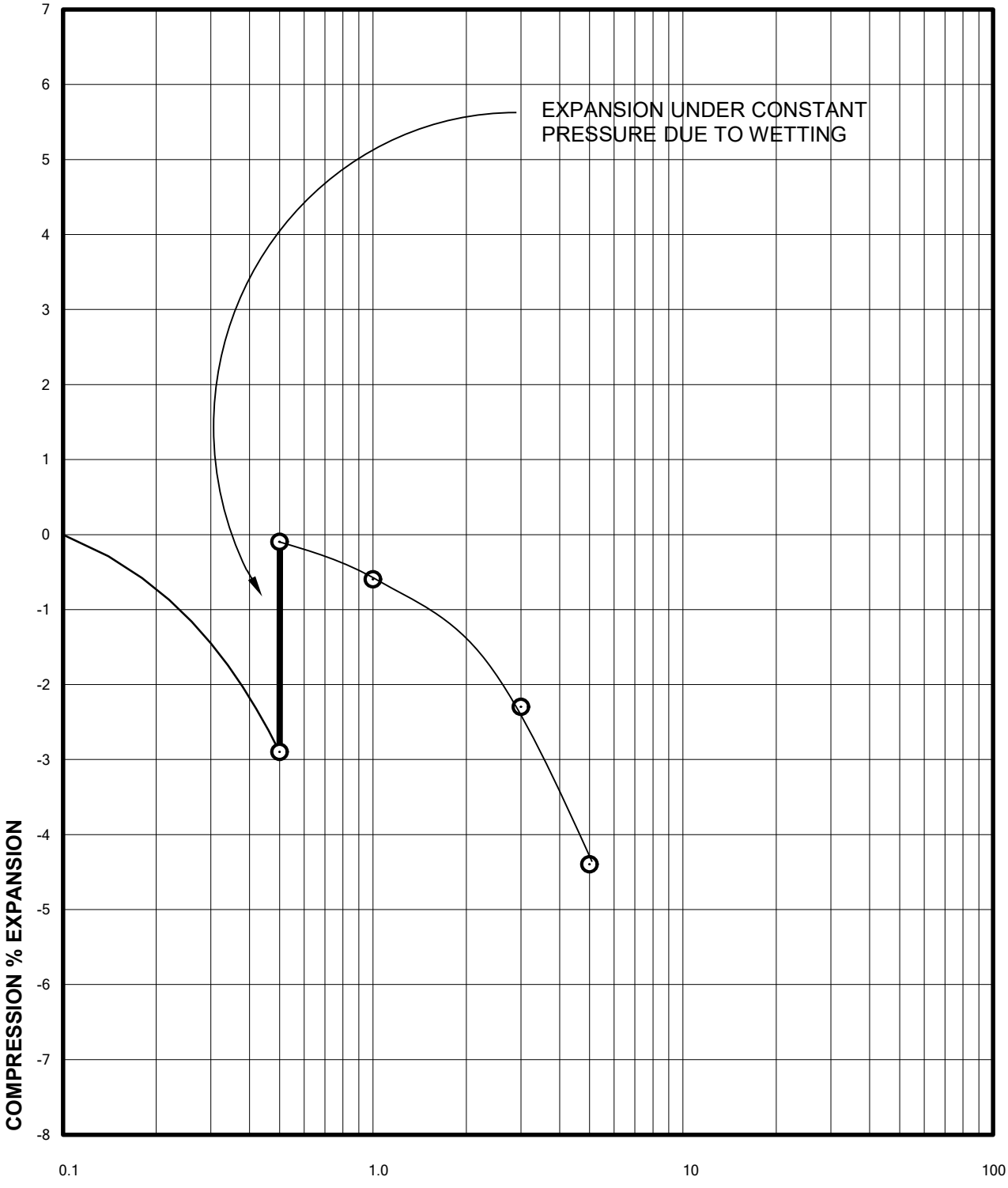
CTL|T PROJECT NO. DN50.360.001-120-R1



Sample of CLAY, SANDY (CL)
From TH-103 AT 4 FEET

DRY UNIT WEIGHT= 111 PCF
MOISTURE CONTENT= 13.7 %

Swell Consolidation Test Results

