Geotechnical Design Memorandum for Preliminary 20% Design

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SUMMARY

Subject/Objective

This memorandum presents the geologic setting, geotechnical ground characterization, geotechnical properties for Preliminary Engineering, and supporting information for the DART D2 Geotechnical Baseline Report for 20% Design, based on data available as of August 29, 2019.

Conclusions

Ground conditions along the DART D2 underground alignment are variable. Based on the limited available data, they are generally consistent with ground conditions at other Dallas locations. Recommendations for design are provided in Section 9. Construction considerations are presented in Section 10.

1 INTRODUCTION

1.1 Purpose

The purpose of this Geotechnical Design Memorandum (GDM) is to present the geologic setting, geotechnical ground characterization, geotechnical parameters for 20% design, and supporting information for the Geotechnical Baseline Report (GBR) for 20% design based on data as of August 29, 2019, and the underground alignment current as of December 20, 2019.

1.2 Scope

The scope of this memorandum is limited to ground characterization and geotechnical design parameters for tunneling and underground excavations for the proposed DART D2 subway. Specifically, this memorandum:

- Provides sources of information used for ground characterization
- Summarizes the geologic setting and ground water regime in the DART D2 project area
- Defines reaches for the underground portion of the DART D2 subway for 20% design
- Presents the DART D2 tunnel ground classification system and the baseline distribution of DART D2 project ground classes for 20% design
- Presents recommended geotechnical design parameters and preliminary baseline values for DART D2 project soil properties for 20% design
- Defines and describes DART D2 project rock types and presents their preliminary baseline distribution for 20% design

- Presents ranges, recommended geotechnical design parameters, and preliminary baseline values for intact rock properties of DART D2 project rock types for 20% design
- Presents current understanding of rock mass structures and presents ranges, recommended geotechnical design parameters, and preliminary baseline orientations of joint sets and faults for 20% design
- Presents recommended geotechnical design parameters for rock mass mechanical properties for DART D2 project rock types for 20% design
- Presents current understanding of site groundwater conditions, including hydraulic properties of site materials
- Summarizes DART D2 project site geotechnical conditions by underground alignment reach, including preliminary baseline distribution by reach of ground classes and rock types, rock mass characteristics, and groundwater conditions for 20% design
- Presents DART D2 project underground construction considerations related to geology and ground characteristics for 20% design

Following this introductory section, Section 2 of this GDM gives background information and data sources. Sections 3, 4, and 5 describe the geologic setting, underground alignment reaches, and the ground classification system, respectively. Section 6 discusses excavation face conditions. Section 7 describes the geotechnical properties of site subsurface materials, and Section 8 describes site geotechnical conditions by reach. Section 9 summarizes recommendations for design, and Section 10 discusses construction considerations. Section 11 lists references cited.

Tables and Figures follow the text of this GDM. Figure 1 presents a geologic map of the DART D2 project area, and Figure 2 shows legend and notes for the boring and reach location plan in Figure 3 and the general geologic profile in Figure 4-A through 4-I. All are based on data available as of August 29, 2019, and the underground alignment current as of December 20, 2019. Other tables, figures, and appendices provide supporting information.

2 BACKGROUND

2.1 Project Description

The D2 alignment begins south of Victory Station. It then proceeds within DART ROW in the center of Museum Way. The alignment crosses under Woodall Rodgers then begins it transition to below grade. It remains underground under Griffin Street and Commerce Street then transitions back to at-grade after the intersection of Pacific Avenue and Cesar Chavez Boulevard. It remains at-grade roughly parallel and south of Swiss Avenue. It then ties to the existing Green Line in the median of Good-Latimer.

As configured as of December 20, 2019, the DART D2 LPA includes four stations, three of which are underground, along with two underground cross passages and two tunnel portals.

The underground portion of the LPA, including tunnel portals, is 7,230 feet long. Depth from the ground surface to proposed invert ranges from about 11 feet to 90 feet, averaging about 52 feet.

Construction of the underground portions will include mined and cut-and-cover twin tunnels, one mined underground station, two cut-and-cover underground stations, station entrance shafts and ventilation shafts, mined cross passages, and U-wall retained excavations for portals and portal approach structures.

2.2 Inputs

This GDM is based on DART D2 project geotechnical information presented in the GDR issued August 29, 2019, (GPC6, 2019) and the 20% design alignment and configuration current as of December 20, 2019.

Data used for development of geotechnical ground characterization and geotechnical design parameters were primarily from logs of borings drilled for the DART D2 project and other data presented in the Geotechnical Data Report (GDR) prepared by Alliance Geotechnical Group (GPC6, 2019). Geotechnical data collected for the project and presented in the GDR includes soil and rock boring logs, rock core discontinuity data, rock core photos, soil and rock laboratory test data, groundwater level measurements, and surveyed boring locations and elevations.

Figure 1 presents a local geologic map, and Figure 2 presents a legend and notes for the boring and reach location plan in Figure 3 and the general geologic profile in Figures 4-A through 4-I.

Site groundwater conditions were characterized based on boring and well installation logs and groundwater level measurements in the GDR (GPC6, 2019), supplemented with regional and historical information from data sources listed in Section 11. Maximum and minimum groundwater levels and the dates recorded are cumulatively presented in Table 27.

Field and laboratory geotechnical data collected for the following other Dallas-area projects were used to supplement the geotechnical data available for the DART D2 project as of August 29, 2019. Cited references are included in the reference list in Section 11.

- DART North Central Line Routh Street to Mockingbird Lane Section NC-1 (Huitt-Zollars, 1992)
- Texas Department of Transportation, Dallas District Office, IH-635 Managed Lanes Project (Lachel Felice & Associates, 2006)
- Texas Department of Transportation, IH-635 (LBJ Freeway) Corridor, Section 4-West (Fugro Consultants, 2004)
- Texas Department of Transportation, Dallas District, LBJ Corridor Study Project, (Terra-Mar, 1998)

- U.S. Department of Energy, Superconducting Super Collider Project (Lundin et al., 1990; Earth Technology Corporation, 1990)
- City of Dallas, Trinity Watershed Management Department, Mill Creek/Peaks Branch/State Thomas Drainage Relief Project (HNTB, 2014; 2015)

Excerpts from calculation packages for ground classes and intact rock properties, which support conclusions in this memorandum, are presented in Appendices A and B

2.3 Assumptions and Limitations

2.3.1 ASSUMPTIONS

It has been assumed that the DART D2 project alignment and configuration is that which was current as of December 20, 2019. Any changes in this alignment or configuration could affect assumptions regarding ground behavior and construction considerations.

It has been assumed that boring logs and other data in the GDR (GPC6, 2019) accurately represent actual subsurface conditions.

It has also been assumed that any additional geotechnical data to be collected will be generally consistent with the data collected to date and presented in the GDR (GPC6, 2019). If additional geotechnical data are collected and if they are not wholly consistent with the currently available data, then the characterizations and recommendations presented in this GDM will need to be revised as necessary to consider all available data.

It has also been assumed that interpretations of ground conditions and construction considerations developed from the available data and presented in this GDM will remain constant through the project construction period. Any changes in conditions due to construction of other projects, environmental effects, regulatory requirements, or other factors could cause these interpretations and considerations to require revision.

It has also been assumed that the anticipated construction methods described in this GDM will be generally representative of those which will actually be used. Material differences in construction methods could result in significant differences in expected ground behavior.

Additional assumptions are listed in the calculation packages prepared in support of this memorandum, excerpts of which are presented in Appendices A and B.

2.3.2 LIMITATIONS

The ground conditions described in this GDM were inferred from the limited currently available site-specific geotechnical information, and the descriptions were supplemented by published information and data collected for other projects in the Dallas area. Actual ground conditions encountered during construction may differ from those described.

This GDM describes inferred ground conditions prior to any on-site construction. Ground conditions, including groundwater conditions, may be modified or disturbed as a result of temporary support, groundwater control measures, ground improvement, or construction in progress, and geotechnical design assumptions may need to be modified as a result, even after more site-specific data become available.

Interpretations of excavation conditions, ground classes, rock types, groundwater levels, and other subsurface conditions presented throughout this GDM are based on limited information which was interpolated between relatively widely spaced borings and from borings performed by others. Groundwater conditions may vary seasonally and over time. Subsurface conditions between borings may differ from those at boring locations, and more or fewer ground classes than shown may be present at specific locations. Contacts between different ground classes may be gradational and not distinct, as implied by estimated distributions. Interpretations of soil and rock properties were developed from limited laboratory test data may not be representative of properties across the full length of the alignment.

This GDM does not specifically address hazardous substances or contaminated soil, rock, or groundwater which may require special construction methods, handling, and disposal. The geotechnical field investigations and laboratory testing by Alliance Geotechnical Group were performed for the express purpose of obtaining information on geotechnical properties of subsurface materials for DART D2 project tunnel design and construction. Their investigations were not intended to locate or characterize subsurface occurrences of potentially hazardous substances. This GDM does not specifically address hazardous substances or contaminated soil, rock, or groundwater which may require special construction methods, handling, or disposal.

Data collected by others for other projects were used with limitations because of possible differences in data collection, sampling, and testing methods. They were considered for general stratigraphy and ground conditions, approximate level of top of rock, and corroboration of DART D2 data. Data by others were not used alone for drawing definitive conclusions or development of geotechnical design parameters except as noted in this GDM.

3 GEOLOGIC SETTING

The following sections describe the regional geology, physiography, topography and drainage, stratigraphy, regional geologic structure, regional groundwater conditions, and seismicity of the DART D2 project area. Figure 1 presents a geologic map of Dallas County. Site geotechnical conditions are described in Sections 5, 6, 7, and 8 of this GDM.

3.1 Regional Geology

The proposed DART D2 project is located in Dallas County, in north-central Texas, at the northwestern limit of the East Texas Embayment (Allen and Flanigan, 1986).

The Dallas region is underlain at depth by the Ouachita fold belt, a northeast-trending Paleozoic-age mountain range marking the collision and suture of the North and South American tectonic plates. Following 200 million years of erosion, the formerly rugged mountains were worn down to a nearly flat plane, and by Cretaceous time, seas had flooded the region and laid down thousands of feet of sediments.

As regional uplift to the west and sinking of the Gulf of Mexico to the east continued during the Cretaceous period, a series of volcanic eruptions expelling plumes of ash, rock, and steam took place along fractures in a northeast-trending line south of Dallas, following the Balcones fault. Subsequently, several phases of uplift raised the Cretaceous rocks to about 2000 feet above sea level, forming the Edwards Plateau. The last of these uplifts occurred during Miocene time along the Balcones fault, in a zone trending northeast near San Antonio, Austin, and Waco, and toward Dallas.

Thick layers of sediment accumulated during progressive Tertiary-age downwarping of the Gulf of Mexico. In Dallas County, most of these Tertiary marine sediments have been eroded away (DPG, 1941), but they are still present in Kaufman County to the east (UT BEG, 1987). A series of north-south faults separating Cretaceous-age rocks from the younger Tertiary-age rocks were activated during Miocene time and are related to the Balcones fault. One of these, the Mexia fault system, passes through Dallas, and like the Balcones fault zone south of the city, follows the edge of the old buried Ouachita mountain range.

Subsequent stream erosion during the Pleistocene epoch entrenched major streams across Texas, including the Trinity River in Dallas. The sea level rose once again as North American glaciers receded at the close of the Pleistocene epoch and the start of the Holocene epoch. The resulting terraced sediments and alluvium were deposited along Trinity River and its three Dallas-area tributaries during Pleistocene and Holocene time.

3.2 Physiography

Dallas is located in the Blackland Prairies of the West Gulf Coastal Plain Section of the Coastal Plain Physiographic Province of the Atlantic Plain Division (Fenneman, 1938). The West Gulf Coastal Plain Section is characterized as a young coastal plain grading inland to a mature coastal plain (UT BEG, 1996; Fenneman, 1946). From sea level at the Gulf of Mexico, the elevation of the Gulf Coastal Plain increases northward and westward to more than about 400 feet above sea level in Dallas.

The Blackland Prairies, extending across Texas from the Red River southwestward to San Antonio, are underlain by chalks and marls which weather to deep, black, fertile clay soils, in contrast to the thin red and tan sandy and clay soils of the Interior Gulf Coastal Plains to the east. The blacklands have a gently undulating surface, cleared of most natural vegetation and cultivated for crops (UT BEG, 1996).

The White Rock Escarpment, underlain by the white rock of the Austin Chalk, lies on the west side of Dallas. It rises about 200 feet above the flatter lowland ground underlain by the Eagle Ford Shale. The escarpment constitutes the innermost zone of the Coastal Plain (Fenneman, 1938; UT BEG, 1996).

3.3 Topography and Drainage

Ground surface elevations in Dallas County generally range from 400 to 700 feet above sea level.

The topography of the Dallas area is generally controlled by differential erosion and the east-southeast dip of the shale, chalk, and marl rock that are exposed in the city, resulting in a series of nearly north-south trending rock outcrop bands.

Belts of weaker shale have been worn down more rapidly than the relatively resistant Austin Chalk, producing a series of escarpments, or cuestas. West-facing slopes of the escarpments are steep, and east-facing slopes are gentle and capped by the resistant east-dipping beds of Austin Chalk. The most prominent of these escarpments is the White Rock Escarpment, which underlies the highest parts of Dallas County. Continuous sloughing of the underlying Eagle Ford Shale has produced locally undermined slopes.

The Trinity River is the major drainage of the region. Two tributaries, Elm Fork and West Fork, join the Trinity River just west of Dallas. The Trinity River then continues across the city, joined by East Fork to the southeast. The river's main flood plain is carved into the Austin Chalk, and its valleys are filled with four to five terraced alluvial units (Allen and Flanigan, 1986). Based on studies of these terrace deposits, the ancestral Trinity River cut a much wider flood plain and carried larger material than the present river system.

3.4 Stratigraphy

Soil and rock units in the Dallas region are described below in order from oldest to youngest. Figure 1 presents a geologic map of Dallas County. Section 7 presents site-specific engineering properties of these materials, and Section 8 describes site geotechnical conditions by specific reaches of the DART D2 underground alignment.

3.4.1 ROCK

EAGLE FORD SHALE

The Late Cretaceous-age Eagle Ford Shale, variously defined as a group or as a formation, consists mostly of organic-rich clay shale. Within Dallas County it has an average thickness of about 475 feet (DPG, 1941). The following descriptions focus on the upper part of the formation, which is the portion most likely to affect the DART D2 project.

The undivided Eagle Ford Group (Kef in Figure 1) north of Hill County has been described by UT BEG, 1988 as: medium to dark gray shale, sandstone, and limestone; shale, bituminous, selenitic, with calcareous concretions and large septaria; platy, burrowed; in lower part bentonitic.

Moreman (1927) divided the Eagle Ford into three units. In ascending order, these are: the Tarrant, a basal sandy facies; the Britton, mostly blue clay with a few flaggy limestone seams and concretions; and the Arcadia Park, predominantly shale, with 20 feet of blue clay at its base followed by 1 to 3 feet of flaggy limestone, which in turn are succeeded by 75 feet of shale containing numerous calcareous concretions (DPG, 1941). The upper unit, the Arcadia Park, is most relevant for the DART D2 project.

When moistened, the shale disintegrates into a highly plastic mass consisting of clay particles enclosing small chips or scales of shale. A single drenching rain will cause the surface of fresh shale to become uniformly covered with this sticky paste, which develops mud cracks upon drying. Almost all the shale banks in the Dallas area, including the steepest, are plastered with this mud-cracked film, which can be destroyed and reformed during a single heavy rainstorm (DPG, 1941).

The plasticity of the moistened shale makes it particularly susceptible to mass-wasting by slumping. Slumped blocks were once present at nearly every undercut bank, and recurrence of slumping tends to erode the shale banks rapidly, maintaining their steep slopes (DPG, 1941).

The Eagle Ford has numerous features characteristic of black shales deposited in waters deficient in oxygen, including its thinly laminated bedding, lack of burrows of mud-eating organisms, distinctive fossil types and distribution patterns, presence of pyrite and marcasite, and scattered beds of sandstone and sandy shale (DPG, 1941).

The Eagle Ford Shale is rich in expansive clay minerals. Its general mineralogic content is 40 percent montmorillonite, 7 percent illite, 5 percent kaolinite, 2 to 8 percent calcite, 11 percent quartz, and 27 percent other minerals (Allen and Flanigan, 1986). Chemical analysis indicates relatively high content of sulfur trioxide, which is attributed to the presence of gypsum and iron sulfide as marcasite or pyrite. Decomposition of the iron sulfide is believed to have formed sulfuric acid which reacted with the calcium carbonate in the shale to produce hydrous calcium sulfate in the form of gypsum (DPG, 1941).

Excavations for the DART D2 project will encounter the Eagle Ford Shale in the central and western portion of the alignment, based on boring logs in the GDR (GPC6, 2019) and the conceptual underground alignment and configuration current as of December 20, 2019.

AUSTIN CHALK

The Late Cretaceous-age Austin Chalk consists of recrystallized, fossiliferous, interbedded chalk and marl. The maximum thickness of the Austin Chalk is about 550 feet in the City of Dallas and 675 feet in Dallas County (Allen and Flanigan, 1986).

Because of its superior hardness and resistance to erosion, the Austin Chalk crops out over a relatively larger area than the Eagle Ford Shale. Outcrops and quarries in the Dallas area are common.

An unconformity exists at the contact between the Eagle Ford Shale and the overlying Austin Chalk (Collier, 2015; HNTB, 2016). Above the unconformity is a layer of argillaceous chalk with an abundance of fossil detritus, fish teeth and vertebrae, pyrite and phosphate nodules, and reworked material from the Eagle Ford Shale. This layer is locally referred to as the "Transition Zone" and was named by Taff (1893) as the "Fish Bed Conglomerate." It ranges in thickness from 1 to 12 feet (Sellards et al., 1932), and its reported thickness in Dallas County is 4 feet (DPG, 1941).

The Austin Chalk (Kau on Figure 1) has been divided into three members in Dallas County: the lower chalk, the middle marl, and the upper chalk (DPG, 1941; UT BEG, 1988).

The upper and lower members of the Austin Chalk are described by UT BEG (1988) as: light gray, mostly microgranular crystalline calcite, massive, with some interbeds and partings of calcareous clay and thin bentonitic beds locally in the lower part. Marly and shaly partings are reportedly generally about 1 inch thick (DPG, 1941). Thicknesses of the upper and lower chalk members are 180 feet and 200 feet, respectively (DPG, 1941).

In addition to calcite crystals and amorphous calcareous matter, the upper and lower members contain whole shells or fragments of fossil foraminifera, pelecypods, gastropods, echinoids, and fish. The lower member is locally burrowed, and marcasite-pyrite nodules are common. Some strata are durable and fracture conchoidally, but even the hardest beds can be easily cut with a hand saw or knife (DPG, 1941).

The middle marl member of the Austin Chalk is described as light gray, mostly thin-bedded calcareous marl with interbeds of massive chalk up to two feet thick (DPG, 1941). It is softer than the chalk members above and below. Marine megafossils are scarce in the middle member. Its thickness is about 220 feet (DPG, 1941).

Based on Dallas-area mapping (Allen and Flanigan, 1986), the lower and upper members of the Austin Chalk in the Dallas area consist of massive beds of chalk 2 to 5 feet thick, interbedded with 1- to 2- foot thick beds of marl. The middle member consists of beds of marl 2 to 5 feet thick, interbedded with 1- to 2-foot thick beds of chalk.

Excavations for the DART D2 project will be primarily in the Austin Chalk, based on boring logs in the GDR (GPC6, 2019) and the conceptual underground alignment and configuration current as of December 20, 2019.