FIG. A-2

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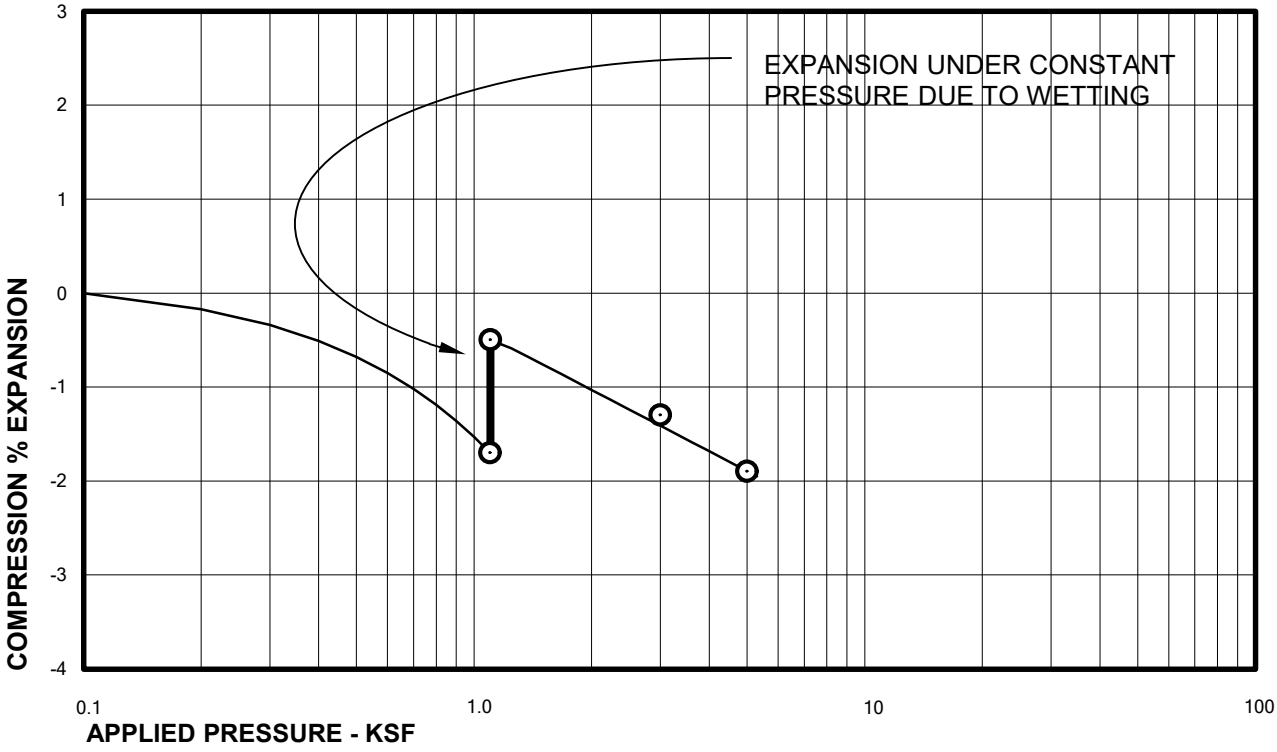
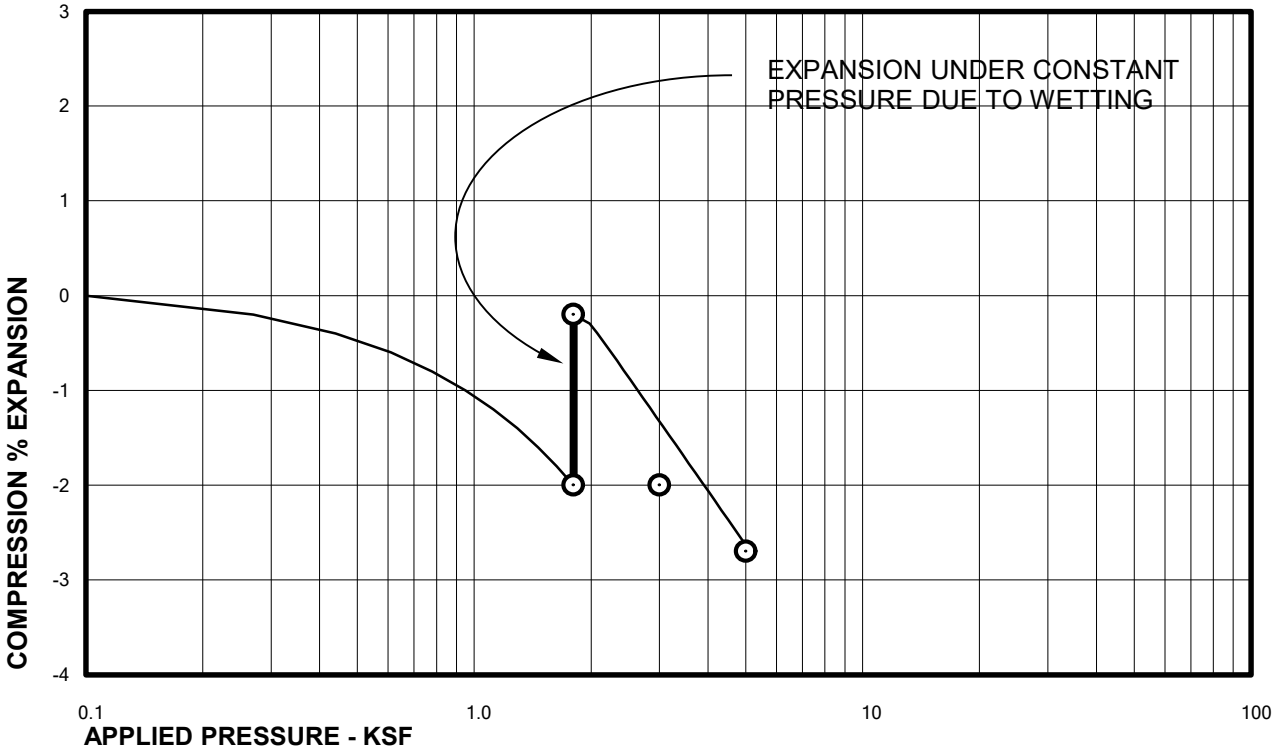
CTL|T PROJECT NO. DN50.360.001-120-R1