OZAN FORMATION

The Ozan Formation outcrops in the easternmost part of the City of Dallas (Ko on Figure 1). Also known as "lower Taylor marl," it is a medium gray, soft, laminated montmorillonitic, calcareous marine shale, described by UT BEG (1988) as having thin bentonitic beds locally in the lower part. It will not be encountered in excavations for the currently planned DART D2 project.

3.4.2 OVERBURDEN

A zone of highly to completely weathered rock mantles bedrock throughout the region.

Much of the weathered rock in Dallas County is covered with a layer of brown to black silty clay to clay residual soil 20 to 80 inches thick (Allen and Flanigan, 1986). The residual soil is typically thickest over flat-lying areas on the Eagle Ford Shale, the middle member of the Austin Chalk, and the Ozan Formation. Residual soil is generally Unified Soil Classification System (USCS) classification CH-CL.

Elsewhere in the region, weathered rock is overlain by alluvium, including flood plain alluvium and terrace deposits. Alluvium thickness is 5 to 15 feet on small tributaries and 55 to 90 feet on the major streams (Allen and Flanigan, 1986). Quaternary flood plain deposits (Qal on Figure 1), including indistinct low terrace deposits, consist of gravel, sand, silt, silty clay, and organic matter (UT BEG, 1988). Quaternary terrace deposits (Qt on Figure 1) consist of red-brown gravel, sand, silt, and clay. At least four levels of terrace deposits have been identified in the Dallas Central Business District area according to their height above the floodplain (Allen and Flanigan 1986). Terrace deposits in the region range in thickness from 10 to 45 feet and are locally mined for gravel (Allen and Flanigan, 1986).

3.5 Regional Geologic Structure

Structurally, Dallas County lies between the Fort Worth Basin to the west and the East Texas Embayment to the east.

The Balcones fault zone is a major tensional structure extending from south central Texas to northeast Texas, near Dallas. The Balcones fault zone comprises many smaller normal faults with associated horsts and grabens. Last activity along the Balcones fault was during the Miocene epoch, about 15 million years ago, and was related to subsidence of the Texas Gulf Coastal Plain.

Normal fault continuations of the Balcones fault system may extend into southern Dallas County (Allen and Flanigan, 1986), striking northeast to east-northeast across the area and following the structural grain of the Paleozoic Ouachita fold belt (Raney et al, 1987). Most reportedly dip 50 to 70 degrees toward the northwest and southeast (Raney, 1987). Faults elsewhere in the Dallas area are reported to strike N10W (Blakemore, 1939, Allen and Flanigan, 1986). Most faults in the City of Dallas are normal faults with usually less than 15 feet of displacement. These minor faults occur in all outcropping formations in the city: the Eagle Ford Shale, the Austin Chalk, and the Ozan Formation (lower Taylor Marl). The age of the faulting is believed to be early Cretaceous to Miocene (Allen and Flanigan, 1986).

The Mexia fault zone is east of Dallas, in neighboring Kaufman County (DPG, 1941). It is characterized by faults downthrown on the southeast side and faults downthrown on the northwest side, with a graben of varying width between them. Its last movement is believed to have been during Miocene time.

Due to post-Cretaceous period tilting, bedding in the Cretaceous sedimentary rocks underlying Dallas County dip gently east or southeast toward the East Texas Embayment at 50 to 100 feet per mile (Allen and Flanigan, 1986). The dip angle becomes steeper toward the eastern edge of the City of Dallas.

Joint systems studied by Blakemore (1939) are shown to be related to the faults. One major joint set in the Dallas area reportedly strikes N65E (Allen and Flanigan, 1986).

Results of in-situ hydrofracturing stress testing in Austin Chalk and Eagle Ford Shale for the design of the Superconducting Super Collider Interaction Hall in Ellis County, Texas, about 30 miles south of Dallas, showed that the differences between the principal stresses were within about 100 psi (0.7 MPa), which is relatively small (Kim and Schmidt, 1992). The ratio of the maximum horizontal stress (σ_H) to the vertical stress (σ_V) was found to range from 1.2 to 2.2, and the ratio of the minimum horizontal stress (σ_h) to the vertical stress (σ_V) was 0.9 to 1.8. Within just the Austin Chalk, the mean ratio of the maximum horizontal stress (σ_H) to the vertical stress (σ_V) was 2.0 and was attributed to denudation of overlying sedimentary deposits.

3.6 Regional Groundwater Conditions

Major aquifers in Dallas County are the Late Cretaceous-age Woodbine sands and the Early Cretaceous-age Trinity and Paluxy sands, which occur at depths of 400 to 1000 feet in Dallas. The near-surface Holocene and Pleistocene sands and gravels of the flood plains and terraces are also considered aquifers.

The surface water storage system of the city of Dallas provides most of the public water supply, with groundwater considered an emergency water source for the city. Current minor groundwater use is mostly by local industries.

The Trinity, Paluxy, and Woodbine are confined systems, and water levels in early wells in the region were near the ground surface. Extensive cones of depression have developed in the piezometric surface of each of the region's principal aquifers, coinciding with areas of large ground-water withdrawals (Baker et al., 1990). Yields from these aquifers range from 100 to more than 1,000 gallons per minute (gpm) of fresh to slightly saline water.

The Holocene alluvium and the Pleistocene terrace deposits can reportedly produce yields of more than 1,000 gpm. Neither the Austin Chalk nor the Eagle Ford Shale are productive water supply aquifers. The Austin Chalk yields 100 to 1000 gpm of fresh to moderately saline water from wells in counties northeast of Dallas. The Eagle Ford Shale is very limited as an aquifer, yielding less than 100 gpm from shallow wells (Baker et al., 1990).

Hydrocarbons have been identified in groundwater in downtown Dallas (Allen and Flanigan, 1986). The hydrocarbon releases are believed to be due to abandonment of underground fuel oil tanks as the city’s streets were widened.

Chapters 7 and 8 address DART D2 project site-specific groundwater conditions.

3.7 Seismicity

Like most of North America east of the Rocky Mountains, damaging earthquakes are rare in the Dallas region, and most occur as faulting within bedrock, usually several miles deep. As in other areas of the south-central states of the U.S., many seismologists believe that a significant majority of recent earthquakes have been triggered by human activities that have altered stress conditions sufficiently to induce faulting. Activities that have induced felt earthquakes include water impoundment behind dams, injection or extraction of fluids or gas, and quarrying operations (USGS, 2018).

According to the U.S. Geologic Survey 2014 National Seismic Hazard Map of Texas (USGS 2015), peak horizontal acceleration with 10 percent probability of exceedance in 50 years, expressed as a percent of gravity, is 1 to 2% g in the DART D2 project area. The northeast corner of Dallas County is subject to a slightly higher peak horizontal acceleration of 2 to 3% g. The peak horizontal acceleration with a 2 percent probability of exceedance in 50 years is 4 to 6% g for all of Dallas County (USGS, 2015).

The strongest recent earthquake recorded in North Texas was a magnitude 3.4 event occurring in May 2015 near Venus, in Johnson County, about 30 miles southwest of Dallas (USGS, 2018). More recently, on October 1, 2019, a shallow (about 5.0 km depth) 3.2 magnitude earthquake occurred with an epicenter near Mansfield, also in Johnson County and about 25 miles southwest of Dallas (USGS, 2020).

The fault along which the Johnson County earthquakes occurred is associated with previous, smaller earthquakes which began 10 years earlier, shortly after wastewater injection disposal into deep aquifers was initiated in the region. These and other earthquakes in the Fort Worth Basin, which underlies the Dallas-Fort Worth area, are believed to be related to effects wastewater injection disposal on potentially seismogenic faults (Hennings et al., 2019). It is possible that the recent Dallas-area earthquakes were induced by human activities.

4 UNDERGROUND ALIGNMENT REACHES AND EXCAVATION HORIZONS

4.1 Reach Definition

Assumptions and detailed methodology for definition of reaches are included in the Ground Class Study excerpted in Appendix A.

Underground alignment reaches were defined based on the alignment and configuration, portal and station locations, and stationing current as of December 20, 2019.

In areas where the design current as of December 20, 2019, indicates that either cut-and-cover or SEM construction may be used, it was assumed for baseline purposes that construction would be by cut-and-cover. Where the design current as of December 20, 2019, indicates that mining may be by either SEM or Tunnel Boring Machine (TBM), it was assumed for baseline purposes that mining would be by SEM.

Reach limits apply to both eastbound and westbound alignments.

Ten reaches were defined for the proposed DART D2 project underground alignment. Reach limits were defined based on proposed structures and anticipated construction methods. Reach locations are shown in Figure 3, and reach limits and general ground conditions are shown in Table 1. Limits for the general types of reaches were defined as follows:

- Limits of Reaches 1 and 10 were defined on the basis of limits of proposed U-wall retained cuts at the West Portal and East Portal, respectively.
- Limits of Reaches 2 and 9 were defined on the bases of limits of proposed cut-and-cover tunnel construction adjacent to the West Portal and East Portal, respectively.
- Limits of Reaches 3 and 8 were defined on the basis of limits of proposed cut-and-cover station construction for Metro Center Station and CBD East Station, respectively.
- Limits of Reach 5 were defined on the basis of limits of proposed SEM station excavation for Commerce Station.
- Limits of Reaches 4 and 6 were defined on the basis of limits of proposed SEM tunnel excavation adjacent to the west end and east end of Commerce Station, respectively.
- Limits of Reach 7 were defined on the basis of limits of proposed cut-and-cover tunnel construction adjacent to the west end of CBD East Station.

Reach stationing in Table 1 is shown for the project reference alignment, which is the eastbound track. General reach descriptions apply to both alignments. GDR data from logs of borings drilled for DART D2 project investigations within 400 feet of the excavation limits were considered applicable.

4.2 Excavation Horizon Definition

Excavation horizons were defined for proposed tunnels, stations, and portal retained cuts. All excavation limits were based on top-of-rail elevations on 20 percent design alignment profile current as of December 20, 2019. The following upper and lower excavation limits conventions were followed:

- At proposed portals, excavation extends from invert, which is 5.0 feet below Top of Rail, to ground surface.
- At proposed cut-and-cover tunnels, excavation extends from invert, which is 5.7 feet below Top of Rail, to ground surface.
- At proposed mined (SEM) tunnels, excavation extends from invert, which is 5.5 feet below Top of Rail, to crown, which is 22.2 feet above invert.

- At proposed cut-and-cover stations, excavation horizon extends from invert, which is 9.5 feet below Top of Rail at Metro Center Station and 5.3 feet below Top of Rail at CBD East Station, to ground surface.
- At mined (SEM) Commerce Station, excavation horizon extends 44.0 feet upward from invert, which is 10.0 feet below Top of Rail.

General ground conditions within excavation horizons are included in the reach descriptions shown in Table 1.

5 GROUND CLASSIFICATION

5.1 Assumptions and Methodology

Assumptions and methodology for development of ground classifications and the distribution of ground classes along the proposed Downtown Tunnel alignment are included in the Ground Class Study excerpt in Appendix A. Key points are summarized in the following paragraphs.

5.2 Ground Classification System

A ground classification system was established for the DART D2 project based on the following general requirements:

- Applicable to anticipated construction methods, including SEM, optional TBM, and methods for open cut and cut-and-cover construction
- Quantitative, objective, and based on subsurface data collected and to be presented in project geotechnical data reports
- Standardized terminology
- Unambiguously communicable in terms of baseline values
- Baseline classifications can be verified during construction
- Same system can be applied to all DART D2 project underground construction

The DART D2 project ground classification criteria consider the project's geologic setting and specific soil and rock features affecting underground construction.

Weathering grades of the International Society for Rock Mechanics (ISRM), shown in Table 2 (from ISRM, 1981), were considered appropriate for ground class distinctions for rock of various degrees of weathering ranging from unweathered to residual soil. For classification purposes, it was assumed that weathering grades shown on draft boring logs are relative grades for this region and not necessarily directly correlated with ISRM grades.

Ground classes and their distinguishing characteristics are summarized in Table 3. The following conventions were followed:

- Top of rock is defined as the level at which rock coring was begun, with recovery of at least 50 percent, as shown in the boring logs in the GDR (GPC6, 2019).
- For unweathered to moderately weathered rock, classes are linked to ISRM weathering grades shown in Table 2, fracture spacing, strength, number of sets of slickensided fractures, number and thickness of planar weakness zones, and presence/absence of inherently weak rock types.
- Highly and completely weathered rock are here considered Intermediate Geomaterials (IGM). Their classification is linked to ISRM criteria for weathering grades IV and V, including decomposition and disintegration.
- For soils, two natural soil groups were defined along with an additional soil unit for fill. Alluvial soils include terrace deposits and Holocene alluvium. It was not possible to distinguish alluvial soils from residual soils corresponding to ISRM weathering grade VI based on information on draft boring logs, but the classification was retained for possible future use.

Section 7, Geotechnical Properties of Site Materials, provides additional details on ground class characteristics.

As shown in Table 3, the 12 defined ground classes were grouped into eight Ground Class Groups. Ground Class Groups occur in the following general stratigraphic sequence from the ground surface down:

- Fill
- Alluvium
- Residual Soil
- “Weathered Rock”
- Ground Class III Rock
- Ground Class II Rock
- Ground Class I Rock
- Bentonite

Table 3 also shows how the three broader General Ground Class Groups, and the geologic profile in Figures 4-A through 4-I presents the lateral distribution of these broad groups with depth along the alignment current as of December 20, 2019.

As additional data are collected, ground classes may be grouped differently depending on contractual baselining needs. For example, it may become more appropriate to group classes by rock type rather than by rock quality and weathering.

5.3 Ground Class Distributions

5.3.1 APPROACH

The distribution of ground classes was determined based on the data presented in the GDR (GPC6, 2019) and the alignment and configuration current as of December 20, 2019.

For the purpose of finding ground class distributions, borings within 400 feet of the underground alignment were considered relevant. Boring locations were orthogonally projected to the alignment to determine reach. For each boring, the upper and lower depths of the excavation horizon were determined as described in Section 4.2, based on the underground alignment current as of December 20, 2019.

Ground classification criteria were applied to each foot of depth in each applicable boring in each reach along the proposed underground alignment. This information is presented in Appendix A.

PORTAL U-WALL RETAINED EXCAVATIONS

For portal reaches (Reaches 1 and 10), the proportions of each ground class in each boring were calculated as percentages of the total boring footage and as a percentage of boring footage within the proposed portal U-wall excavations. Results are included in Appendix A and presented in Table 4.

Results were compiled by reach by finding the maximum, minimum, median, and total percentages of each ground class for the borings within each portal reach. Ground class distributions for excavation of portal Reaches 1 and 10 are summarized in Table 5 and in Table 6.

CUT-AND-COVER TUNNEL EXCAVATION

For cut-and-cover tunnel reaches (Reaches 2, 7, and 9), the proportions of each ground class in each boring were calculated as percentages of the total boring footage and as a percentage of boring footage within the tunnel excavation. Results are included in Appendix A and presented in Table 4.

Results were compiled by reach by finding the maximum, minimum, median, and total percentages of each ground class for the borings within each cut-and-cover tunnel reach along the underground alignment. Ground class distributions for excavation of cut-and-cover tunnel Reaches 2, 7, and 9 are summarized in Table 5 and in Table 7.

MINED (SEM) TUNNEL EXCAVATION

For mined (SEM) tunnel reaches (Reaches 4 and 6), the proportions of each ground class in each boring were calculated as percentages of the total boring footage and as a percentage of boring footage within the tunnel excavation. Results are included in Appendix A and presented in Table 4.

Results were compiled by reach by finding the maximum, minimum, median, and total percentages of each ground class for the borings within each SEM tunnel reach along the underground alignment. Ground class distributions for excavation of mined (SEM) tunnel Reaches 4 and 6 are summarized in Table 5 and in Table 8.

CUT-AND-COVER STATION EXCAVATION

For cut-and-cover Metro Center and CBD East Station reaches (Reaches 3 and 8), the proportions of each ground class in each boring were calculated as percentages of the total boring footage and as a percentage of boring footage within the proposed station excavation. Results are included in Appendix A and presented in Table 4.

Results were compiled by reach by finding the maximum, minimum, median, and total percentages of each ground class for the borings within each cut-and-cover station reach. Ground class distributions for excavation of cut-and-cover station Reaches 3 and 8 are summarized in Table 5 and in Table 9.

MINED (SEM) STATION EXCAVATION

For the mined (SEM) Commerce Station reach (Reach 5), the proportions of each ground class in each boring were calculated as percentages of the total boring footage and as a percentage of boring footage within the proposed station excavation. Results are included in Appendix A and presented in Table 4.

Results were compiled by reach by finding the maximum, minimum, median, and total percentages of each ground class for the borings within the Commerce Station reach. Ground class distributions for excavation of mined (SEM) station Reach 5 is summarized in Table 5 and in Table 10.

5.3.2 RESULTS

Table 4 summarizes results for all underground excavations. Reach-specific results are presented in the following tables:

Table 6	Portal U-wall retained excavations	Reaches 1 and 10
Table 7	Cut-and-cover tunnels	Reaches 2, 7, and 9
Table 8	SEM tunnels	Reaches 4 and 6
Table 9	Cut-and-cover stations	Reaches 3 and 8
Table 10	SEM station	Reach 5

In each table, ranges of estimated volume percentages of each ground class within the proposed excavation for each reach are shown as follows:

- The maximum/minimum range by reach, representing the range of ground class percentages that could be encountered within a vertical slice orthogonal to the alignment anywhere within a given reach.
- The median percentage by reach, representing the median or typical mix of ground classes at the excavation face throughout the length of a given reach.
- The total percentage by reach, representing the estimated mix of ground classes that are anticipated to be excavated throughout the length of a given reach.

All percentages are by volume.

Tables 11, 12, and 13 present summaries of percent volumes for Ground Class Groups for excavations for portal U-wall excavation, cut-and-cover excavation, and SEM excavation, respectively.

The generalized geologic profile presented in Figures 4-A through 4-I shows the spatial distribution of Ground Class Groups and rock types along the length of the DART D2 underground alignment. It should be noted that this an interpreted profile and that information was extrapolated and interpolated between widely spaced borings. Actual ground conditions may differ from the conditions shown. Levels shown for top of rock and top of shale were estimated from D2 project data supplemented by data from historical boring logs in Collier, 2015.

Although based on the limited project-specific data currently available, the ranges and distributions of ground classes shown in Tables 4 through 13 and discussed in the following sections are suggested for use at this time in preliminary design estimates and as preliminary baselines for excavations for underground portions of the DART D2 alignment.

GROUND CLASS DISTRIBUTION FOR PORTAL U-WALL RETAINED EXCAVATIONS

Based on the limited available data, excavations for the portal U-wall retained cuts will be entirely in Fill and Alluvium, as shown in Table 6 and Table 11. No rock excavation at either the West Portal or the East Portal is indicated by the limited available data. However, because the invert is not far above the overburden-rock contact, a small amount of "Weathered Rock" or Rock could also be present at both the West Portal and the East Portal.

GROUND CLASS DISTRIBUTION FOR CUT-AND-COVER TUNNELS

Based on the limited available data, excavations for the proposed cut-and-cover tunnels in Reach 2 and Reach 7 will both encounter rock. In Reach 2, more than half the excavation will be in Alluvium (52 percent), with the remainder in Ground Class I limestone (35 percent), "Weathered Rock," (8 percent), Fill (5 percent), and Ground Class II limestone (1 percent). In Reach 7, about half the excavation will be in rock, including Ground Class I limestone (41 percent) and Ground Class II limestone (8 percent). The remainder of the excavation will be in Alluvium (31 percent), "Weathered Rock" (11 percent), and Fill (9 percent).

Excavations for the proposed cut-and-cover tunnel in Reach 9, adjacent to the East Portal, will encounter a small amount (<10 percent) of Ground Class II limestone. The remainder of excavation in Reach 9 will be Fill, Alluvium, and some "Weathered Rock."