Sample of CLAY, SANDY (CL) DRY UNIT WEIGHT= 122 PCF

From TH-103 AT 9 FEET MOISTURE CONTENT= 10.2 %



Sample of CLAY, SANDY (CL) DRY UNIT WEIGHT= 117 PCF

From TH-103 AT 14 FEET MOISTURE CONTENT= 14.5 %

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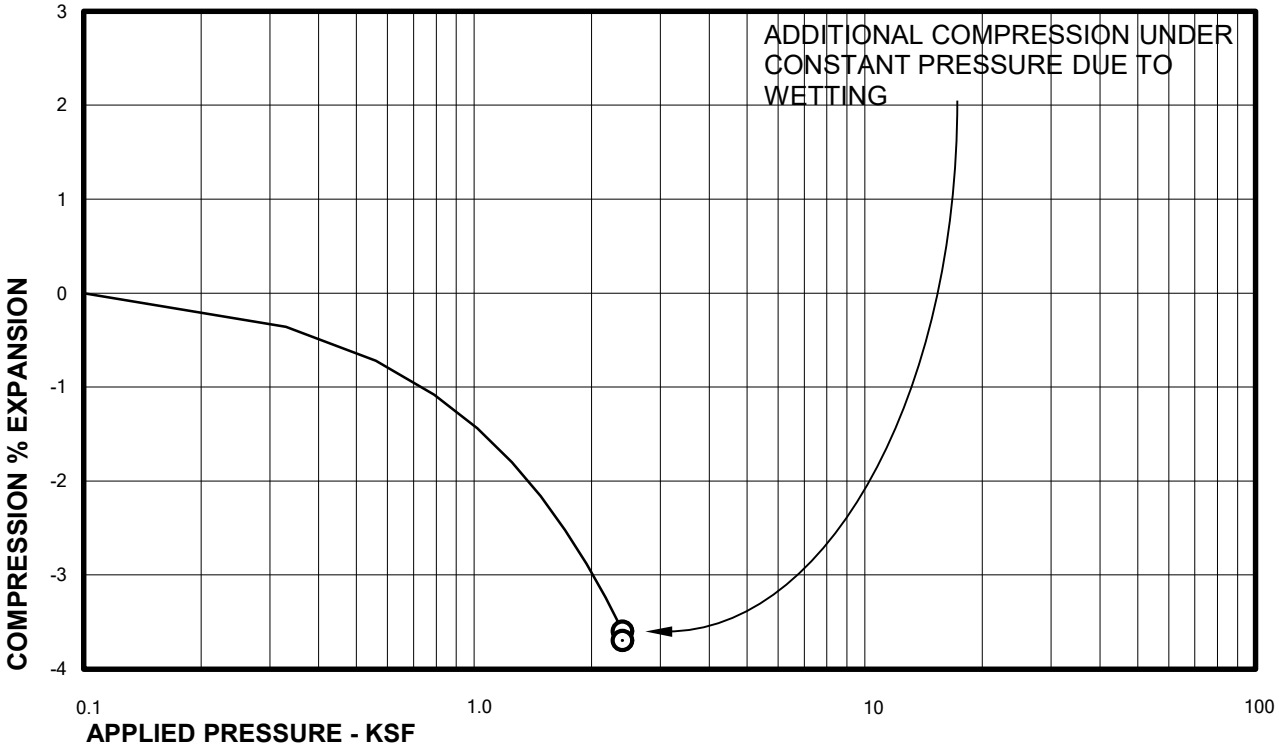
CTL|T PROJECT NO. DN50.360.001-120-R1

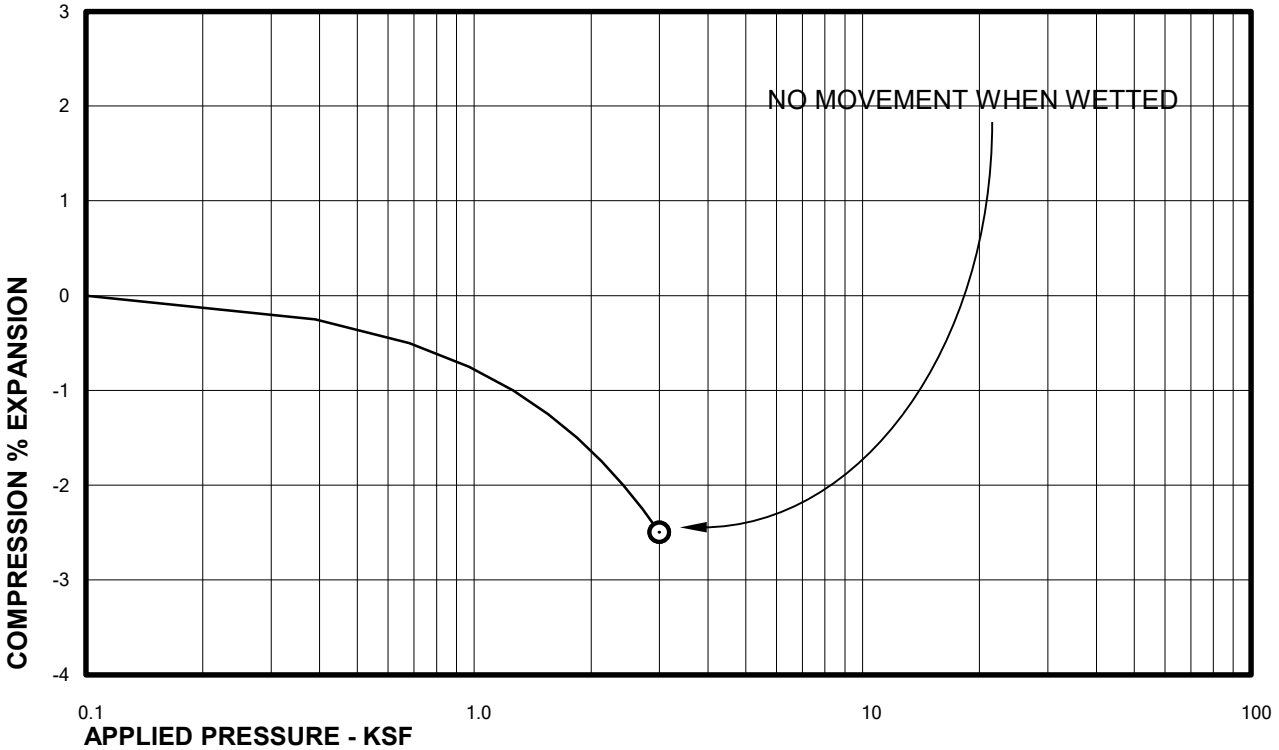
Swell Consolidation Test Results

FIG. A-3



Sample of CLAY, SANDY (CL)
From TH-103 AT 19 FEET

DRY UNIT WEIGHT= 103 PCF
MOISTURE CONTENT= 21.5 %



Sample of SANDSTONE
From TH-103 AT 24 FEET

DRY UNIT WEIGHT= 106 PCF
MOISTURE CONTENT= 18.0 %

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CTL|T PROJECT NO. DN50.360.001-120-R1