GROUND CLASS DISTRIBUTION FOR MINED (SEM) TUNNELS

All SEM tunnel excavation will be in rock.

Excavations for the proposed SEM tunnels in Reach 4 will be mostly (62 percent) in Ground Class I limestone. The remainder of excavation in Reach 4 will be in Ground Class II limestone and Ground Class II shale.

Excavations for the proposed SEM tunnels in Reach 6 will be mostly (75 percent) in Ground Class I limestone. The remainder of excavation in Reach 6 will be in Ground Class II limestone.

GROUND CLASS DISTRIBUTION FOR CUT-AND-COVER STATIONS

Both proposed cut-and-cover stations will be excavated in overburden and rock.

Nearly half (48 percent) of the volume of excavated material at Metro Center Station (Reach 3) will be Ground Class I limestone. The remainder of excavation will include Ground Class II limestone, Ground Class I and II shale, "Weathered Rock," Alluvium, and Fill.

More than three-quarters (79 percent) of the volume of excavated material at CBD East Station (Reach 8) will be clayey alluvium. The remainder of excavation will include fill, sandy alluvium, "Weathered Rock," and Ground Class I and II limestone. No shale is anticipated to be encountered in Reach 8 based on available information. A 1.5-foot thick bentonite layer is anticipated to be encountered within excavations in limestone for CBD East Station.

GROUND CLASS DISTRIBUTION FOR SEM STATION

All SEM excavation for Commerce Station will be in rock.

Almost all (98 percent) of the volume of excavated material at Commerce Station will be Ground Class I limestone.

Based on available information, the remaining volume of excavated material will be Ground Class II limestone.

Because the proposed Commerce Station invert nearly coincides with the limestone-shale contact, some shale could be encountered in excavations near the invert.

6 TUNNEL EXCAVATION FACE CONDITIONS

6.1 Approach

As is typical for a weathering profile in this region, the top of rock along the DART D2 underground alignment is not a well-defined line but a gradational zone, the thickness and nature of which depend on parent material, erosion, drainage history, and other factors. The DART D2 ground classification approach has established the top of Ground Class III or better rock as the level below which material behavior will be primarily rock-like.

Rock was thus defined as Ground Classes L-I, L-II, and L-III for limestone and S-I, S-II, and S-III for shale. Until additional laboratory test data are available to provide more detail on material properties, it was assumed that the top of rock corresponds to the level at which rock coring was begun as shown on the boring logs in the GDR (GPC6, 2019).

Above the top of Ground Class Group III or better rock, the "Weathered Rock" ground class was defined as highly and completely weathered rock, corresponding to ISRM weathering grades IV and V. This material is a highly variable transitional material which will behave differently than either soil or rock, especially in the presence of water. This material was typically not sampled during DART D2 investigations, and descriptions on draft boring logs were generally based on cuttings and observations of drilling behavior.

Overburden was defined as the non-lithified material above the "Weathered Rock" and is here considered to be fill and either residual soil (ISRM weathering grade VI) or alluvium, including alluvium and terrace deposits.

6.2 Results

"Mixed face" here refers to an excavation condition in which Rock (Ground Class Groups I, II, or III) is overlain by weathered rock (Ground Class Group "Weathered Rock") or overburden (Ground Class Group Overburden) within the excavation face.

The general geologic profile in Figures 4-A through 4-I shows the alignment profile current as of December 20, 2019, and the approximate top of rock as inferred from available data.

Boring data indicate that excavations for the proposed U-wall portals will be primarily in overburden. However, because the invert is near the top of rock and borings are widely spaced, some limestone is anticipated to be present near the invert of both excavations, especially at the east portal, as shown in the profile.

All cut-and-cover excavations will include rock, weathered rock, and overburden. At Metro Center Station and the tunnel section east of the station, more half of the excavation (48 to 61 percent) is anticipated to be in rock.

Based on available information, SEM excavations will be entirely in rock, with no mixed-face excavation anticipated.

7 GEOTECHNICAL PROPERTIES OF SITE MATERIALS

The following sections describe the physical characteristics of distinguishable Overburden, "Weathered Rock," and Rock materials that will be encountered in excavations for the proposed DART D2 underground alignment. Descriptions are based on DART D2 boring logs presented in the GDR (GPC6, 2019) and supported by the published reports and the investigations by others listed in Section 2.2. Hydraulic properties of site materials are discussed separately in Section 7.4.

Overburden and Weathered Rock Group materials are classified according to ground class. Rock is classified according to ground class and rock type. ISRM weathering grades are provided in Table 2, ground class descriptions are provided in Table 3, and summaries of ground class distributions are provided in Tables 4 through 13. Figures 4-A through 4-I present a general geologic profile graphically showing distribution of General Ground Class Groups and rock types.

7.1 Soil Properties (Overburden Ground Classes)

Overburden thickness varies along the length of the proposed DART D2 underground alignment, ranging from less than about 10 feet near Ervay Street to more than 40 feet in the vicinity of proposed CBD East Station near Elm Street.

Three overburden ground classes have been defined for the proposed DART D2 underground alignment: Fill (F), Cohesive Alluvium (A1), Granular Alluvium (A2), and Residual Soil (RS). Total thickness of these overburden ground classes above "Weathered Rock" as reported on DART D2 boring logs in the GDR ranges from 6 feet to 41.5 feet and averages 22.1 feet. The following sections describe their occurrence and properties.

Preliminary recommended geotechnical design parameters for soil are based on results of tests as presented in the GDR (GPC6, 2019), including, index tests, consolidation tests, strength tests, corrosivity tests, and assigned USCS classifications. These preliminary recommendations may need revision as additional project-specific data become available.

Preliminary recommended geotechnical design parameters for Overburden ground classes described in the following sections are presented in Table 14, which includes preliminary recommended design values and baseline values or ranges for each ground class for the following properties:

- Index Properties
    - Unit weight
    - Dry density
    - Specific Gravity
    - Natural Water Content

    - Percent Gravel
    - Percent Sand
    - Percent Fines (Passing No. 200)
    - Liquid Limit
    - Plastic Limit
    - Plasticity Index
- Strength Properties
    - Standard Penetration Resistance, N_{SPT}
    - Unconfined Compressive Strength
    - UU Compressive Strength
    - Triaxial Strength, Effective Stress
    - Direct Shear Strength, Effective Stress
- Consolidation Properties
    - Compression Ratio
    - Recompression Ratio
    - Overconsolidation Ratio
- Swell Properties
    - Simple Swell (% of Ho)
    - ASTM D4546-1D Swell Test, Method A
    - ASTM D4546 Methods A and C, Swell Pressure
- Corrosivity Properties
    - pH
    - Electrical Resistivity
    - Chloride Content
    - Sulfide Content
    - Soluble Sulfate Content

7.1.1 FILL (GROUND CLASS F)

Based on available draft boring logs, the maximum thickness of Fill along the proposed DART D2 underground alignment is about 9.5 feet.

Based on boring logs in the GDR (GPC6, 2019), Fill is typically intermixed stiff to hard and from dark brown to tan clay, with varying amounts of sand and silt and traces of gravel, brick, concrete, and limestone fragments.

Only limited design parameters for Fill are shown in Table 14 because of the range and variability of its materials. These parameters should be adjusted for design based on the nature of the material at specific locations. N-values are not recommended to be used for parameter correlations for Fill because of its variability.

7.1.2 ALLUVIUM (GROUND CLASSES A1 AND A2)

As used herein, "alluvium" includes both alluvial and terrace deposits. Underlying Fill, fine-grained, cohesive alluvial deposits (Ground Class A1) along the DART D2 underground alignment range in thickness from 1 foot to 30.5 feet. Based on boring logs in the GDR, average thickness is 12.8 feet. They tend to be thickest in the vicinity of proposed CBD East Station. These deposits generally consist of low to high plasticity clay and sandy and silty clays, with some clayey sand. They constitute the Holocene alluvium and Pleistocene terrace deposits.

Granular alluvial deposits (Ground Class A2) often underlie and are locally mixed with the cohesive alluvial deposits of Ground Class A1. They are up to 18 feet thick along the DART D2 underground alignment, and their average thickness based on boring logs in the GDR is 7.0 feet. They are thickest along the western portion of the alignment. The deposits are typically cohesionless material ranging from silty sands to sand and gravel, with some intermixed clay.

As shown in Table 14, the cohesive alluvial deposits, Ground Class A1, have high swell potential. As elsewhere in Dallas, alluvial deposits are reportedly highly expansive soils with USCS classification of CH-CL (Allen and Flanigan, 1986). To minimize differential settlement for major structures, structural loads are typically transferred through alluvium to the bedrock by means of drilled shafts. Alternatively, drilled shafts founded in clay are under-reamed to anchor the piers to resist the upward forces of the expansive soils.

Terrace deposits in downtown Dallas are less plastic than alluvium deposits and residual soils, and lightly loaded structures experience fewer problems due to shrinkage and swelling (Allen and Flanigan, 1986).

Table 14 presents geotechnical properties for Alluvium ground classes A1 and A2, based on data presented in the GDR (GPC6, 2019).

7.1.3 RESIDUAL SOIL (GROUND CLASS RS)

Residual Soil could not be distinguished from Alluvium or "Weathered Rock" based on information on GDR boring logs without supporting laboratory test data. In the Dallas area, completely weathered Austin Chalk is sometimes classified as residual soil although it may retain some evidence of the original rock fabric. Huitt and Zollars (1992) report that the stratum is typically about 10 feet thick but may exceed 20 feet in thickness. They report that it is difficult to visually distinguish residual soil from the underlying weathered limestone. No residual soil was identified on available DART D2 draft boring logs. Laboratory test data or further detailed sample examination could allow definition of residual soil as a distinct ground class for the DART D2 project.

Residual soils developed on the Austin Chalk elsewhere in the Dallas area are described as very stiff to hard, moderately to highly plastic clay with USCS classifications of CL or CH (Lachel Felice, 2006).

The montmorillonitic residual soils are known to be expansive, and where greater than 40 inches thick, they cause a risk of differential settlement for lightly loaded structures due to expansion and contraction with varying seasonal moisture.

Shoring and cribbing are usually used in areas with thicker residual soils because these areas are prone to sudden sidewall failures along the pre-existing slickensided failure planes that are common in residual soils in Dallas (Allen and Flanigan, 1986).

Table 14 shows geotechnical properties for Residual Soil Ground Class RS based on data from Lachel Felice, 2006.

7.2 Overburden-Rock Transition Properties

The highly weathered rock and completely weathered rock described as "weathered rock" on DART D2 draft boring logs in the GDR correspond to ISRM weathering grades IV and V and are considered Intermediate Geomaterial (IGM). It is typically described on logs as moderately hard to hard, tan to gray, fractured weathered limestone, and occasionally as decomposed with clay seams. Although not sampled, examination of cuttings and observation of drilling behavior provided information for log descriptions.

Thickness of IGM along the DART D2 underground alignment ranges from 1 foot to 10.5 feet, based on boring logs in the GDR. Average thickness encountered in DART D2 borings was 3.7 feet.

Table 15 summarizes geotechnical properties for Ground Class IGM ("Weathered Rock") based data presented by Lachel Felice (2006) for weathered Austin Chalk. It is assumed that "weathered rock" described on draft DART D2 boring logs will have similar properties. Table 15 also presents preliminary recommended geotechnical design parameters for Ground Class IGM ("Weathered Rock") for these properties:

- Index Properties
    - Dry Unit Weight
    - Natural Water Content
    - Liquid Limit
    - Plasticity Index
- Strength and Mechanical Properties
    - Unconfined Compressive Strength

  - Modulus of Elasticity
  - Point Load Strength, Axial
  - Point Load Strength, Diametral

7.3 Rock Properties (Ground Classes L-I, S-1, L-II, S-II, L-III, S-III)

7.3.1 ROCK TYPE DESCRIPTIONS AND INTACT ROCK PROPERTIES

Rock along the DART D2 underground alignment comprises two general sedimentary rock types, limestone of the Austin Chalk and shale of the Eagle Ford Shale, each with lithologic variations in grain size and proportion of argillaceous, arenaceous, and fossil content. In addition, bentonite layers occur in both limestone and shale. Bentonite will be addressed as a separate rock type in this section because its engineering properties can be critical for tunneling.

Based on DART D2 boring logs in the GDR (GPC6, 2019), most of the rock to be excavated will be Austin Chalk limestone, with some Eagle Ford Shale to be encountered in excavations in the western portion of the alignment, in Reaches 3 and 4. Specific distribution of rock types by reach is discussed in Section 8.

Table 16 presents a summary of intact rock properties, preliminary design values, and preliminary baseline values by rock type based on data in the GDR. Details are provided in Tables 17 through 24. Classification ranges for drillability indices are given in Table 25 and are based on Dahl et al., 2012. The assumptions and method used to develop these values are included in the calculation package excerpted in Appendix B.

Values in Table 16 are generally consistent with test results presented in Lachel Felice (2006). The maximum-minimum values shown indicate relative variability. Table 16 includes the following properties for unweathered to slightly weathered limestone and shale of rock Ground Classes I and II:

- Index Properties
  - Bulk Density
- Strength and Mechanical Properties
  - Unconfined Compressive Strength
  - Dynamic Elastic Modulus, E
  - Dynamic Poisson's Ratio, v
  - Splitting Tensile Strength
- Abrasiveness and Drillability
  - CERCHAR Abrasiveness Index, CAI
  - Rebound Hammer Hardness

- Slaking Properties
  - Slake Durability Index
- Drillability Indices
  - Drilling Rate Index (DRI)
  - Bit Wear Index (BWI)
  - Cutter Life Index (CLI)

Percentile plots showing distribution of laboratory test results for each rock type are shown in Figures 5 through 16. Median values were selected as design values, as shown in Table 16.

Table 16 also includes preliminary baseline values. For rock groups and properties for which data were sufficient to determine ranges, medians, and quartiles, 75^{th} quartile values were generally selected as preliminary baseline values, assuming that the worst-case excavation condition had not been encountered in testing and to consider possible extreme values not reflected in laboratory test results.

For Drilling Rate Index (DRI), Cutter Life Index (CLI), and Slake Durability Index, the 25^{th} quartile was selected as a preliminary baseline value. For these parameters, the lower quartile values represent a more adverse condition than the median values.

Intact rock strength is likely to be highest in a direction perpendicular to the orientation of any aligned mineral grains or fossil fragments, even in rock with no evident penetrative fabric and little or no visible anisotropy. The near-horizontal beddings planes are an additional cause of anisotropy in intact rock samples that can skew laboratory test results, especially in shale. Because DART D2 underground excavations will mostly be advanced in a direction subparallel to the rock fabric, and the loading direction for most laboratory strength tests was perpendicular to mineral alignment and bedding planes, rock strengths encountered in construction could be lower than average laboratory test values shown in Table 16.

The following sections characterize the DART D2 limestone, shale, and bentonite and their intact rock properties.

LIMESTONE (AUSTIN CHALK)

Based on DART D2 boring logs in the GDR, limestone of the Austin Group will constitute about 53.5 percent of material to be excavated along the DART D2 underground alignment current as of December 20, 2019. It will be encountered in excavations in all reaches except the West and East Portal reaches, Reach 1 and Reach 10. Even in these reaches, some limestone excavation is possible near the invert.

As described on the DART D2 boring logs, the limestone is generally light to medium gray, medium hard to hard, and unweathered to slightly weathered below the level of start of coring. Fracture spacing is described as very close to wide (greater than 6 feet).

Bedding in the limestone is generally indistinct, especially in zones of fine-grained chalk. Where visible, bedding in the limestone is reported to dip 0 to about 15 degrees. Many logged fractures appear to be along bedding planes, but numerous non-bedding plane fractures are also recorded on draft boring logs.

The limestone includes argillaceous layers, and generally becomes more argillaceous with depth in DART D2 borings. The limestone also includes calcareous layers, very hard calcareous stringers and nodules, and occasional shale seams, all generally less than about 3 inches thick. Frequency and thickness of shale layers increases approaching the underlying shale. The boring logs report several observations of pyrite in limestone.

Fossils observed in the limestone include linear fossils, possibly worm burrow, shell fossils, and small black spots inferred to be altered microfossils. Some fossils are partially replaced with calcite or pyrite.

As expected, thin-section petrographic analyses in the GDR (GPC6, 2019) indicate that the primary mineral in DART D2 limestone is calcite, constituting 86 to 94 percent by volume. The calcite includes ferroan calcite, a variety which contains iron. The limestone samples were found to be generally composed of coiled and uncoiled microfossil fragments, with a faint fabric due to parallel alignment of elongated fragments.

Small amounts of smectite, 5 to 10 percent by volume, were present in each of the 15 analyzed limestone thin sections. The smectite group of clay minerals, which includes montmorillonite, have a high capacity for expansion in the presence of water. They are a primary constituent of bentonite.

Fish bone and scale fragments in the limestone are indicated by small amounts (2 to 10 percent) of collophane, a cryptocrystalline apatite mineral with Mohs' hardness of 5, harder than calcite.

Opaque minerals, probably pyrite based on boring logs, were found to constitute between 1 and 5 percent of the limestone by volume.

The “Fish Bed Conglomerate” or “Transition Zone” at the base of the limestone of the Austin Chalk, described in Section 3, is not evident from descriptions on DART D2 draft boring logs.

Rock quality of the limestone is generally good, with recovery and RQD both typically recorded as greater than 90 percent on draft boring logs.

According to ISRM criteria (ISRM, 1981), DART D2 tested limestone samples were generally weak, soft, non-abrasive, and not prone to slaking, as shown by the intact rock properties presented in Table 16. As shown, unconfined compressive strength ranges from 1,543 to 5,792 pounds per square inch (psi) with a median value of 3,238 psi. Median bulk density is 129 pounds per cubic foot (pcf).

SHALE (EAGLE FORD SHALE)

Based on boring logs in the GDR, shale of the Eagle Ford Group will constitute about 4.5 percent of material to be excavated along the DART D2 underground alignment current as of December 20, 2019, and will only be encountered at Metro Center Station, Reach 3, and in the adjacent tunnels of Reach 4.

As described on the DART D2 boring logs, the shale is generally gray to dark gray, fine-grained, soft to medium hard, and unweathered. Fracture spacing is described as very close (less than 2 inches) to wide (greater than 6 feet). Where visible in core samples, bedding in the shale dips 0 to about 15 degrees, and many, but not all, fractures occur along bedding.

The shale is described as including moderately hard seams of calcareous shale and very hard calcareous nodules and stringers. Logs also report two layers of sandy mudstone and fine-grained sandstone 3 to 5 feet thick and where present, generally occur between depth 95 and 120 feet. Scattered 2-inch thick layers of soft shale are also reported, as well as limestone layers less than 1 inch thick.

The single shale thin-section petrographic analysis in the GDR (GPC6, 2019) showed a composition of 84 percent smectite by volume. This high smectite content confirms the reported swelling behavior commonly observed in Eagle Ford shale.

Also present in the shale thin section were quartz (12 percent), as quartz silt and very fine sand. Opaque minerals were reported at 4 percent, and as recorded in boring logs in the GDR, were probably pyrite. These results indicate that despite the high content of soft clay, the shale may be somewhat abrasive and that hydrogen sulfide and acid groundwater are to be expected.

Only limited project-specific test data are available for DART D2 intact shale properties. Ranges and preliminary baseline values for selected engineering properties for Shale are summarized in Table 16. Details are included in Tables 17 through 19 and 21 through 23, and percentile plots are presented in Figures 6, 8, and 16. Data in the GDR indicate that according to ISRM classification criteria (ISRM, 1981), DART D2 Shale is generally weak to very weak, soft, and prone to slaking.

Allowable bearing capacity in the Eagle Ford Shale is reportedly variable, ranging from 1 to 18 tons per square foot, depending on lithology (Allen and Flanigan, 1986). Except for its layers of hard limestone, the Eagle Ford Shale is reportedly easy to excavate and moderately to highly erodible (Allen and Flanigan, 1986). Cut slopes are reportedly susceptible to both rapid mass movements and long-term creep. The clay shales of this formation have a moderate to very high swell potential (Allen and Flanigan, 1986).

BENTONITE

A regionally persistent bentonite layer, locally known as the Bentonite Marker Bed, is reported (Lachel Felice, 2006) to be present in the Dallas area near the boundary of the lower and middle members of the Austin Chalk about 90 feet above the top of the Eagle

Ford Shale (Lachel Felice, 2006). At 9 to 12 inches thick, it is reported to be nearly continuous and can be traced between boreholes.

Along the DART D2 underground alignment, a 14-inch thick bentonite layer is reported in the log for boring TS-206, located near the east end of proposed CBD East Station. At depth 36.6 to 37.8 feet below the ground surface (elevation 425.9 to 427.1 feet), the bentonite layer observed in this boring is at least 84 above the top of shale (top of shale was below the bottom of the boring). This bentonite layer may correspond to the Bentonite Marker Bed. It is present just below invert level of CBD East Station.

Additional, thinner bentonite seams are noted in limestone on DART D2 boring logs, but data are insufficient to correlate these seams between borings.

Table 14 includes geotechnical properties for bentonite based on data presented in Lachel Felice (2006).

7.3.2 ROCK MASS PROPERTIES

Few site-specific data are currently available for characterization of rock mass properties. The following descriptions are based on published information and the DART D2 boring logs in the GDR (GPC6, 2019).

WEATHERING, CORE RECOVERY, AND ROCK QUALITY DESIGNATION (RQD)

Limestone

Logs of borings along the DART D2 underground alignment indicate that below the level of start of coring, the limestone is generally unweathered to slightly weathered. Fracture spacing is described as very close to wide (greater than 6 feet).

Rock quality of the limestone is generally good, with recovery and RQD both typically recorded as greater than 90 percent on the DART D2 boring logs. The lowest reported RQDs in limestone were 60 percent, at boring TS-111 (west of Reach 8), and 78 percent, at boring B-1 (in Reach 3). Most borings with RQDs in limestone less than about 85 percent were located within or offset from Reaches 3 and 4 and were sometimes associated with logged slickensides.

Shale

Except for localized iron staining and zones of closely spaced fractures that are more weathered, the DART D2 boring logs in the GDR (GPC6, 2019) indicate the weathering grade of the shale is generally unweathered to slightly weathered.

Rock quality of the shale is generally good, with recovery and RQD both typically reported as greater than 90 percent on DART D2 boring logs. Lowest reported recovery and RQD not due to apparent drilling problems were 48% and 40%, respectively at boring TS-16. Like the limestone, most borings with reduced RQDs in shale, less than about 70 percent, were located within Reaches 3 and 4.

DART D2 boring logs indicate that lower RQDs in shale were associated with non-bedding fractures which were iron-stained or slickensided, zones of weakly cemented sand and clay, clay-coated fractures, and tan or brown discoloration. Laminated bedding was sometimes evident in zones with increased weathering.

ROCK MASS MECHANICAL PROPERTIES

Mechanical properties at the rock mass scale differ from intact rock properties which can be derived from laboratory data, especially in jointed rock. The interaction of intact rock blocks and the discontinuities which separate them strongly influences the behavior of the rock mass in response to excavation. Sparse site-specific rock mass data are currently available. The following discussion is based on the limited data in the DART D2 data, published data, and data collected for other projects. It should be revised to incorporate additional project-specific data when they become available.

The Geological Strength Index (GSI) is a system of rock mass characterization used to select parameters relevant for prediction of rock mass strength and deformability, often for numerical analysis for design of tunnels. The limited available site-specific rock data and data from other projects were used to develop preliminary, estimated GSI values for the DART D2 underground alignment.

For both rock types, limestone and shale, and for the three Ground Class Groups, I, II, and III, ranges of GSI were estimated using the general chart for GSI estimates from geologic observations (Marinos et al., 2005), considering lithology, rock structure, tectonic history, and condition of fracture surfaces. Results are summarized in Table 26.

The limestone-chalk rock along the DART D2 alignment generally presents a simple structure, and based on rock core data available to date, most bedding planes do not appear to be clearly defined discontinuity surfaces. For this reason, the GSI structure classifications for “blocky” or “massive” are applicable. However, the discontinuities are seldom better than a “good,” rating, and the relatively low intact rock strength assumed from data collected for other projects yields a GSI of about 50 to 65 for L-I, 40 to 50 for L-II, and 30 to 40 for L-III.

Because the GSI system is not directly applicable to highly anisotropic rock masses, it should be applied only with caution to the shale along the DART D2 alignment, especially where bedding is laminated. For Ground Class S-1 shale, the relatively low shear strength along bedding planes will control rock mass behavior. However, review of data collected for other projects for Ground Class S-II and S-III shale indicates that the difference between the intact rock strength and the strength along discontinuities is likely to be small enough that the mass will behave isotropically, and GSI would be applicable. As shown in Table 26, estimated GSI is 20 to 30 for Ground Class S-II and 10 to 20 for S-III.

Site-specific boring log data currently available are insufficient to calculate rock mass quality Q-values (Barton, 2002), a rock mass classification system used for design of rock support for underground excavations.

ROCK MASS DISCONTINUITIES

This section describes rock mass discontinuities and other rock mass properties for rock along the DART D2 alignment.

A rock mass discontinuity is here defined as a boundary or break in the rock mass which marks a change in rock properties. Rock mass discontinuities in the DART D2 area include lithologic contacts, bedding planes, faults, and fractures and joint sets. The nature of these discontinuities was considered in the development of ground classifications described in Section 5.

Orientation, spacing, and condition of rock mass discontinuities will influence ground behavior and support requirements for both mined and open cut excavations in rock. The means and methods of construction, as well as the sequences and timing of excavation and ground support, will also influence the behavior of the rock mass during construction.

Lithologic Contacts

The formational contact between the Austin Chalk and the underlying Eagle Ford Shale is an erosional disconformity. As described in Section 3 the "Transition Zone" or "Fish Bed Conglomerate" at the contact is an arenaceous zone 1 to 12 feet thick with marine fossil debris, pyrite and marcasite crystals, and reworked Eagle Ford Shale. This zone is likely to be a plane of weakness subparallel to bedding as well as a zone of increased groundwater flow.

Contacts between interbeds of chalk, marl, calcareous shale, argillaceous limestone, shale, and bentonite are likely to be laterally continuous but do not appear to represent significant planes of weakness based on DART D2 boring logs in the GDR (GPC6, 2019). Quantitative information on their strength is not available.

Bedding Planes

Except for dip angles shown on DART D2 boring logs in the GDR, no site-specific data on bedding orientation are currently available.

Preliminary observations of bedding as recorded in DART D2 boring logs in the GDR indicate that dip angles are nearly horizontal, ranging from 0 to about 20 degrees. Site-specific bedding dip direction is not known. Regionally, bedding in the Upper Cretaceous rocks exposed at the surface in Dallas County strikes north-northeast and dips at low angles to the east (DPG, 1941). Average strike of Upper Cretaceous rocks in Dallas County is reportedly north-northeast with a dip of 0 to 40 degrees east (DPG, 1941).

Based on Dallas-area mapping by others (Allen and Flanigan, 1986), the lower and upper members of the Austin Chalk in the Dallas area consist of massive beds of chalk 2 to 5 feet thick, interbedded with 1- to 2- foot thick beds of marl. The middle member consists of beds of marl 2 to 5 feet thick, interbedded with 1- to 2-foot thick beds of chalk.

<u>Faults</u>

Section 3 presents a regional-scale discussion of faulting. No site-specific fault data are currently available, except for observations of slickensided surfaces recorded on boring logs in the GDR.

The DART D2 boring logs do not indicate a major fault zone crossing the DART D2 underground alignment. The Geologic Database of Texas of the Texas Natural Resources Information System (TNRIS, 2007) also shows no mapped faults within Dallas County.

However, normal faults of small displacements are abundant in the Austin Chalk throughout the Dallas area, particularly in the lower chalk member through which most DART D2 excavation will take place. Fault dip angles in the Austin Chalk reportedly average between 45 and 60 degrees. Where faults are closely spaced, they generally dip in opposite directions, forming small horst and graben structures (DPG, 1941).

The slickensided fractures dipping 30 to 60 degrees which are reported on numerous DART D2 boring logs in the GDR (GPC6, 2019) support these observations by others. The slickensided fractures are often coated with calcite and show various levels of associated weathering and deterioration.

Where a fault cuts across interbedded chalk and calcareous shale, it is generally deflected at the contact such that the dip angle is less in the shale than in the chalk (DPG, 1941), thus limiting fault persistence and size of potential rock wedges.

Maximum observed fault displacement in the area is 10 feet, although displacement is generally less than 5 feet (DPG, 1941). Displacements across the Austin-Eagle Ford contact cannot be traced more than a few feet down into the shale, where deformation was likely accomplished by plastic deformation instead of by fracture.

Boring logs in the GDR (GPC6, 2019) indicate the presence of faulting at three locations.

1. Slickensides indicative of faulting are reported on several sets of fractures at various orientations in borings west and east of Reach 3 and 4, including T-15, T-104, and B-5. The orientation and continuity of these features cannot be determined from the available data.
2. Two sets of slickensided fractures, dipping 45 to 50 degrees and 60 degrees, were recorded on the log of the boring near the central part proposed Commerce Station, boring TS-202. The slickensided fractures were observed in the limestone above the proposed crown level. Additional slickensided fractures, dipping 40 degrees, were observed in shale below the proposed station invert level.

   Similar observations of fault evidence were recorded on the boring log for boring B-3, near the eastern end of proposed Commerce Station. Above, within, and below the proposed station excavation, faults were recorded on fractures dipping 10 degrees, 35 degrees, and 20 degrees, at depths 30.7 feet, 75.9 feet, and 112.8 feet, respectively. “Shears,” inferred to be faults with small displacements, were recorded on fractures dipping 55 degrees, 60 degrees, and 20 degrees, on fractures at depths 33.2 feet, 55.0 feet, and 117.5 feet. Fracture dip directions are not available.

3. About 500 feet west of Reach 8, at boring TS-111, slickensides are reported on 55- and 45-degree fractures, "shears" on 20-, 30-, and 60-degree fractures, and a fault on a 10- to 15-degree fracture. These features occur below the tunnel excavation horizon, between depths 94 and 101.5 feet. If these features have an eastward dip component, they may be related to the fault features observed in borings at proposed Commerce Station. Alternatively, they could intercept the alignment at another location to the west at a higher elevation within or above the excavation horizon. Fracture dip directions are not available.

Fractures and Joint Sets

Only limited site-specific data on the nature of fractures and joint sets in rock along the DART D2 are available and are reported in the GDR. Based on published information (Allen and Flanigan, 1986), while many of the fractures, faults, and joints within the Austin Chalk are tight and healed by secondary mineralization, others are open and represent potential planes of weakness.

Joints with smooth fracture surfaces are reportedly common in the chalky beds of the Austin Chalk and less common in the shales and marls. They are nearly vertical and occur in sets with consistent trends over small areas (DPG, 1941). Mapped strike directions are:

- N65E and due north at Chalk Hill (Blakemore, 1939)
- N30E and N80W near White Rock Lake, with minor sets striking N63E, N58W, and N5W
- N15E and N85W in the marly beds of the middle unit of the Austin Chalk at White Rock Lake

It appears likely that two near-vertical joint sets are present along the DART D2 alignment, one of which may strike about N65E.

Healed, slickensided fractures with small displacements are here considered faults. As described in the previous section, their average dip in the area is 45 to 60 degrees, often in opposite directions to form horst and graben structures.

Fractures along bedding planes are common in near surface rocks in the area and are generally superficial phenomena related to development of tensile stresses due to drying and shrinking. These fractures have rough surfaces parallel to bedding. They are most closely spaced in clay-rich shales and marls and more widely spaced in limestone and chalk. Bedding plane fractures are commonly reported in DART D2 boring logs in the GDR (GPC6, 2019).

7.4 Groundwater Conditions

7.4.1 HYDRAULIC PROPERTIES OF SUBSURFACE MATERIALS

No in-situ testing of hydraulic conductivity in rock or overburden has been performed for DART D2 investigations to date.

No information is available on hydraulic properties of Alluvium and Fill ground classes along the length of the alignment.

Lachel Felice (2006) reports hydraulic conductivity for the Eagle Ford Shale to be 2.2×10^{-7} cm/sec, based on a single field packer test performed for another Dallas-area project. Lachel Felice, 2006 also reports hydraulic conductivity of the Austin Chalk ranging from zero to 2.6×10^{-5} cm/sec, averaging 1.8×10^{-6} cm/sec, based on 17 field packer tests.

For both shale and limestone, hydraulic conductivity is likely to be anisotropic, with significantly higher groundwater flow along low-angle bedding plane joints.

Fast-flow paths are also anticipated along more steeply dipping open fractures across bedding planes. DART D2 boring logs report iron staining on non-bedding fractures dipping 15 to 40 degrees, indicating presence of past groundwater flow.

7.4.2 GROUNDWATER LEVELS

Maximum and minimum groundwater levels and the dates they were recorded are shown graphically on the general geologic profile in Figures 4-A through 4-I and summarized in Table 27. Data are presented in the GDR. Supplemental groundwater level measurements for wells TS-202S, TS-202D, TS-206S, TS-202D, TS-111S, TS-111D are not included in the GDR but were submitted separately by Alliance Geotechnical Group on December 5, 2019. These more recent readings were considered in determination of maximum and minimum groundwater levels shown on the profile and in Table 27. The overall period of record was April 2016 through December 2019.

Groundwater levels measured during drilling and measured periodically in observation wells ranged in depth from 4.5 feet to 30.9 feet below ground surface.

At locations where nested observation wells were installed, one screened in overburden and one screened in rock, groundwater levels were up to about 8 feet deeper in the deep well than in the shallow well of the pair. An exception was reported at the nested wells installed at boring T-208, in Reach 7, where water levels in the deep well were 20 feet deeper than those in the shallow well.

As shown in the geologic profile in Figures 4-A through 4-I, groundwater levels reported in the GDR were generally within the Alluvium Ground Class Group. Exceptions are seen at the at the deep well at boring TS-202 in Reach 5, and at boring TS-207 and TS-208, both in Reach 7.

Well responses to precipitation events are not evident in the available data but are expected. Some seasonal fluctuations in groundwater levels are also expected but are not evident in the available data.

Artesian conditions have been locally reported in Dallas (Lachel Felice, 2006), but no site-specific supporting data are available.

7.4.3 GROUNDWATER QUALITY

No DART D2 site-specific groundwater quality data have been collected to date.

7.5 Subsurface Gases

Construction of the DART 3.5-mile long twin tunnels under North Central Expressway encountered fuel-contaminated soil and pockets of methane gas. The methane source is believed to be an oil or natural gas deposit nearly 2 miles below the expressway (Dallas Morning News, 1994; Doyle, 2001). Methane concentrations reportedly exceeded the lower explosive limit (LEL), and methane occurrence appeared to be concentrated at rock fractures.

The observed and reported pyrite, marcasite, iron concretions, and gypsum in rock along the alignment indicates the possible presence of hydrogen sulfide gas in the groundwater.

8 SITE GEOTECHNICAL CONDITIONS BY REACH

As discussed in Section 4, ten reaches were defined for the proposed DART D2 underground alignment. Reach limits were defined based on proposed structure and anticipated construction method. Reach locations are shown in plan in Figure 3 and in profile in Figures 4-A through 4-I and are described in Table 1. Groundwater levels from the GDR (GPC6, 2019) are summarized in Table 27.

All stationing and structure locations are from the 20% design alignment and configuration current as of December 20, 2019. Stationing provided in this section is for the eastbound, reference alignment. The preliminary ground descriptions in this section also apply to the westbound alignment.

Preliminary geotechnical ground characterization by reach is discussed in the following sections.

8.1 Reach 1 (West Portal)

8.1.1 PROPOSED STRUCTURES

The proposed structure to be constructed within Reach 1 consists of a 620-foot length of U-wall retained cut from Station 35+30 to 41+50, based on the 20% alignment current as of

December 20, 2019. The depth of the proposed excavation ranges from about 10 feet to about 27 feet, as shown in Figure 4-C.

8.1.2 GROUND CLASSES, ROCK TYPES, AND ROCK MASS PROPERTIES

Three DART D2 borings have been drilled within 400 feet of the alignment within Reach 1, two of which are more than 200 feet from the alignment, as shown in Figure 3.

As shown in the ground class summaries for portal excavations in Table 6 and Table 11, which are based on information in the GDR and the 20% alignment current as of December 20, 2019, about 79 percent of the volume to be excavated in Reach 1 will be Alluvium. The remaining portion will be excavated in Fill (21 percent). Based on the geologic profile in Figure 4-C which interpolates data between borings, some IGM ("Weathered Rock") and Ground Class L-1 limestone will be encountered at the far eastern end of the reach near the excavation invert.

Geotechnical properties of Overburden, "Weathered Rock," and Rock ground classes are discussed in Sections 7.1, 7.2, and 7.3.

8.1.3 GROUNDWATER CONDITIONS

Groundwater level measurements taken during drilling from two boring (T-1 and T-6) are available for Reach 1.

As shown in the geologic profile in Figure 4-C, groundwater levels in Reach 1 range from elevation 410.7 feet to 411.4 feet based on the groundwater level data presented in the GDR (GPC6, 2019). These levels are 20.5 feet to 19.5 feet below the ground surface, within Overburden, and about 5 feet above the top of rock.

8.2 Reach 2 (Cut-and-Cover Tunnel)

8.2.1 PROPOSED STRUCTURES

As shown in Table 1, the proposed structure to be constructed within Reach 2 consists of 777 feet of running tunnels, from Station 41+50 to 49+27, based on the 20% alignment current as of December 20, 2019. Assumed construction will be by cut-and-cover method. The depth of excavation ranges from about 27 feet at the western limit to about 61 feet at the eastern limit, as shown in Figures 4-C and 4-D.

8.2.2 GROUND CLASSES, ROCK TYPES, AND ROCK MASS PROPERTIES

Two DART D2 borings have been drilled within 400 feet of the alignment within Reach 2, one of which is more than 200 feet from the alignment, as shown in Figure 3.

As shown in the ground class summaries for cut-and-cover tunnels in Table 7 and Table 12, which are based on information in the GDR and the 20% alignment current as of December 20, 2019, excavation in Reach 2 will be largely in Overburden, including Fill, Alluvium, and

"Weathered Rock." About one-third of the excavation for the cut-and-cover tunnels in Reach 2 will be in Ground Class L-1 limestone.

As shown in Figures 4-C and 4-D, depth to top of rock in Reach 2 ranges from about 22 feet to about 27 feet. Thickness of rock to be excavated ranges from about 4 feet at the reach's western limit to about 35 feet at the eastern limit.

Geotechnical properties of Overburden, "Weathered Rock," and Rock ground classes are discussed in Sections 7.1, 7.2, and 7.3.

8.2.3 GROUNDWATER CONDITIONS

Groundwater level measurements taken during drilling from two boring (T-102 and T-103) are available for Reach 2.

As shown in the geologic profile in Figures 4-C and 4-D, groundwater levels in Reach 2 range from elevation 409.7 feet to 410.4 feet, based on the water levels measured during drilling of borings T-102 and T-103 which are presented in the GDR (GPC6, 2019). These levels are 19.0 to 18.0 below the ground surface, within Overburden, and about 7 feet above the top of rock.