Swell Consolidation Test Results

FIG. A-4

TABLE A - I

SUMMARY OF LABORATORY TEST RESULTS

BORING	DEPTH (ft)	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	SWELL TEST DATA				SOIL SUCTION VALUE (pF)	SOLUBLE SULFATE CONTENT (%)	PASSING NO. 200 SIEVE (%)	SOIL TYPE
				SWELL (%)	COMPRESSION (%)	APPLIED PRESSURE (psf)	SWELL PRESSURE (psf)				
TH-101	4	8.3	104						<0.01	32	SANDSTONE
TH-101	9	7.3	100							20	SANDSTONE
TH-101	19	13.5	113	0.3		2,400					CLAYSTONE
TH-102	4	7.0	110							44	SANDSTONE
TH-102	14	4.7	131							41	SANDSTONE
TH-103	4	13.7	111	2.8		500	3,300	3.97			CLAY, SANDY (CL)
TH-103	9	10.2	122	1.2		1,100	4,000	4.07			CLAY, SANDY (CL)
TH-103	14	14.5	117	1.8		1,800	3,900	3.96			CLAY, SANDY (CL)
TH-103	19	21.5	103		0.1	2,400		3.84			CLAY, SANDY (CL)
TH-103	24	18.0	106	0.0		3,000		2.56			SANDSTONE

APPENDIX B

FLEXIBLE AND RIGID PAVEMENT MATERIALS, CONSTRUCTION, AND MAINTENANCE GUIDELINES

MATERIAL GUIDELINES FOR FLEXIBLE AND RIGID PAVEMENTS

Aggregate Base Course (ABC)

1. A Class 5 or 6 Colorado Department of Transportation (CDOT) specified aggregate base course should be used. A recycled concrete alternative which meets the Class 5 or 6 designation is also acceptable.

2. Aggregate base course should have a minimum Hveem stabilometer value of 84. Aggregate base course or recycled concrete material must be moisture stable. The change in R-value from 300 psi to 100 psi exudation pressure should be 12 points or less.

3. Aggregate base course or recycled concrete should be laid in thin lifts not to exceed 6 inches, moisture treated to within 2 percent of optimum moisture content, and compacted to at least 95 percent of maximum modified Proctor dry density (ASTM D 1557, AASHTO T 180). The material should be placed without segregation.

4. Placement and compaction of aggregate base course or recycled concrete should be observed and tested by a representative of our firm. Placement should not commence until the underlying subgrade is properly prepared and tested.

Hot-Mix Asphalt (HMA)

1. HMA should be composed of a mixture of aggregate, filler, hydrated lime and asphalt cement. Mixes shall be designed with 1 percent lime. Some mixes may require polymer modified asphalt cement, or make use of up to 20 percent reclaimed asphalt pavement (RAP). A project mix design is recommended and periodic checks on the project site should be made to verify compliance with specifications.

2. HMA should be relatively impermeable to moisture and should be designed with crushed aggregates that have a minimum of 80 percent of the aggregate retained on the No. 4 sieve with two mechanically fractured faces.

3. Gradations that approach the maximum density line (within 5 percent between the No. 4 and 50 sieves) should be avoided. A gradation with a nominal maximum size of 1 or 2 inches developed on the fine side of the maximum density line should be used.

4. Total void content, voids in the mineral aggregate (VMA) and voids filled should be considered in the selection of the optimum asphalt cement content. The optimum asphalt content should be selected at a total air void content of about 4 percent. The mixture should have a minimum VMA of 14 percent and between 65 percent and 80 percent of voids filled.

5. Asphalt cement should meet the requirements of the Superpave Performance Graded (PG) Binders. The minimum performing asphalt cement should be PG 64-22 for use along the Front Range. The use of PG 58-28 or PG 58-22 asphalt

cement has been known to cause tenderness in pavements in the Front Range area and should be avoided.

6. Hydrated lime should be added at the rate of 1 percent by dry weight of the aggregate and should be included in the amount passing the No. 200 sieve. Hydrated lime for aggregate pretreatment should conform to the requirements of ASTM C 207, Type N.

7. Paving should only be performed when subgrade temperatures are above 40˚F and air temperature is at least 40˚F and rising.

8. HMA should not be placed at a temperature lower than 245˚F for mixes containing PG 64-22 asphalt, and 290˚F for mixes containing polymer modified asphalt. The breakdown compaction should be completed before the mixture temperature drops 20˚F.

9. The maximum compacted lift should be 3 inches and joints should be staggered. No joints should be placed within wheel paths.

10. HMA should be compacted to between 92 and 96 percent of Maximum Theoretical Density. The surface shall be sealed with a finish roller before the mix cools to 185˚F.

11. Placement and compaction of HMA should be observed and tested by a representative of our firm. Placement should not commence until the subgrade is properly prepared, tested and proof-rolled.

Portland Cement Concrete (PCC)

1. Portland cement concrete should meet CDOT Class P concrete and have a minimum compressive strength of 4,200 psi at 28 days and a minimum modulus of rupture (flexural strength) of 650 psi. A job mix design is recommended and periodic checks on the job site should be made to verify compliance with specifications.

2. Portland cement should be Type II “low alkali” and should conform to ASTM C 150. Portland cement should conform to ASTM C 150.

3. Portland cement concrete should not be placed when the subgrade or air temperature is below 40ºF.

4. Free water should not be finished into the concrete surface. Atomizing nozzle pressure sprayers for applying finishing compounds are recommended whenever the concrete surface becomes difficult to finish.

5. Curing of the portland cement concrete should be accomplished by the use of a curing compound. The curing compound should be applied in accordance with manufacturer recommendations.

6. Curing procedures should be implemented, as necessary, to protect the pavement against moisture loss, rapid temperature change, freezing, and mechanical injury.

7. Construction joints, including longitudinal joints and transverse joints, should be formed during construction or sawed after the concrete has begun to set, but prior to uncontrolled cracking.

8. All joints should be properly sealed using a rod back-up and approved epoxy sealant.

9. Traffic should not be allowed on the pavement until it has properly cured and achieved at least 80 percent of the design strength, with saw joints already cut.

10. Placement of portland cement concrete should be observed and tested by a representative of our firm. Placement should not commence until the subgrade is properly prepared and tested.

FLEXIBLE PAVEMENT CONSTRUCTION GUIDELINES

Experience has shown that construction methods can significantly affect the life and serviceability of a pavement system. A site-specific mix design is recommended and periodic checks during the project should be made to verify compliance with specifications. We recommend the proposed pavement be constructed in the following manner:

1. The subgrade should be stripped of organic matter, scarified, moisture conditioned and compacted. Subgrade soils should be moisture conditioned to within 2 percent of optimum moisture content for sand and within 1 and 4 percent above optimum for clay, and compacted to at least 95 percent of maximum standard Proctor dry density (ASTM D 698, AASHTO T 99).

2. Utility trenches and all subsequently placed fill should be moisture conditioned, compacted, and tested prior to paving. As a minimum, fill should be compacted to 95 percent of maximum standard Proctor dry density.

3. After final subgrade elevation has been reached and the subgrade compacted, the resulting subgrade should be checked for uniformity and all soft or yielding materials should be replaced prior to paving. Concrete should not be placed on soft, spongy, frozen, or otherwise unsuitable subgrade.

4. If areas of soft or wet subgrade are encountered, the material should be sub-excavated and replaced with properly compacted structural backfill. Where extensively soft, yielding subgrade is encountered, we recommend the excavation be inspected by a representative of our office.

5. Aggregate base course should be laid in thin, loose lifts no more than 6 inches, moisture treated to within 2 percent of optimum moisture content, and compacted to at least 95 percent of modified Proctor maximum dry density (ASTM D 1557, AASHTO T 180).

6. Asphaltic concrete should be hot plant-mixed material compacted to between 92 and 96 percent of maximum Theoretical density. The temperature at laydown time should be at least 245°F. The surface shall be sealed with a finish roller prior to the mix cooling to 185°F.

7. The maximum compacted lift should be 3 inches and joints should be staggered. No joints should be within wheel paths.

8. Paving should only be performed when subgrade temperatures are above 40°F and air temperature is at least 40°F and rising.

9. Subgrade preparation and placement and compaction of all pavement material should be observed and tested. Compaction criteria should be met prior to the placement of the next paving lift. The additional requirements of the City of Arvada should apply.