8.3 Reach 3 (Cut-and-Cover Station - Metro Center Station)

8.3.1 PROPOSED STRUCTURES

As shown in Table 1, the proposed structure to be constructed within Reach 3 is Metro Center Station, from Station 49+27 to 54+22, based on the 20% alignment current as of December 20, 2019. For purposes of preliminary ground characterization, the 495-foot long station is assumed to be designed with a center pillar and a center platform and assumed to be constructed by cut-and-cover method. Depth of excavation ranges from about 66.5 feet at the western limit to about 72 feet at the eastern limit, as shown in Figure 4-D.

8.3.2 GROUND CLASSES, ROCK TYPES, AND ROCK MASS PROPERTIES

Three DART D2 boring have been drilled within Reach 3, one of which is more than 200 feet from the alignment, as shown in Figure 3.

Ground class summaries for cut-and-cover stations are shown in Table 9 and Table 12, which are based on information in the GDR and the 20% alignment current as of December 20, 2019. As shown, about half of the material to be excavated in Reach 3 will be limestone, mostly Ground Class L-I, with a small amount (2 percent) of Ground Class L-II. The remaining material to be excavated will be Ground Class S- I and S-II shale (together, 11 percent), Alluvium (32 percent), and Fill and "Weathered Rock" (together, 8 percent).

As shown in Figure 4-D, depth to top of rock in Reach 3 ranges from about 22 feet to about 28 feet. Thickness of rock to be excavated ranges from about 36 feet at the reach's western limit to about 44 feet at the eastern limit.

As also shown in Figure 4-D, shale underlies the full length of the invert in Reach 3, with about 1 foot of shale at the western end and 7 feet of shale at the eastern end. Based on boring logs in the GDR, the shale was found to be relatively poorer quality Ground Class S-II at the western end and better-quality Ground Class S-I at the eastern end.

Evidence of faulting in the areas west and east of Reach 3 is discussed in Section 7.3.2. The orientation and continuity of the reported features are not known but could affect rock quality and rock properties.

Geotechnical properties of Overburden, “Weathered Rock,” and Rock ground classes are discussed in Sections 7.1, 7.2, and 7.3.

8.3.3 GROUNDWATER CONDITIONS

Groundwater level measurements from a pair of nested wells (TS-104) and a measurement taken during drilling at one boring (B-1) are available for Reach 3.

As shown in the geologic profile in Figure 4-D, groundwater levels in Reach 3 range from elevation 405.0 feet to 410.5 feet and are within Overburden, about 3 to 8 feet above top of rock.

The water level measured during drilling of boring B-1, as reported in the GDR, was 20.0 feet below the ground surface, corresponding to a water level at about elevation 408.4 feet.

Nested deep and shallow wells were installed at boring TS-104 and as shown in Figure 4-D, water levels in the two wells were generally within 3 feet of each other. At times, the water level in the deep well was higher than that in the shallow well, but at other times the reverse was true. Reported groundwater depths ranged from 17.3 feet to 22.7 feet, corresponding to elevations of 405.0 to 410.5 feet.

If present, the faults in Reach 3 which are discussed in Section 7.3.2 may be zones of increased hydraulic conductivity and potentially act as fast-flow paths.

8.4 Reach 4 (SEM Tunnel)

8.4.1 PROPOSED STRUCTURES

As shown in Table 1, proposed structures to be constructed within Reach 4 consist of 1,383 feet of running tunnels from Station 54+22 to 68+05, Cross Passage 1, and a Pump/Sump Room, based on the 20% alignment current as of December 20, 2019. Tunnel excavation is assumed to be by SEM, but TBM excavation is an option. For purposes of preliminary ground characterization, excavated height of the SEM tunnel is assumed to be 22.2 feet

8.4.2 GROUND CLASSES, ROCK TYPES, AND ROCK MASS PROPERTIES

One DART D2 boring has been drilled in Reach 4, as shown in Figure 3.

Ground class summaries for SEM tunnels are shown in Table 8 and Table 13, which are based on information in the GDR and the 20% alignment current as of December 20, 2019. As shown, SEM excavation for Reach 4 will be entirely in rock.

Most of the rock to be excavated (62 percent) will be Ground Class L-I limestone. The remainder will be Ground Class L-II limestone (18 percent) and Ground Class S-II shale.

As shown in Figures 4-D and 4-E, based on the single DART D2 boring log available for this reach and interpolations from historical borings, the thickness of rock above the proposed tunnel crown level ranges from about 19 feet at the western end of Reach 4 to about 50 feet at the eastern end and consists of Ground Class L-I and L-II limestone.

As also shown in Figures 4-D and 4-E, shale underlies the full length of the invert in Reach 4. Based on the limited available information, shale thickness is 1 to 4 feet, and it is likely to be the reduced quality Ground Class S-II shale.

Proposed Cross Passage 1 is located within about 50 feet of the DART D2 boring in Reach 4, boring T-201. Based on information from this boring, the cross passage will be excavated in Ground Class L-I and L-II limestone.

The proposed Sump/Pump Room in Reach 4 extends about 18.5 feet below tunnel invert level. Based on the limited available information, it will be excavated entirely in shale, as shown in Figure 4-E.

Geotechnical properties of Rock ground classes are discussed in Section 7.3.

8.4.3 GROUNDWATER CONDITIONS

A groundwater level measurement taken during drilling from one boring (T-201) is available for Reach 4.

As shown in the geologic profile in Figure 4-E, the groundwater level measured in Reach 4 at completion of boring T-201 was 15.5 feet below ground surface, corresponding to a water level at about elevation 407.1 feet. This level is within Overburden and about 5.5 feet above the top of rock.

8.5 Reach 5 (SEM Station - Commerce Station)

8.5.1 PROPOSED STRUCTURES

Based on the 20% design current as of December 20, 2019, the proposed structure to be constructed within Reach 5 is Commerce Station, as shown in Table 1. The 721-foot long station will extend from Station 68+05 to 75+26. Station excavation is assumed to be by SEM.

Additional structures, including a ventilation shaft and a station entrance shaft and adit, were in design as of December 20, 2019, and will be addressed in the next revision of this memorandum.

The station is assumed to be designed with a center pillar and a center platform and to be constructed by SEM. Height of the station cavern from invert to crown is about 32 to 35 feet, depending on location, as shown in Figures 4-E and 4-F.

8.5.2 GROUND CLASSES, ROCK TYPES, AND ROCK MASS PROPERTIES

Two DART D2 boring has been drilled in Reach 5, as shown in Figure 3.

Ground class summaries for the SEM station are shown in Table 10 and Table 13, which are based on information in the GDR and the 20% alignment current as of December 20, 2019. As shown, SEM excavation for Reach 5, Commerce Station, will be entirely in rock.

Based on available information, almost all the rock to be excavated (98 percent) will be Ground Class L-I limestone. The remainder will be Ground Class L-II limestone. However, as shown in Figure 4-E, the level of the top of shale as interpolated between borings is up to about 4 feet above invert level for the westernmost 90 feet of the reach.

Based on interpretation of the available information as shown in Figures 4-E and 4-F, thickness of rock above the proposed station cavern crown ranges from about 40 feet near the western end of the cavern to about 47 feet near the eastern end. Available information shows that rock above the crown is Ground Class L-I, L-II, and L-III limestone.

Evidence of faulting in Reach 5 is discussed in Section 7.3.2, including slickensided fractures, faults and shears which are recorded on boring logs in the GDR. Slickensides and "shears" indicate that displacements have occurred along fracture surfaces, resulting in sheared-off surface asperities, increased thickness of fracture coatings due to accelerated weathering, and resulting low shear strength along fracture surfaces. Information on fracture dip direction is not available, but it is likely that these fractures correspond to the regional northeast- and northwest-striking fault sets dipping in opposite directions. Given the west-northwest orientation of the station cavern long axis, these fractures could be configured to form a daylighting rock wedge just above the station crown. Stability of the cavern crown could be adversely affected, and additional support may be required.

Geotechnical properties of Rock ground classes are discussed in Section 7.3.

8.5.3 GROUNDWATER CONDITIONS

Groundwater level measurements from a pair of nested wells (TS-202) and a measurement taken during drilling at one boring (B-3) are available for Reach 5.

As shown in the geologic profile in Figure 4-F, groundwater levels in Reach 5 range from elevation 412.9 to 422.3 and are within Overburden and Rock.

The water level measured during drilling of boring B-3, as reported in the GDR, was 14.0 feet below the ground surface, corresponding to a water level within Rock at about elevation 421.2 feet.

Nested deep and shallow wells were installed at boring TS-202 and as shown in Figure 4-F, water levels in the well screened in rock were about 8 feet deeper than water levels in the well screened in overburden. Reported groundwater depths for the deep well were 19.8 feet to 18.7 feet, corresponding to water levels within Rock at about elevation 413 to 414 feet. Reported groundwater depths for the shallow well were 12.3 feet to 10.3 feet, corresponding to water levels within Overburden at about elevation 420 to 422 feet.

If present, the faults in Reach 5 which are discussed in Section 7.3.2 may be zones of increased hydraulic conductivity and potentially act as fast-flow paths.

8.6 Reach 6 (SEM Tunnel)

8.6.1 PROPOSED STRUCTURE

As shown in Table 1, proposed structures to be constructed within Reach 6 consist of 1,104 feet of running tunnels, from Station 75+26 to 86+30, and Cross Passage 2, based on the 20% alignment current as of December 20, 2019. Tunnel excavation is assumed to be by SEM, but TBM excavation is an option. For purposes of preliminary ground characterization, excavated height of the SEM tunnel is assumed to be 22.2 feet.

8.6.2 GROUND CLASSES, ROCK TYPES, AND ROCK MASS PROPERTIES

Two DART D2 borings have been drilled in Reach 6, as shown in Figure 3.

Ground class summaries for SEM tunnels are shown in Table 8 and Table 13, which are based on information in the GDR and the 20% alignment current as of December 20, 2019. As shown, SEM excavation for Reach 6 will be entirely in rock.

Most of the rock to be excavated (75 percent) will be Ground Class L-I limestone. The remainder will be Ground Class L-II limestone.

As shown in Figures 4-F and 4-G, based on the logs of DART D2 borings in this reach and interpolations from historical borings, the thickness of rock above the proposed tunnel crown level ranges from about 53 feet at the western end of the reach to about 9.5 feet at the eastern end and consists of Ground Class L-I limestone.

Proposed Cross Passage 2 is located between the two DART D2 borings in Reach 6, and based on information from these boring, the cross passage will be excavated in Ground Class L-I and Ground Class L-II limestone.

Geotechnical properties of Rock ground classes are discussed in Section 7.3.

8.6.3 GROUNDWATER CONDITIONS

A groundwater level measurement taken during drilling from one boring (T-204) is available for Reach 6.

As shown in Figure 4-F, the water level measured during drilling of boring T-204, as reported in the GDR, was 9.0 feet below the ground surface, corresponding to a water level within Overburden at about elevation 440 feet.

8.7 Reach 7 (Cut-and-Cover Tunnel)

8.7.1 PROPOSED STRUCTURES

As shown in Table 1, the proposed structure to be constructed within Reach 7 consists of 683 feet of running tunnels, from Station 86+30 to 93+13, based on the 20% alignment current as of December 20, 2019. Depth of excavation ranges from about 63 feet at the western limit to about 37.5 feet at the eastern limit, as shown in Figure 4-G.

8.7.2 GROUND CLASSES, ROCK TYPES, AND ROCK MASS PROPERTIES

Three DART D2 borings have been drilled in Reach 7, one of which is more than 200 from the alignment, as shown in Figure 3.

As shown in the ground class summaries for cut-and-cover tunnels in Table 7 and Table 12, which are based on information in the GDR and the 20% alignment current as of December 20, 2019, about half (49 percent) of the excavation in Reach 7 will be in Rock, mostly Ground Class I limestone, with some (8 percent) Ground Class L-II. The remainder of the excavation will be in Alluvium (31 percent), “Weathered Rock” (11 percent), and Fill (9 percent).

As shown in the geologic profile in Figure 4G, depth to top of rock in Reach 7 ranges from about 30 feet to about 15 feet. Thickness of rock to be excavated ranges from about 32 feet at the reach’s western limit to about 12.5 feet at the eastern limit.

Geotechnical properties of Overburden, “Weathered Rock,” and Rock ground classes are discussed in Sections 7.1, 7.2, and 7.3.

8.7.3 GROUNDWATER CONDITIONS

Groundwater level measurements from two pairs of nested wells (TS-207 and TS-208) and a measurement taken during drilling at one boring (T-205) are available for Reach 7.

As shown in the geologic profile in Figure 4-G, reported groundwater levels in Reach 7 range from elevation 427.6 to 452.7 and are within Overburden and Rock.

The water level measured during drilling of boring T-205, as reported in the GDR, was 21.4 feet below the ground surface, corresponding to a water level within Overburden at about elevation 439.6 feet.

Nested deep and shallow wells were installed at borings TS-207 and TS-208. As shown in Figure 4-G, water levels in the wells screened in rock were about 6 feet deeper at TS-207 and about 20 feet deeper at TS-208 than water levels in the adjacent wells screened in overburden. Reported groundwater depths for the deep wells in Reach 7 were 30.9 feet to 22.3 feet, corresponding to water levels within Rock at about elevation 427.6 feet to 434.7

feet. Reported groundwater depths for the shallow wells were 24.2 feet to 4.5 feet, corresponding to water levels within Overburden at about elevation 434.3 feet to 452.7 feet.

8.8 Reach 8 (Cut-and-Cover Station - CBD East Station)

8.8.1 PROPOSED STRUCTURES

As shown in Table 1, the proposed structure to be constructed within Reach 8 is CBD East Station, from Station 93+13 to 98+05, based on the 20% alignment current as of December 20, 2019. For purposes of preliminary ground characterization, the 492-foot long station is assumed to be designed with a center pillar and a center platform and assumed to be constructed by cut-and-cover method. Depth of excavation ranges from about 37 feet at the western limit to about 35 feet at the eastern limit, as shown in Figures 4-G and 4-H.

8.8.2 GROUND CLASSES, ROCK TYPES, AND ROCK MASS PROPERTIES

Two DART D2 borings have been drilled within Reach 8, one of which is more than 200 feet from the alignment, as shown in Figure 3.

Ground class summaries for cut-and-cover stations are shown in Table 9 and Table 12, which are based on information in the GDR and the 20% alignment current as of December 20, 2019. As shown, most of the material to be excavated in Reach 3 will be Alluvium (79 percent). The remainder will be excavated in Fill (8 percent), Ground Class L-I and L-II limestone (4 percent and 7 percent, respectively), and small amounts (1 percent) of "Weathered Rock" and an identified bentonite layer within the limestone.

The 14-inch thick bentonite layer just below the proposed CBD East Station invert could accelerate deterioration of the invert during construction or lead to excessive swelling or heave if not treated.

As shown in Figures 4-G and 4-H, depth to top of rock in Reach 8 ranges from about 24 feet to about 40 feet, and rock is deepest in the central part of the reach. Rock will only be excavated in the westernmost 230 feet of the reach, with maximum thickness of about 12.5 feet at the western limit of the reach. East of about Station 95+43, available data indicate that there will be no excavation in rock.

Geotechnical properties of Overburden, "Weathered Rock," and Rock ground classes are discussed in Sections 7.1, 7.2, and 7.3.

8.8.3 GROUNDWATER CONDITIONS

Groundwater level measurements from two pairs of nested wells (TS-206 and TS-209) are available for Reach 8.

As shown in the geologic profile in Figure 4-H, reported groundwater levels in Reach 8 range from elevation 443.6 feet to 452.2 feet and are within Overburden.

Nested deep and shallow wells were installed at borings TS-206 and TS-209. As shown in Figure 4-H, water levels in the well screened in rock at TS-206 were 3 to 4 feet deeper than at the adjacent well screened in overburden. At TS-209, water levels in the deep and shallow wells were nearly identical.

Reported groundwater depths for the deep wells in Reach 8 were 20.1 feet to 9.0 feet, corresponding to water levels within Overburden at about elevation 443.6 feet to 452.2 feet, 20 to 30 feet above top of rock. Reported groundwater depths for the shallow wells were 17.2 feet to feet to 9.0 feet, corresponding to water levels within Overburden at about elevation 446.6 feet to 452.2 feet, about 13 to 30 feet above top of rock.

8.9 Reach 9 (Cut-and-Cover Tunnel)

8.9.1 PROPOSED STRUCTURES

As shown in Table 1, the proposed structure to be constructed within Reach 9 consists of 360 feet of running tunnels, from Station 98+05 to 101+65, based on the 20% alignment current as of December 20, 2019. Depth of excavation ranges from about 35.5 feet at the western limit to about 28 feet at the eastern limit, as shown in Figure 4-H.

8.9.2 GROUND CLASSES, ROCK TYPES, AND ROCK MASS PROPERTIES

One DART D2 boring has been drilled in Reach 9, as shown in Figure 3.

As shown in the ground class summaries for cut-and-cover tunnels in Table 7 and Table 12, which are based on information in the GDR and the 20% alignment current as of December 20, 2019, more than half (53 percent) of the excavation in Reach 9 will be in Alluvium, with significant excavation in Fill (26 percent) and “Weathered Rock” (17 percent).

As shown in Figure 4H, the invert in Reach 9 nearly coincides with the top of rock or is up to 5 feet above the top of rock. Consequently, the data indicate that about 5 percent of excavation in Reach 9 will be in Ground Class L-II limestone.

Geotechnical properties of Overburden, “Weathered Rock,” and Rock ground classes are discussed in Sections 7.1, 7.2, and 7.3.

8.9.3 GROUNDWATER CONDITIONS

A groundwater level measurement taken during drilling from one boring (T-112) is available for Reach 9.

As shown in the geologic profile in Figure 4-H, the water level measured during drilling of boring T-112, as reported in the GDR, was 19 feet below the ground surface, corresponding to a water level within Overburden at about elevation 448.5 feet, about 15.5 feet above top of rock.

8.10 Reach 10 (East Portal)

8.10.1 PROPOSED STRUCTURE(S)

The proposed structure to be constructed within Reach 10 consists of a 595-foot length of U-wall retained cut from Station 101+65 to 107+60, based on the 20% alignment current as of December 20, 2019. The depth of the proposed excavation ranges from about 28 feet at the western limit to about 6 feet at the eastern limit, as shown in Figures 4-H and 4-I.

8.10.2 GROUND CLASSES, ROCK TYPES, AND ROCK MASS PROPERTIES

One DART D2 boring has been drilled within Reach 10, as shown in Figure 3.

As shown in the ground class summaries for portal excavations in Table 6 and Table 11, which are based on information in the GDR and the 20% alignment current as of December 20, 2019, about 71 percent of the volume to be excavated in Reach 10 will be Alluvium. The remaining portion will be excavated in Fill (29 percent). Based on the geologic profile in Figure 4-H which interpolates data between borings, some IGM ("Weathered Rock") will also be encountered at the far western end of the reach near the excavation invert.

Geotechnical properties of Overburden, "Weathered Rock," and Rock ground classes are discussed in Sections 7.1, 7.2, and 7.3.

8.10.3 GROUNDWATER CONDITIONS

A groundwater level measurement taken during drilling from one boring (P-102) is available for Reach 10.

As shown in the geologic profile in Figure 4-H, the water level measured during drilling of boring P-102, as reported in the GDR, was 14.0 feet below the ground surface, corresponding to a water level within Overburden at about elevation 455.6 feet, about 7 feet above top of rock.

9 RECOMMENDATIONS FOR 20% DESIGN

9.1 Selection of Geotechnical Parameters for Design

Descriptions and preliminary recommendations for geotechnical properties to be used for design in this memorandum are based on DART D2 data available as of August 29, 2019, and 20% design project alignment and configuration current as of December 20, 2019. These descriptions and recommendations will be confirmed or refined based on site-specific data, updated project design, and selected approach for risk management.

9.2 Underground Alignment Reaches

Definition of underground reaches for preliminary design is summarized in Table 1.