RIGID PAVEMENT CONSTRUCTION GUIDELINES

Rigid pavement sections are not as sensitive to subgrade support characteristics as flexible pavement. Due to the strength of the concrete, wheel loads from traffic are distributed over a large area and the resulting subgrade stresses are relatively low. The critical factors affecting the performance of a rigid pavement are the strength and quality of the concrete, and the uniformity of the subgrade. We recommend subgrade preparation and construction of the rigid pavement section be completed in accordance with the following recommendations:

1. The subgrade should be stripped of organic matter, scarified, moisture conditioned and compacted. Subgrade soils should be moisture conditioned to within 2 percent of optimum moisture content for sand and within 1 and 4 percent above optimum for clay, and compacted to at least 95 percent of maximum standard Proctor dry density (ASTM D 698, AASHTO T 99).

2. After final subgrade elevation has been reached and the subgrade compacted, the resulting subgrade should be checked for uniformity and all soft or yielding materials should be replaced prior to paving. Concrete should not be placed on soft, spongy, frozen, or otherwise unsuitable subgrade.

3. The subgrade should be kept moist prior to paving.

4. Curing procedures should protect the concrete against moisture loss, rapid temperature change, freezing, and mechanical injury for at least 3 days after placement. Traffic should not be allowed on the pavement for at least one week.

5. Curing of the portland cement concrete should be accomplished by use of a curing compound in accordance with manufacturer recommendations.

6. Construction joints, including longitudinal joints and transverse joints, should be formed during construction or should be sawed shortly after the concrete has begun to set, but prior to uncontrolled cracking. All joints should be sealed.

7. Construction control and inspection should be performed during the subgrade preparation and paving procedures. Concrete should be carefully monitored for quality control. The additional requirements of the City of Arvada should apply.

The design sections are based upon 10-year and 20-year periods. Experience in the Denver area indicates virtually no maintenance or overlays are necessary for a 20-year design period. We believe some maintenance and sealing of concrete joints will help pavement performance by helping to keep surface moisture from wetting and softening or heaving subgrade. To avoid problems associated with scaling and to continue the strength gain, we recommend deicing salts not be used for the first year after placement.

MAINTENANCE GUIDELINES FOR FLEXIBLE PAVEMENTS

A primary cause for deterioration of pavements is oxidative aging resulting in brittle pavements. Tire loads from traffic are necessary to "work" or knead the asphalt concrete to keep it flexible and rejuvenated. Preventive maintenance treatments will typically preserve the original or existing pavement by providing a protective seal or rejuvenating the asphalt binder to extend pavement life.

Annual Preventive Maintenance

- Visual pavement evaluations should be performed each year.
- Reports documenting the progress of distress should be kept current to provide information on effective times to apply preventive maintenance treatments.
- Crack sealing should be performed annually as new cracks appear.

3 to 5-Year Preventive Maintenance

- The owner should budget for a preventive treatment (e.g. chip seal, fog seal, slurry seal) at approximate intervals of 3 to 5 years to reduce oxidative embrittlement problems.

5 to 10-Year Corrective Maintenance

- Corrective maintenance (e.g. full-depth patching, milling and overlay) may be necessary, as dictated by the pavement condition, to correct rutting, cracking and structurally failed areas.

MAINTENANCE GUIDELINES FOR RIGID PAVEMENTS

High traffic volumes create pavement rutting and smooth, polished surfaces. Preventive maintenance treatments will typically preserve the original or existing pavement by providing a protective seal and improving skid resistance through a new wearing course.

Annual Preventive Maintenance

- Visual pavement evaluations should be performed each spring or fall.
- Reports documenting the progress of distress should be kept current to provide information of effective times to apply preventive maintenance.
- Crack sealing should be performed annually as new cracks appear.

4 to 8 Year Preventive Maintenance

- The owner should budget for a preventive treatment at approximate intervals of 4 to 8 years to reduce joint deterioration.
- Typical preventive maintenance for rigid pavements includes patching, crack sealing and joint cleaning and sealing.
- Where joint sealants are missing or distressed, resealing is mandatory.

15 to 20 Year Corrective Maintenance

- Corrective maintenance for rigid pavements includes patching and slab replacement to correct subgrade failures, edge damage and material failure.
- Asphalt concrete overlays may be required at 15 to 20 year intervals to improve the structural capacity of the pavement.