9.3 Ground Classes and Distribution

The preliminary design distribution of ground classes by reach is summarized in Table 11 for portal excavations, in Table 12 for cut-and-cover excavations, and in Table 13 for SEM excavations. Table 5 provides an overall summary for all DART D2 underground excavations.

9.4 Mixed-Face and/or Mixed Ground Excavation

Open-cut excavations for U-wall portals will be primarily in Overburden, with up to about 2 feet of localized rock excavation possible near the invert.

All cut-and-cover excavations will be in both Rock and Overburden.

All SEM excavations will be entirely in Rock

9.5 Soil Parameters

Preliminary recommended geotechnical design parameters for DART D2 soils are presented in Table 14.

9.6 "Weathered Rock" Parameters

Table 15 presents preliminary recommended geotechnical design parameters for the Intermediate Geomaterials (IGM) at the overburden-rock transition, described as "weathered rock" on boring logs. This material will require special assessment for selection of location-specific geotechnical parameters for design.

9.7 Rock Parameters

9.7.1 ROCK TYPES AND DISTRIBUTION

Preliminary design distribution of DART D2 rock types is included in Tables 11, 12, and 13.

9.7.2 INTACT ROCK PARAMETERS

Table 16 presents preliminary recommended design values for DART D2 intact rock properties based on data in the DART D2 GDR (GPC6, 2019), supplemented by data from Lachel Felice, 2006. These values should be updated as additional project-specific data become available. Median values were selected for preliminary design.

9.7.3 ROCK MASS PARAMETERS

Few quantitative data on rock mass properties are available. Based on boring logs in the GDR and published information, three joint sets are likely to be present along the alignment: a near-horizontal set along bedding and two near-vertical sets. Small-displacement faults also occur in sets, dipping 30 to 40 degrees and 45 to 60 degrees in opposite directions. No major fault zones are known to intersect the DART D2 alignment.

No quantitative information on orientation ranges, persistence, or shear strength for joint sets or faults sets is available.

Table 26 summarizes preliminary ranges of GSI for development of rock mass mechanical properties, based on the limited available data.

9.8 Groundwater Parameters

No data are available for hydraulic properties of project-area Fill, Alluvium, or “Weathered Rock.”

No project-specific data are available for hydraulic properties of the limestone and shale rock along the alignment. As discussed in Section 7.4, hydraulic conductivity in DART D2 limestone is expected to range from zero to 2.6 x 10-5 cm/sec. Based on the limited data available, the preliminary recommended design value for hydraulic conductivity in limestone is 1.8 x 10-6 cm/sec. The preliminary recommended design value for hydraulic conductivity in shale is 2.2 x 10-7 cm/sec. Hydraulic conductivity will be highest along bedding planes and open fractures in rock and in granular overburden. In both rock types, fast-flow paths are anticipated along faults and along the limestone-shale contact.

Preliminary design groundwater levels along the DART D2 underground alignment are shown in the general geologic profile in Figures 4-A through 4-I. Groundwater levels range from about 4 feet to 30 feet below the ground surface and are typically within Overburden, although deeper levels were recorded for wells sealed in rock.

10 CONSTRUCTION CONSIDERATIONS

The following sections discuss preliminary understanding of geotechnical ground conditions to be considered for construction planning and execution, based on geotechnical data in the GDR (GPC6, 2019) and the 20% design alignment and configuration current as of December 20, 2019. Both design and construction considerations are discussed in greater detail in other topic-specific Geotechnical Design Memoranda.

10.1 Sources of Uncertainty

Subsurface conditions encountered during construction may differ from those anticipated based on results of investigations. The primary sources of uncertainty are:

- The multiple stages and levels of terrace deposits overlying river alluvium and residual soil.
- The location, orientation, and spacing of joint sets and sets of faults with small scale displacements which occur in clusters at various locations and orientations in the Dallas area.

- The depth and thickness of bentonite layers within the Austin Chalk and the Eagle Ford Shale.
- Engineering properties of "Weathered Rock" encountered in DART D2 borings.
- Site-specific groundwater conditions, due to variability of both Overburden and Rock, possible locally confined conditions, possible zones of high transmissivity, and possible groundwater contamination.

10.2 Other Construction Considerations

10.2.1 CONSTRUCTION IN OVERBURDEN

Although the residual soils of the Eagle Ford Shale present the most significant problems with expansive soils in the region, expansive soils are present in overburden throughout the DART D2 area. Potentially high swell pressures need to be considered for design loading and in construction of station walls in clayey soils.

Overburden stratigraphy is variable. Excavations through overburden, some of which will have rock in the invert, may require a combination of support methods for slope and sidewall excavation to ensure stability and water tightness.

Buried debris should be anticipated within fill and could be obstructions for surface-based excavation.

Excavation of shafts or open cuts in the cohesionless alluvial deposits of Ground Class A2 will require dewatering or support of excavation to maintain stability.

10.2.2 CONSTRUCTION IN ROCK

Orientations of vertical joint sets, bedding planes joints, and small-displacement faults forming graben structures may allow formation of potentially unstable rock wedges if a single plane or the line of intersection of two or more planes daylights at the excavation crown or side walls. The sets of faults observed in Reach 3 and Reach 5 at proposed Metro Center and Commerce Stations could form potential rock wedges at these locations. Especially in combination with a horizontal zone of high permeability or increased surface loading, rock wedges which are potentially unstable can result in a major slide in the presence of a sudden heavy rain or additional loading.

If the regionally identified joint set striking N65E is present along the proposed DART D2 alignment, it will be oblique to the long axis of Commerce Station and could potentially affect stability of station or shaft sidewalls, depending on the orientation of other rock mass discontinuities.

The bentonite layers scattered across the site are sub-horizontal, parallel to bedding, and have very low shear strength, especially when wet. They will act as preferred sliding surfaces unless the rock mass is stabilized.

The laterally-continuous Bentonite Marker Bed is believed to be present near the eastern end of the alignment. Boring logs in the GDR show it to be about just below the proposed CBD East Station invert level. If its presence is confirmed, special care in construction or mitigation through design will be necessary to manage invert heave or accelerated invert deterioration during construction.

Both the Eagle Ford Shale and the argillaceous middle part of the Austin Chalk are susceptible to slaking and deterioration upon exposure to air and water. This slaking can result in loosening which causes slabbing along bedding planes at excavated surfaces. A protective sealant or shotcrete applied soon after excavation can reduce this risk.

Solutioning has not been reported in draft boring logs. However, its presence cannot be precluded.

Only limited excavation is anticipated in the Eagle Ford Shale. However, there are several construction considerations specific to that formation.

- Metro Center Station, to be constructed by cut-and-cover method in Reach 3, and the SEM tunnels to be constructed in Reach 4 will have their inverts in softer Eagle Ford Shale and their crowns in Austin Chalk limestone. Special attention will be required during construction to maintain the alignment excavation as the inverts will likely tend to heave. Ponded water at the shale invert in Reaches 3 and 4 will also accelerate deterioration due to construction traffic.
- Gypsum crystals have been reported in the Eagle Ford shale (Lachel Felice, 2006; DPG, 1941). Gypsum dissolves rapidly, especially if native groundwater pH is altered during to construction. Depending on gypsum extent and distribution, such dissolution can lead to subsidence or sudden collapse.
- Hard limestone layers, concretions, and marcasite nodules can create unexpected zones of resistance in the otherwise soft shale matrix.

10.2.3 ROCK COVER

As shown in Figures 4-E and 4-F, rock cover above proposed SEM tunnel excavations ranges from about 19 feet to 50 feet in Reach 4 and 53 to 9.5 feet in Reach 6. Rock cover above the proposed crown of the Commerce Station cavern ranges from 40 feet to 47 feet.

Construction approaches will need to include methods to reduce the risk of unstable excavations, raveling or running ground, and voids or overbreak ahead of the excavation face.

10.2.4 GROUNDWATER CONDITIONS

Groundwater inflows at retained excavations in Fill, Alluvium, “Weathered Rock”, and along the top of rock surface may be unpredictable, and locally high groundwater inflows should be expected.

Localized zones of high groundwater inflow should be anticipated within overburden. Permeable sand and gravel of Ground Class A2 may be irregularly intermixed with less permeable fine-grained soils of Ground Class A1. If the water table is within Alluvium, sudden inflows of high volumes of groundwater during tunnel, cross passage, or station construction could affect stability of the excavation face or cut-and-cover construction.

Measures to control groundwater inflow in surface excavations may need to be extended through overburden into rock.

For open excavations, groundwater must be controlled to minimize erosion and piping of soil particles into the excavation. The seepage will occur through the permeable terrace deposits and also along the top of the rock surface.

Groundwater inflows in rock excavations will largely depend on the spacing, aperture, and connectivity of fractures in the rock. The highest inflows are likely to be from fractured zones. A hydraulic connection through rock to a sustained groundwater recharge source is not evident, and so inflows in rock excavations could be of only limited duration. Groundwater control measures may need to be modified from designed measures to accommodate actual site conditions.

Information on potentially hazardous contaminants in groundwater or soil is not yet available but would be a consideration when planning for disposal of construction groundwater and potential chemical effects on project structures.

10.2.5 SUBSURFACE GASES

Potentially hazardous explosive gases could be encountered during construction, based on previous DART underground construction excavation in the Austin Chalk. A hazardous condition could result if equipment and methods are not designed to meet code requirements for gassy conditions.

The presence of marcasite, pyrite, and gypsum in rock along the alignment imply acidic groundwater, possibly with hydrogen sulfide, a colorless, flammable, extremely hazardous gas with a “rotten egg” smell.

10.2.6 MUCKING

The montmorillonitic clays in the Austin Chalk and the Eagle Ford Shale will expand to many times their original volume if re-wetted after drying out. Clogging of excavation equipment could be one consequence of this rock-water interaction. Such clays can affect tunnel mucking by clogging muck buckets and adhering to muck cars or conveyors, reducing TBM productivity. Potential lubricating, expansive, and dispersive properties of tunnel muck rich in expansive clays will require special consideration for handling and disposal.

10.2.7 EAST PORTAL CONSTRUCTION

The means and methods for temporary shoring and other structural considerations during design and construction of East Portal under IH-345 (Reach 10) will require coordination between the final designer and Texas Department of Transportation (TxDOT). Specific logistical issues to be addressed include existing bridge columns located near planned East Portal construction.

10.2.8 EXISTING UTILITIES AT PLANNED COMMERCE STATION

SEM excavations in rock for planned Commerce Station will require installation of an excavation support system, including rock bolts which will extend upward and outward from excavations. Rock bolt lengths may require modification to avoid potential damage to the existing storm sewer and other utilities overlying the tunnel alignment under Commerce Street. Similar adjustments may be required for proposed passenger/ventilation adits at Commerce Station.

10.2.9 RETAINING WALLS

Retaining wall heights should be coordinated with TxDOT to ensure that all wall heights are compatible and can accommodate future street crossings.

Based on available project-specific geotechnical information in the GDR (GPC6, 2019) and currently known site constraints, retaining wall systems for retained (U-wall) portals and headwall structures, as well as for proposed shafts for station entrances and ventilation structures, should consider:

- use of non-driven/pre-drilled elements for support-of excavation (SOE) systems to mitigate potential noise and vibration damage impacts on nearby existing structures at future portal cut and shaft excavation locations
- use of internal bracing support systems to accommodate limited existing roadway right-of-way and avoid easement requirements associated with tieback anchor systems

10.2.10 DEWATERING

The acceptable level of dewatering should be determined by site -specific construction impact evaluation and will vary by location, site-specific ground conditions, and type of existing structures potentially affected. For planned cut-and-cover construction, use of rigid SOE systems, such as slurry walls or secant-pile walls, keyed into top of rock with grouted groundwater cut-off, can mitigate potential damage to existing building foundations susceptible to dewatering-induced settlement.

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TABLES

Table 1. DART D2 Underground Alignment Reach Descriptions

Reach [1]	Proposed Structures [2]	General Ground Conditions within Proposed Excavation	Approximate Stationing		Approximate length along alignment, ft
			From	to	
1	West Portal (U-Wall)	Overburden and rock	35+30	41+50	620
2	Tunnel (Cut-and-Cover)	Overburden and rock	41+50	49+27	777
3	Metro Center Station (Cut-and-Cover)	Overburden and rock	49+27	54+22	495
4	Tunnel (SEM) Cross Passage 1 Pump/Sump Room	All rock	54+22	68+05	1,383
5	Commerce Station (SEM)	All rock	68+05	75+26	721
6	Tunnel (SEM) Cross Passage 2	All rock	75+26	86+30	1,104
7	Tunnel (Cut-and-Cover)	Overburden and rock	86+30	93+13	683
8	CBD East Station (Cut-and-Cover)	Overburden and rock	93+13	98+05	492
9	Tunnel (Cut-and-Cover)	Overburden and rock	98+05	101+65	360
10	East Portal (U-Wall)	All overburden	101+65	107+60	595
					7,230

NOTES:

(1) Reaches were defined based on locations of proposed structures and anticipated construction.

(2) Proposed structures, alignment, and stationing are current as of December 20, 2019.

Table 2. International Society for Rock Mechanics (ISRM) Weathering Grades

Term	Description	Grade
Fresh	No visible sign of rock material weathering; perhaps slight discoloration on major discontinuity surfaces.	I
Slightly weathered	Discoloration indicates weathering of rock material and discontinuity surfaces. All the rock material may be discolored by weathering and may be somewhat weaker externally than in its fresh condition.	II
Moderately weathered	Less than half of the rock material is decomposed and/or disintegrated to a soil. Fresh or discolored rock is present either as a continuous framework or as corestones.	III
Highly weathered	More than half of the rock material is decomposed and/or disintegrated to a soil. Fresh or discolored rock is present either as a discontinuous framework or as corestones.	IV
Completely weathered	All rock material is decomposed and/or disintegrated to a soil. The original mass structure is still largely intact.	V
Residual soil	All rock material is converted to soil. The mass structure and material fabric are destroyed. There is a large change in volume, but the soil has not been significantly transported.	VI

NOTE:

From International Society for Rock Mechanics, 1981. “Suggested Methods for the Quantitative Description of Discontinuities in Rock Masses,” *in ISRM Suggested Methods: Rock Characterization, Testing and Monitoring*, E. T. Brown, editor, Pergamon Press, Oxford, p. 31.

Table 3. DART D2 Ground Classification System

	Ground Class Group	Ground Class	Distinguishing Characteristics [1]
Overburden	Fill	F	• Intermixed stiff to hard and from dark brown to tan clay with varying amounts of sand and silt with traces of gravel, brick, concrete, and limestone fragments
	Alluvium	A1	• Cohesive alluvium; low to high plastic clays and sandy and silty clays, and sandy clay
		A2	• Granular alluvium; mostly cohesionless material ranging from silty sands to sand and gravel and clayey sand
	Residual Soil	RS	• "Residual Soil" overlying Austin Chalk; completely decomposed limestone that exhibits a rock-like fabric (as described by Huitt-Zollars, 1992). Note: *Not truly residual soil, which has no relict rock structure.* • All rock material is converted to soil • Recovered with soil sampling equipment; drive samples generally possible • No visible rock fabric or structure
Weathered Rock	"Weathered Rock"	IGM	• Highly to completely weathered limestone or shale (ISRM Weathering Grades IV and V) • Rock core Recovery <50%; SPT N>50/6" • Original rock mass structure largely intact • Includes Fish Bed Conglomerate, basal pebbly beds, reworked fossils and pebble-to cobble-size fragments of chalky limestone (HNTB, 2016, D2 Geotech Report) • Includes transitional arenaceous, fossiliferous zone (Collier, 2015) • Includes tan, highly weathered limestone of variable thickness; very soft to soft with occasional to frequent interbeds of tan silty clay and clay seams (Huitt-Zollars, 1992) • More than half of the rock material matrix is weathered to a soil (Weathering Grade IV) or all rock material is decomposed and disintegrated to soil (Weathering Grade V) • Fresh or discolored rock is present either as a discontinuous framework or as corestones (Weathering Grade IV)
Rock	III	L-III and S-III	• L-III: Predominantly limestone with some shale • S-III: Predominantly shale with some limestone, mudstone, and sandstone • Generally, Recovery >50%; RQD<50% • Slightly to moderately weathered rock (ISRM Weathering Grade II to III), and • Fracture spacing less than 2 feet [2], or • Multiple sets of slickensided, polished fracture surfaces, or • Multiple planar weakness zones with fillings of disintegrated rock or alteration products less than 6 inches thick, or • A single planar weakness zone with filling greater than 6 inches thick, or • Less than half of the rock material matrix is weathered to a soil • Moderately blocky to very blocky and seamy [3]
	II	L-II and S-II	• L-II: Predominantly limestone with some shale • S-II: Predominantly shale with some limestone, mudstone, and sandstone • Generally, RQD = 50% to 90% • Fracture spacing 2 to 6 feet [2], or • One set of slickensided, polished fracture surfaces present within the excavation horizon, or • One planar weakness zone containing clay or disintegrated rock, with a thickness of disintegrated rock or alteration products less than 6 inches • Moderately blocky [3]
	I	L-I and S-I	• L-I: Predominantly limestone with some shale • S-I: Predominantly shale with some limestone, mudstone, and sandstone • Generally, RQD > 90% • Fracture spacing greater than 6 feet [2], and • Joint surfaces range from rough or irregular to smooth and planar, and • Fracture surfaces are unaltered to slightly altered, with non-softening mineral coatings, and • No obvious planar weakness zones with alteration products • Massive to moderately jointed [3]
	Bentonite	B	• Bentonite and bentonitic shale in vertical thickness >/= 6 inches

NOTES:
(1) ISRM Weathering Grades are from International Society for Rock Mechanics, 1981, "Suggested Methods for the Quantitative Description of Discontinuities in Rock Masses," in *ISRM Suggested Methods: Rock Characterization, Testing and Monitoring*, E. T. Brown, editor, Pergamon Press, Oxford, p. 31.
(2) For fractures with minimum persistence of 3 feet.
(3) Terzaghi rock mass description from Proctor, R. V. and T L. White, 1968, *Rock Tunneling with Steel Supports, Revised*, Commercial Shearing and Stamping Company, Youngstown, Ohio.

Table 4. Ground Classes for Excavation Horizons, by Boring and Reach

Reach	Proposed Structures	No. of Borings	Reach Length, ft	Excavation Horizon Thickness, ft	Borings	Percentage of Ground Class Within Excavation Horizon											
						F	A1	A2	RS	IGM	L-III	S-III	L-II	S-II	L-I	S-I	B
1	West Portal (U-Wall)	3	620	15.8	T-1	44.8%	0.0%	55.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
					T-5*	2.8%	25.0%	72.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
					T-6*	15.1%	30.1%	54.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	Tunnel (Cut-and-Cover)	2	777	48.4	T-102*	4.8%	36.7%	30.3%	0.0%	9.6%	0.0%	0.0%	1.1%	0.0%	17.5%	0.0%	0.0%
					T-103	5.4%	20.0%	16.3%	0.0%	5.4%	0.0%	0.0%	0.0%	0.0%	52.8%	0.0%	0.0%
3	Metro Center Station (Cut-and-Cover)	3	495	67.8	TS-13A*	4.4%	11.8%	18.4%	0.0%	2.2%	0.0%	0.0%	0.0%	5.2%	46.5%	11.5%	0.0%
					B-1	2.2%	14.0%	20.6%	0.0%	8.8%	0.0%	0.0%	0.0%	2.9%	51.5%	0.0%	0.0%
					TS-104	1.4%	7.9%	23.1%	0.0%	3.6%	0.0%	0.0%	7.2%	0.0%	45.5%	11.1%	0.0%
4	Tunnel (SEM)	1	1383	22.2	T-201	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	18.5%	19.4%	62.2%	0.0%	0.0%
5	Commerce Station (SEM)	2	721	44.0	TS-202	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.0%	0.0%	97.0%	0.0%	0.0%
					B-3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%
6	Tunnel (SEM)	2	1104	22.2	T-203	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%
					T-204	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	50.8%	0.0%	49.2%	0.0%	0.0%
7	Tunnel (Cut-and-Cover)	3	683	45.6	T-205*	0.0%	43.0%	2.6%	0.0%	16.2%	0.0%	0.0%	7.7%	0.0%	30.5%	0.0%	0.0%
					TS-207	5.1%	43.1%	0.0%	0.0%	4.2%	0.0%	0.0%	16.9%	0.0%	30.7%	0.0%	0.0%
					TS-208	20.7%	5.2%	0.0%	0.0%	12.9%	0.0%	0.0%	0.0%	0.0%	61.2%	0.0%	0.0%
8	CBD East Station (Cut-and-Cover)	2	492	35.5	TS-206*	7.5%	58.7%	7.5%	0.0%	2.5%	0.0%	0.0%	13.7%	0.0%	7.1%	0.0%	3.0%
					TS-209	8.7%	76.8%	14.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
9	Tunnel (Cut-and-Cover)	1	360	34.2	T-112	26.3%	52.5%	0.0%	0.0%	16.6%	0.0%	0.0%	4.6%	0.0%	0.0%	0.0%	0.0%
10	East Portal (U-Wall)	1	595	13.0	P-102	29.4%	70.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Total		20	7,230														

Reaches	Proposed Structures	Total Length, ft
1, 10	Portals (U-Walls)	1,215
2, 7, 9	Cut-and-Cover Tunnels	1,820
4, 6	SEM Tunnels	2,487
3, 8	Cut-and-Cover Stations	987
5	SEM Station	721
		7,230

NOTES:

(1) Borings more than 400 ft from proposed excavation limits were not included.

(2) Proposed excavation horizon for portal U-wall retained excavations and cut-and-cover reaches for tunnels, and stations extends from invert to ground surface (Reaches 1, 2, 3, 7, 8, 9, and 10).

(3) Thickness of excavation horizon for U-wall retained excavation reaches and cut-and-cover reaches is taken as thickness at longitudinal midpoint of reach (Reaches 1, 2, 3, 7, 8, 9, and 10).

(4) Thickness of excavation horizon for SEM tunnels is taken as 22.2 feet (Reaches 4 and 6).

(5) Thickness of excavation horizon for SEM station (Commerce Station) is taken as 44 ft (Reach 5) over its full length.

(6) Alignment and configuration are current as of 12/20/2019.

Table 5. Ground Classes for Excavations, by Reach and Overall

Ground Class	Percent Volume	Reach 1	2	3	4	5	6	7	8	9	10	Percent Volume of All Excavation		Ground Class Group	Percent Volume, All Excavation	General Ground Class Group	Percent Volume, All Excavation
F	Max	44.8%	5.4%	4.4%	0.0%	0.0%	0.0%	20.7%	8.7%	26.3%	29.4%	Max	44.8%	Fill	7.6%	Overburden	42.0%
	Min	2.8%	4.8%	1.4%	0.0%	0.0%	0.0%	0.0%	7.5%	26.3%	29.4%	Min	0.0%				
	Median	15.1%	5.1%	2.2%	0.0%	0.0%	0.0%	5.1%	8.1%	26.3%	29.4%	Median	5.1%				
	Total	20.9%	5.1%	2.7%	0.0%	0.0%	0.0%	8.6%	8.1%	26.3%	29.4%	Total	7.6%				
A1	Max	30.1%	36.7%	14.0%	0.0%	0.0%	0.0%	43.1%	76.8%	52.5%	70.6%	Max	76.8%	Alluvium	31.3%		
	Min	0.0%	20.0%	7.9%	0.0%	0.0%	0.0%	5.2%	58.7%	52.5%	70.6%	Min	0.0%				
	Median	25.0%	28.3%	11.8%	0.0%	0.0%	0.0%	43.0%	67.7%	52.5%	70.6%	Median	26.7%				
	Total	18.4%	28.3%	11.2%	0.0%	0.0%	0.0%	30.4%	67.7%	52.5%	70.6%	Total	21.3%				
A2	Max	72.2%	30.3%	23.1%	0.0%	0.0%	0.0%	2.6%	14.5%	0.0%	0.0%	Max	72.2%				
	Min	54.8%	16.3%	18.4%	0.0%	0.0%	0.0%	0.0%	7.5%	0.0%	0.0%	Min	0.0%				
	Median	55.2%	23.3%	20.6%	0.0%	0.0%	0.0%	0.0%	11.0%	0.0%	0.0%	Median	0.0%				
	Total	60.7%	23.3%	20.7%	0.0%	0.0%	0.0%	0.9%	11.0%	0.0%	0.0%	Total	10.0%				
RS	Max	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	Max	0.0%	Residual Soil	0.0%		
	Min	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	Min	0.0%				
	Median	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	Median	0.0%				
	Total	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	Total	0.0%				
IGM	Max	0.0%	9.6%	8.8%	0.0%	0.0%	0.0%	16.2%	2.5%	16.6%	0.0%	Max	16.6%	"Weathered Rock"	3.1%		
	Min	0.0%	5.4%	2.2%	0.0%	0.0%	0.0%	4.2%	0.0%	16.6%	0.0%	Min	0.0%				
	Median	0.0%	7.5%	3.6%	0.0%	0.0%	0.0%	12.9%	1.2%	16.6%	0.0%	Median	0.6%				
	Total	0.0%	7.5%	4.9%	0.0%	0.0%	0.0%	11.1%	1.2%	16.6%	0.0%	Total	3.1%				
L-III	Max	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	Max	0.0%	III	0.0%	Rock	58.0%
	Min	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	Min	0.0%				
	Median	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	Median	0.0%				
	Total	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	Total	0.0%				
S-III	Max	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	Max	0.0%				
	Min	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	Min	0.0%				
	Median	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	Median	0.0%				
	Total	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	Total	0.0%				
L-II	Max	0.0%	1.1%	7.2%	18.5%	3.0%	50.8%	16.9%	13.7%	4.6%	0.0%	Max	50.8%	II	13.1%		
	Min	0.0%	0.0%	0.0%	18.5%	0.0%	0.0%	0.0%	0.0%	4.6%	0.0%	Min	0.0%				
	Median	0.0%	0.6%	0.0%	18.5%	1.5%	25.4%	7.7%	6.9%	4.6%	0.0%	Median	3.1%				
	Total	0.0%	0.6%	2.4%	18.5%	1.5%	25.4%	8.2%	6.9%	4.6%	0.0%	Total	9.3%				
S-II	Max	0.0%	0.0%	5.2%	19.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	Max	19.4%				
	Min	0.0%	0.0%	0.0%	19.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	Min	0.0%				
	Median	0.0%	0.0%	2.9%	19.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	Median	0.0%				
	Total	0.0%	0.0%	2.7%	19.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	Total	3.9%				
L-I	Max	0.0%	52.8%	51.5%	62.2%	100.0%	100.0%	61.2%	7.1%	0.0%	0.0%	Max	100.0%	I	44.8%		
	Min	0.0%	17.5%	45.5%	62.2%	97.0%	49.2%	30.5%	0.0%	0.0%	0.0%	Min	0.0%				
	Median	0.0%	35.2%	46.5%	62.2%	98.5%	74.6%	30.7%	3.5%	0.0%	0.0%	Median	33.0%				
	Total	0.0%	35.2%	47.8%	62.2%	98.5%	74.6%	40.8%	3.5%	0.0%	0.0%	Total	44.3%				
S-I	Max	0.0%	0.0%	11.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	Max	11.5%				
	Min	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	Min	0.0%				
	Median	0.0%	0.0%	11.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	Median	0.0%				
	Total	0.0%	0.0%	7.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	Total	0.5%				
B	Max	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.0%	0.0%	0.0%	Max	3.0%	Bentonite	0.1%		
	Min	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	Min	0.0%				
	Median	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.5%	0.0%	0.0%	Median	0.0%				
	Total	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.5%	0.0%	0.0%	Total	0.1%				
															100.0%		100.0%

NOTES:

(1) Data from borings more than 400 ft from proposed excavation limits were not included.

(2) Alignment and configuration are current as of 12/20/2019.

Table 6. Ground Classes for Portal U-Wall Retained Excavations, by Reach and Overall

Ground Class	Reach: Percent Volume	Reach: 1	Reach: 10	Percent Volume of Portal Excavation		Ground Class Group	Percent Volume, All Portal Excavation	General Ground Class Group	Percent Volume, All Portal Excavation
F	Max	44.8%	29.4%	Max	44.8%	Fill	25.1%	Overburden	100.0%
	Min	2.8%	29.4%	Min	2.8%				
	Median	15.1%	29.4%	Median	22.2%				
	Total	20.9%	29.4%	Total	25.1%				
A1	Max	30.1%	70.6%	Max	70.6%	Alluvium	74.9%		
	Min	0.0%	70.6%	Min	0.0%				
	Median	25.0%	70.6%	Median	47.8%				
	Total	18.4%	70.6%	Total	44.0%				
A2	Max	72.2%	0.0%	Max	72.2%				
	Min	54.8%	0.0%	Min	0.0%				
	Median	55.2%	0.0%	Median	27.6%				
	Total	60.7%	0.0%	Total	31.0%				
RS	Max	0.0%	0.0%	Max	0.0%	Residual Soil	0.0%		
	Min	0.0%	0.0%	Min	0.0%				
	Median	0.0%	0.0%	Median	0.0%				
	Total	0.0%	0.0%	Total	0.0%				
IGM	Max	0.0%	0.0%	Max	0.0%	"Weathered Rock"	0.0%		
	Min	0.0%	0.0%	Min	0.0%				
	Median	0.0%	0.0%	Median	0.0%				
	Total	0.0%	0.0%	Total	0.0%				
L-III	Max	0.0%	0.0%	Max	0.0%	III	0.0%	Rock	0.0%
	Min	0.0%	0.0%	Min	0.0%				
	Median	0.0%	0.0%	Median	0.0%				
	Total	0.0%	0.0%	Total	0.0%				
S-III	Max	0.0%	0.0%	Max	0.0%				
	Min	0.0%	0.0%	Min	0.0%				
	Median	0.0%	0.0%	Median	0.0%				
	Total	0.0%	0.0%	Total	0.0%				
L-II	Max	0.0%	0.0%	Max	0.0%	II	0.0%		
	Min	0.0%	0.0%	Min	0.0%				
	Median	0.0%	0.0%	Median	0.0%				
	Total	0.0%	0.0%	Total	0.0%				
S-II	Max	0.0%	0.0%	Max	0.0%				
	Min	0.0%	0.0%	Min	0.0%				
	Median	0.0%	0.0%	Median	0.0%				
	Total	0.0%	0.0%	Total	0.0%				
L-I	Max	0.0%	0.0%	Max	0.0%	I	0.0%		
	Min	0.0%	0.0%	Min	0.0%				
	Median	0.0%	0.0%	Median	0.0%				
	Total	0.0%	0.0%	Total	0.0%				
S-I	Max	0.0%	0.0%	Max	0.0%				
	Min	0.0%	0.0%	Min	0.0%				
	Median	0.0%	0.0%	Median	0.0%				
	Total	0.0%	0.0%	Total	0.0%				
B	Max	0.0%	0.0%	Max	0.0%	Bentonite	0.0%		
	Min	0.0%	0.0%	Min	0.0%				
	Median	0.0%	0.0%	Median	0.0%				
	Total	0.0%	0.0%	Total	0.0%				

NOTES:
(1) Data from borings more than 400 ft from proposed excavation limits were not included
(2) Proposed excavation horizon for portal U-wall retained excavations extends from invert to ground surface.
(3) Alignment and configuration are current as of 12/20/2019.

Table 7. Ground Classes for Cut-and-Cover Tunnel Excavation, by Reach and Overall

Ground Class	Reach				Percent Volume of C&C Tunnel Excavation		Ground Class Group	Percent Volume, C&C Tunnel Excavation	General Ground Class Group	Percent Volume, C&C Tunnel Excavation
	Percent Volume	2	7	9						
F	Max	5.4%	20.7%	26.3%	Max	26.3%	Fill	10.6%	Overburden	65.4%
	Min	4.8%	0.0%	26.3%	Min	0.0%				
	Median	5.1%	5.1%	26.3%	Median	5.1%				
	Total	5.1%	8.6%	26.3%	Total	10.6%				
A1	Max	36.7%	43.1%	52.5%	Max	52.5%	Alluvium	44.2%		
	Min	20.0%	5.2%	52.5%	Min	5.2%				
	Median	28.3%	43.0%	52.5%	Median	43.0%				
	Total	28.3%	30.4%	52.5%	Total	33.9%				
A2	Max	30.3%	2.6%	0.0%	Max	30.3%				
	Min	16.3%	0.0%	0.0%	Min	0.0%				
	Median	23.3%	0.0%	0.0%	Median	0.0%				
	Total	23.3%	0.9%	0.0%	Total	10.3%				
RS	Max	0.0%	0.0%	0.0%	Max	0.0%	Residual Soil	0.0%		
	Min	0.0%	0.0%	0.0%	Min	0.0%				
	Median	0.0%	0.0%	0.0%	Median	0.0%				
	Total	0.0%	0.0%	0.0%	Total	0.0%				
IGM	Max	9.6%	16.2%	16.6%	Max	16.6%	"Weathered Rock"	10.7%		
	Min	5.4%	4.2%	16.6%	Min	4.2%				
	Median	7.5%	12.9%	16.6%	Median	12.9%				
	Total	7.5%	11.1%	16.6%	Total	10.7%				
L-III	Max	0.0%	0.0%	0.0%	Max	0.0%	III	0.0%	Rock	34.6%
	Min	0.0%	0.0%	0.0%	Min	0.0%				
	Median	0.0%	0.0%	0.0%	Median	0.0%				
	Total	0.0%	0.0%	0.0%	Total	0.0%				
S-III	Max	0.0%	0.0%	0.0%	Max	0.0%				
	Min	0.0%	0.0%	0.0%	Min	0.0%				
	Median	0.0%	0.0%	0.0%	Median	0.0%				
	Total	0.0%	0.0%	0.0%	Total	0.0%				
L-II	Max	1.1%	16.9%	4.6%	Max	16.9%	II	4.2%		
	Min	0.0%	0.0%	4.6%	Min	0.0%				
	Median	0.6%	7.7%	4.6%	Median	4.6%				
	Total	0.6%	8.2%	4.6%	Total	4.2%				
S-II	Max	0.0%	0.0%	0.0%	Max	0.0%				
	Min	0.0%	0.0%	0.0%	Min	0.0%				
	Median	0.0%	0.0%	0.0%	Median	0.0%				
	Total	0.0%	0.0%	0.0%	Total	0.0%				
L-I	Max	52.8%	61.2%	0.0%	Max	61.2%	I	30.3%		
	Min	17.5%	30.5%	0.0%	Min	0.0%				
	Median	35.2%	30.7%	0.0%	Median	30.7%				
	Total	35.2%	40.8%	0.0%	Total	30.3%				
S-I	Max	0.0%	0.0%	0.0%	Max	0.0%				
	Min	0.0%	0.0%	0.0%	Min	0.0%				
	Median	0.0%	0.0%	0.0%	Median	0.0%				
	Total	0.0%	0.0%	0.0%	Total	0.0%				
B	Max	0.0%	0.0%	0.0%	Max	0.0%	Bentonite	0.0%		
	Min	0.0%	0.0%	0.0%	Min	0.0%				
	Median	0.0%	0.0%	0.0%	Median	0.0%				
	Total	0.0%	0.0%	0.0%	Total	0.0%				

NOTES:

(1) Data from borings more than 400 ft from proposed excavation limits were not included.

(2) Proposed excavation horizon for cut-and-cover tunnels extends from invert to ground surface.

(3) Alignment and configuration are current as of 12/20/2019.

Table 8. Ground Classes for SEM Tunnel Excavation, by Reach and Overall

Ground Class	Reach			Percent Volume of SEM Tunnel Excavation		Ground Class Group	Percent Volume, SEM Tunnel Excavation	General Ground Class Group	Percent Volume, SEM Tunnel Excavation
	Percent Volume	4	6						
F	Max	0.0%	0.0%	Max	0.0%	Fill	0.0%	Overburden	0.0%
	Min	0.0%	0.0%	Min	0.0%				
	Median	0.0%	0.0%	Median	0.0%				
	Total	0.0%	0.0%	Total	0.0%				
A1	Max	0.0%	0.0%	Max	0.0%	Alluvium	0.0%		
	Min	0.0%	0.0%	Min	0.0%				
	Median	0.0%	0.0%	Median	0.0%				
	Total	0.0%	0.0%	Total	0.0%				
A2	Max	0.0%	0.0%	Max	0.0%				
	Min	0.0%	0.0%	Min	0.0%				
	Median	0.0%	0.0%	Median	0.0%				
	Total	0.0%	0.0%	Total	0.0%				
RS	Max	0.0%	0.0%	Max	0.0%	Residual Soil	0.0%		
	Min	0.0%	0.0%	Min	0.0%				
	Median	0.0%	0.0%	Median	0.0%				
	Total	0.0%	0.0%	Total	0.0%				
IGM	Max	0.0%	0.0%	Max	0.0%	"Weathered Rock"	0.0%		
	Min	0.0%	0.0%	Min	0.0%				
	Median	0.0%	0.0%	Median	0.0%				
	Total	0.0%	0.0%	Total	0.0%				
L-III	Max	0.0%	0.0%	Max	0.0%	III	0.0%	Rock	100.0%
	Min	0.0%	0.0%	Min	0.0%				
	Median	0.0%	0.0%	Median	0.0%				
	Total	0.0%	0.0%	Total	0.0%				
S-III	Max	0.0%	0.0%	Max	0.0%				
	Min	0.0%	0.0%	Min	0.0%				
	Median	0.0%	0.0%	Median	0.0%				
	Total	0.0%	0.0%	Total	0.0%				
L-II	Max	18.5%	50.8%	Max	50.8%	II	32.3%		
	Min	18.5%	0.0%	Min	0.0%				
	Median	18.5%	25.4%	Median	21.9%				
	Total	18.5%	25.4%	Total	21.5%				
S-II	Max	19.4%	0.0%	Max	19.4%				
	Min	19.4%	0.0%	Min	0.0%				
	Median	19.4%	0.0%	Median	9.7%				
	Total	19.4%	0.0%	Total	10.8%				
L-I	Max	62.2%	100.0%	Max	100.0%	I	67.7%		
	Min	62.2%	49.2%	Min	49.2%				
	Median	62.2%	74.6%	Median	68.4%				
	Total	62.2%	74.6%	Total	67.7%				
S-I	Max	0.0%	0.0%	Max	0.0%				
	Min	0.0%	0.0%	Min	0.0%				
	Median	0.0%	0.0%	Median	0.0%				
	Total	0.0%	0.0%	Total	0.0%				
B	Max	0.0%	0.0%	Max	0.0%	Bentonite	0.0%		
	Min	0.0%	0.0%	Min	0.0%				
	Median	0.0%	0.0%	Median	0.0%				
	Total	0.0%	0.0%	Total	0.0%				

NOTES:

(1) Data from borings more than 400 ft from proposed excavation limits were not included.

(2) Proposed excavation horizon for SEM tunnels extends 22.2 feet upward from invert to crown.

(3) Alignment and configuration are current as of 12/20/2019.

Table 9. Ground Classes for Cut-and-Cover Station Excavation, by Reach and Overall

Ground Class	Reach			Percent Volume of C&C Station Excavation		Ground Class Group	Percent Volume, C&C Station Excavation	General Ground Class Group	Percent Volume, C&C Station Excavation
	Percent Volume	3	8						
F	Max	4.4%	8.7%	Max	8.7%	Fill	5.4%	Overburden	63.7%
	Min	1.4%	7.5%	Min	1.4%				
	Median	2.2%	8.1%	Median	5.2%				
	Total	2.7%	8.1%	Total	5.4%				
A1	Max	14.0%	76.8%	Max	76.8%	Alluvium	55.3%		
	Min	7.9%	58.7%	Min	7.9%				
	Median	11.8%	67.7%	Median	39.8%				
	Total	11.2%	67.7%	Total	39.4%				
A2	Max	23.1%	14.5%	Max	23.1%				
	Min	18.4%	7.5%	Min	7.5%				
	Median	20.6%	11.0%	Median	15.8%				
	Total	20.7%	11.0%	Total	15.9%				
RS	Max	0.0%	0.0%	Max	0.0%	Residual Soil	0.0%		
	Min	0.0%	0.0%	Min	0.0%				
	Median	0.0%	0.0%	Median	0.0%				
	Total	0.0%	0.0%	Total	0.0%				
IGM	Max	8.8%	2.5%	Max	8.8%	"Weathered Rock"	3.1%		
	Min	2.2%	0.0%	Min	0.0%				
	Median	3.6%	1.2%	Median	2.4%				
	Total	4.9%	1.2%	Total	3.1%				
L-III	Max	0.0%	0.0%	Max	0.0%	III	0.0%	Rock	36.3%
	Min	0.0%	0.0%	Min	0.0%				
	Median	0.0%	0.0%	Median	0.0%				
	Total	0.0%	0.0%	Total	0.0%				
S-III	Max	0.0%	0.0%	Max	0.0%				
	Min	0.0%	0.0%	Min	0.0%				
	Median	0.0%	0.0%	Median	0.0%				
	Total	0.0%	0.0%	Total	0.0%				
L-II	Max	7.2%	13.7%	Max	13.7%	II	6.0%		
	Min	0.0%	0.0%	Min	0.0%				
	Median	0.0%	6.9%	Median	3.4%				
	Total	2.4%	6.9%	Total	4.6%				
S-II	Max	5.2%	0.0%	Max	5.2%				
	Min	0.0%	0.0%	Min	0.0%				
	Median	2.9%	0.0%	Median	1.4%				
	Total	2.7%	0.0%	Total	1.3%				
L-I	Max	51.5%	7.1%	Max	51.5%	I	29.5%		
	Min	45.5%	0.0%	Min	0.0%				
	Median	46.5%	3.5%	Median	25.0%				
	Total	47.8%	3.5%	Total	25.8%				
S-I	Max	11.5%	0.0%	Max	11.5%				
	Min	0.0%	0.0%	Min	0.0%				
	Median	11.1%	0.0%	Median	5.6%				
	Total	7.5%	0.0%	Total	3.8%				
B	Max	0.0%	3.0%	Max	3.0%	Bentonite	0.7%		
	Min	0.0%	0.0%	Min	0.0%				
	Median	0.0%	1.5%	Median	0.7%				
	Total	0.0%	1.5%	Total	0.7%				

NOTES:

(1) Data from borings more than 400 ft from proposed excavation limits were not included.

(2) Proposed excavation horizon for cut-and-cover stations extends from invert to ground surface.

(3) Alignment and configuration are current as of 12/20/2019.

Table 10. Ground Classes for SEM Station Excavation, by Reach and Overall

Ground Class	Reach: Percent Volume	Reach: 5	Percent Volume of SEM Station Excavation		Ground Class Group	Percent Volume, SEM Stationl Excavation	General Ground Class Group	Percent Volume, SEM Station Excavation
F	Max	0.0%	Max	0.0%	Fill	0.0%	Overburden	0.0%
	Min	0.0%	Min	0.0%				
	Median	0.0%	Median	0.0%				
	Total	0.0%	Total	0.0%				
A1	Max	0.0%	Max	0.0%	Alluvium	0.0%		
	Min	0.0%	Min	0.0%				
	Median	0.0%	Median	0.0%				
	Total	0.0%	Total	0.0%				
A2	Max	0.0%	Max	0.0%				
	Min	0.0%	Min	0.0%				
	Median	0.0%	Median	0.0%				
	Total	0.0%	Total	0.0%				
RS	Max	0.0%	Max	0.0%	Residual Soil	0.0%		
	Min	0.0%	Min	0.0%				
	Median	0.0%	Median	0.0%				
	Total	0.0%	Total	0.0%				
IGM	Max	0.0%	Max	0.0%	"Weathered Rock"	0.0%		
	Min	0.0%	Min	0.0%				
	Median	0.0%	Median	0.0%				
	Total	0.0%	Total	0.0%				
L-III	Max	0.0%	Max	0.0%	III	0.0%	Rock	100.0%
	Min	0.0%	Min	0.0%				
	Median	0.0%	Median	0.0%				
	Total	0.0%	Total	0.0%				
S-III	Max	0.0%	Max	0.0%				
	Min	0.0%	Min	0.0%				
	Median	0.0%	Median	0.0%				
	Total	0.0%	Total	0.0%				
L-II	Max	3.0%	Max	3.0%	II	1.5%		
	Min	0.0%	Min	0.0%				
	Median	1.5%	Median	1.5%				
	Total	1.5%	Total	1.5%				
S-II	Max	0.0%	Max	0.0%				
	Min	0.0%	Min	0.0%				
	Median	0.0%	Median	0.0%				
	Total	0.0%	Total	0.0%				
L-I	Max	100.0%	Max	100.0%	I	98.5%		
	Min	97.0%	Min	97.0%				
	Median	98.5%	Median	98.5%				
	Total	98.5%	Total	98.5%				
S-I	Max	0.0%	Max	0.0%				
	Min	0.0%	Min	0.0%				
	Median	0.0%	Median	0.0%				
	Total	0.0%	Total	0.0%				
B	Max	0.0%	Max	0.0%	Bentonite	0.0%		
	Min	0.0%	Min	0.0%				
	Median	0.0%	Median	0.0%				
	Total	0.0%	Total	0.0%				
						100.0%		100.0%

NOTES:

(1) Data from borings more than 400 ft from proposed excavation limits were not included.

(2) Proposed excavation horizon for SEM station (Commerce Station) extends 44.0 feet from invert to crown.

(3) Alignment and configuration are current as of 12/20/2019.

Table 11. Summary of Portal U-Wall Excavation

Ground Class Group	Percent Volume for Reach	
	1	10
	(West Portal)	(East Portal)
Fill	21%	29%
Alluvium	79%	71%

NOTE: For details, see Tables 4, 5, and 6.

Table 12. Summary of Cut-and-Cover Excavation

Ground Class Group	Rock Type	Percent Volume for Reach				
		2	3	7	8	9
		(Tunnel)	(Metro Center Station)	(Tunnel)	(CBD East Station)	(Tunnel)
Fill	N/A	5%	3%	9%	8%	26%
Alluvium	N/A	52%	32%	31%	79%	53%
“Weathered Rock”	N/A	8%	5%	11%	1%	17%
I	Limestone	35%	48%	41%	4%	0%
II	Limestone	1%	2%	8%	7%	5%
I	Shale	0%	8%	0%	0%	0%
II	Shale	0%	3%	0%	0%	0%
Bentonite		0%	0%	0%	1%	0%

NOTE: For details, see Tables 4, 5, 7, and 9.

Table 13. Summary of SEM Excavation

Ground Class Group	Rock Type	Percent Volume for Reach		
		4	5	6
		(Tunnel)	(Commerce Station)	(Tunnel)
I	Limestone	62%	98%	75%
II	Limestone	18%	2%	25%
I	Shale	0%	0%	0%
II	Shale	19%	0%	0%

NOTE: For details, see Tables 4, 5, 8, and 10.

Table 14. Summary of Properties for Overburden Ground Classes and Bentonite

Ground Class				Fill	A1	A2	RS	Bentonite
USCS Classifications				CH, SC, SP	CH, CL, SC	SP, SC, CL	CH, CL	CH
Index Properties	Unit weight	Min	pcf	96.0	68.5	107.3	-	-
		Max	pcf	122.3	148.6	110.7	-	-
		Mean (preliminary design)	pcf	106.6	112.5	109.0	-	-
		Preliminary baseline value or range (25th-75th percentile)	pcf	102-109	109-118	108-110	-	-
	Dry density	Min	pcf	-	56.1	-	100	75
		Max	pcf	-	120.9	-	94	4
		Mean (preliminary design)	pcf	-	104.4	-	104	83
		Preliminary baseline value or range (25th-75th percentile)	pcf	-	106-111	-	104	83
	Specific Gravity	Min		2.78	2.68	2.59	-	-
		Max		2.78	2.77	2.75	-	-
		Mean (preliminary design)		2.78	2.71	2.67	-	-
		Preliminary baseline value or range (25th-75th percentile)		2.78	2.69-2.72	2.65-2.70	-	-
	Natural Water Content	Min	%	10.5	8.6	4.1	15	22
		Max	%	28.6	110.4	20.7	39	42
		Mean (preliminary design)	%	17.5	17.2 (median)	11.7	26	36
		Preliminary baseline value or range (25th-75th percentile)	%	11-20	15-19	7-16	26	36
	Percent Gravel	Min	%	-	0.0	0.0	-	-
		Max	%	-	11.2	7.1	-	-
		Mean (preliminary design)	%	-	0.0 (median)	1.4	-	-
		Preliminary baseline value or range (25th-75th percentile)	%	-	0.0-0.7	0-2	-	-
	Percent Sand	Min	%	21.5	5.4	35.9	-	-
		Max	%	53.9	75.4	87.4	-	-
		Mean (preliminary design)	%	35.8	26.5	66.0	-	-
		Preliminary baseline value or range (25th-75th percentile)	%	30-43	12-38	60-76	-	-
	Percent Fines (Passing No. 200)	Min	%	24.9	24.6	9.1	98	97
		Max	%	71.8	94.6	64.1	98	97
		Mean (preliminary design)	%	59.0	72.7	32.6	98	97
		Preliminary baseline value or range (25th-75th percentile)	%	55.0-68.7	61.8-88.4	20-39	98	97
	Liquid Limit	Min	%	48	24	NP	30	80
		Max	%	48	64	NP	74	80
		Mean (preliminary design)	%	48	45	NP	54	80
		Preliminary baseline value or range (25th-75th percentile)	%	48	39-52	NP	54	80
	Plastic Limit	Min	%	19	11	NP	15	27
		Max	%	19	24	NP	44	27
		Mean (preliminary design)	%	19	18	NP	23	27
		Preliminary baseline value or range (25th-75th percentile)	%	19	16-20	NP	23	27
	Plasticity Index	Min	%	29	13	NP	15	53
		Max	%	29	40	NP	52	53
		Mean (preliminary design)	%	29	27	NP	31	53
		Preliminary baseline value or range (25th-75th percentile)	%	29	22-34	NP	31	53
Strength Properties	Standard Penetration Resistance, N_{SPT}	Min	bpf	-	5	4	-	-
		Max	bpf	-	16	14	-	-
		Mean (preliminary design)	bpf	-	9	9	-	-
		Preliminary baseline value or range (25th-75th percentile)	bpf	-	6-9	7-11	-	-
	Unconfined Compressive Strength	Min	psf	-	2,160	-	2,448	-
		Max	psf	-	67,968	-	3,108	-
		Mean (preliminary design)	psf	-	20,593	-	2,736	-
		Preliminary baseline value or range (25th-75th percentile)	psf	-	4,896-28,656	-	2736	-
	UU Compressive Strength	Min	psf	-	3,150	-	-	-
		Max	psf	-	7,352	-	-	-
		Mean (preliminary design)	psf	-	5,733	-	-	-
		Preliminary baseline value or range (25th-75th percentile)	psf	-	5,733	-	-	-

Table 14. Summary of Properties for Overburden Ground Classes and Bentonite (continued)

Ground Class					Fill	A1	A2	RS	Bentonite
Strength Properties	Triaxial Strength, Effective Stress (peak)	ϕ '	Min	deg	-	24	-	-	18
			Max	deg	-	24	-	-	35
			Mean (preliminary design)	deg	-	24	-	-	24
			Preliminary baseline value or range (25th-75th percentile)	deg	-	24	-	-	-
		c'	Min	psf	-	466	-	-	500
			Max	psf	-	466	-	-	2,500
			Mean (preliminary design)	psf	-	466	-	-	1,467
			Preliminary baseline value or range (25th-75th percentile)	psf	-	466	-	-	1,467
	Direct Shear Strength, Effective Stress (peak)	ϕ '	Min	deg	-	-	-	-	35
			Max	deg	-	-	-	-	48
			Mean (preliminary design)	deg	-	-	-	-	42
			Preliminary baseline value or range (25th-75th percentile)	deg	-	-	-	-	42
		c'	Min	psf	-	-	-	-	1.1
			Max	psf	-	-	-	-	1.8
			Mean (preliminary design)	psf	-	-	-	-	1.5
			Preliminary baseline value or range (25th-75th percentile)	psf	-	-	-	-	1.5
Consolidation Properties	Compression Ratio		Min	-	-	0.16	NP	-	-
			Max	-	-	0.27	NP	-	-
			Mean (preliminary design)	-	-	0.21	NP	-	-
	Recompression Ratio		Min	-	-	0.04	NP	-	-
			Max	-	-	0.08	NP	-	-
			Mean (preliminary design)	-	-	0.06	NP	-	-
	Overconsolidation Ratio		Min	-	-	17.0	NP	-	-
			Max	-	-	45.0	NP	-	-
			Mean (preliminary design)	-	-	See Note (8)	NP	-	-
			Preliminary baseline value or range (25th-75th percentile)	-	-	See Note (8)	NP	-	-
Swell Properties	Simple Swell (% of H_o)		Min	%	-	0.2	-	-	-
			Max	%	-	6.7	-	-	-
			Mean (preliminary design)	%	-	4.0	-	-	-
			Preliminary baseline value or range (25th-75th percentile)	%	-	3.3-5.8			
	ASTM D4546-1D Swell Test, Method A		Min	%	-	0.0	-	-	-
			Max	%	-	4.0	-	-	-
			Mean (preliminary design)	%	-	0.8	-	-	-
			Preliminary baseline value or range (25th-75th percentile)	%	-	0.0-1.0			
	ASTM D4546 Methods A and C, Swell Pressure		Min	tsf	-	0.1	-	-	8
			Max	tsf	-	1.6	-	-	30
			Mean (preliminary design)	tsf	-	0.6	-	-	14
			Preliminary baseline value or range (25th-75th percentile)	tsf	-	0.3-0.6	-	-	14
Corrosivity Properties	pH		Min	mg/kg	7.0	7.2	7.8	-	-
			Max	mg/kg	7.0	8.4	8.4	-	-
			Mean (preliminary design)	mg/kg	7.0	7.8	8.1	-	-
			Preliminary baseline value or range (25th-75th percentile)	mg/kg	7	7.5-8.0	7.9-8.2	-	-
	Electrical Resistivity		Min	ohm-cm	850	170	-	-	-
			Max	ohm-cm	850	1768	-	-	-
			Mean (preliminary design)	ohm-cm	850	1092	-	-	-
			Preliminary baseline value or range (25th-75th percentile)	ohm-cm	850	800-1451	-	-	-
	Chloride Content		Min	mg/kg	262.0	0.0	484.0	-	-
			Max	mg/kg	262.0	1,800.0	484.0	-	-
			Mean (preliminary design)	mg/kg	262.0	455.9	484.0	-	-
			Preliminary baseline value or range (25th-75th percentile)	mg/kg	262	2.5-534	484	-	-
	Sulfide Content		Min	mg/kg	-	0.000	0.00	-	-
			Max	mg/kg	-	0.000	0.00	-	-
			Mean (preliminary design)	mg/kg	-	0.000	0.00	-	-
			Preliminary baseline value or range (25th-75th percentile)	mg/kg	-	0.000	0.00	-	-
	Soluble Sulfate Content		Min	mg/kg	0.0	0.0	0.00	-	-
			Max	mg/kg	0.0	99.5	0.00	-	-
			Mean (preliminary design)	mg/kg	0.0	24.9	0.00	-	-
			Preliminary baseline value or range (25th-75th percentile)	mg/kg	0.0	0.0-24.9	0.00	-	-

NOTES:

(1) Source for Fill, A1, and A2 data except UU Compressive Strength: GDR (GPC6, 2019). Source for RS and Bentonite data: Lachel Felice & Associates, 2006.
(2) UU Compressive Strength test results reported in the GDR for A1 are irregular; values shown are from Lachel Felice 2006.
(3) N_{SPT}-values for Fill may not be reliable due to variable conditions and obstructions.
(4) Properties presented in this table are for the ground class as a whole. Site-specific parameters may be used at locations of particular proposed project
(5) Ground Class RS is residual soil developed on Austin Chalk.
(6) USCS Classification for Bentonite is for disaggregated rock.
(7) NP = nonplastic soil; test not performed.
(8) "-" means no data
(9) Overconsolidation ratios are inconsistently high for site conditions; no preliminary design or baseline values are assigned due to possible irregularities in testing or sample condition.
(10) Samples with liquid limits test results >200% were excluded.

Table 15. Summary of Properties for Ground Class IGM ("Weathered Rock")

Ground Class				IGM ("Weathered Rock") Limestone
USCS Classification of disaggregated rock				CH
Index Properties	Dry Unit Weight	Min	pcf	98
		Max	pcf	135
		Mean (preliminary design)	pcf	117
	Natural Water Content	Min	%	9
		Max	%	37
		Mean (preliminary design)	%	18
	Liquid Limit	Min	%	31
		Max	%	58
		Mean (preliminary design)	%	44
	Plasticity Index	Min	%	15
		Max	%	36
		Mean (preliminary design)	%	24
Strength and Mechanical Properties	Unconfined Compressive Strength	Min	psi	13
		Max	psi	3,253
		Mean (preliminary design)	psi	1,142
	Modulus of Elasticity, E	Min	10^6 psi	0.06
		Max	10^6 psi	0.50
		Mean (preliminary design)	10^6 psi	0.20
	Point Load Strength, Axial	Min	psi	241
		Max	psi	505
		Mean (preliminary design)	psi	379
	Point Load Srength, Diametral	Min	psi	377
		Max	psi	377
		Mean (preliminary design)	psi	377

NOTES:

(1) Source: Lachel Felice & Associates, 2006 data for Weathered Austin Chalk.

(2) Properties presented in this table are for the ground class as a whole. Site-specific parameters may be used at locations of particular proposed project structures.

Table 16. Summary of Intact Rock Properties

LIMESTONE					
Property		Range		Median Value (Design)	75th/25th Percentile Value (Preliminary Baseline) (6)(7)
		minimum	maximum		
Index Properties	Bulk Density, pcf (1)	121	137	129	132
Strength & Mechanical Properties	Unconfined Compressive Strength, psi				
	- from tests by ASTM D7012-C and D7012-D (2)	1,543	5,792	3,238	4,255
	- estimated from axial PLI tests (3)	3,680	5,410	4,650	4,840
	Dynamic Elastic Modulus, E, 10^6 psi (4)(5)(6)	0.25	2.94	0.43	-
	Dynamic Poisson's Ratio, v (4)(5)(6)	0.15	0.49	0.39	-
	Splitting Tensile Strength, psi	225	254	239	247
Abrasiveness & Hardness	CERCHAR Abrasiveness Index	0.50	0.64	0.53	0.59
	Rebound Hammer Hardness, H_R	17.1	23.3	20.7	21.6
Slaking Properties	Slake Durability Index, %	86.1	97.8	97.0	97.7
Drillability Indices (8)	Drilling Rate Index (DRI)	88	89	88.5 (extremely high)	88.8 (extremely high)
	Bit Wear Index (BWI)	8	8	8 (extremely low)	8 (extremely low)
	Cutter Life Index (CLI)	112.6	115.4	114.0 (extremely high)	114.7 (extremely high)

SHALE					
Property		Range		Median Value (Design)	75th/25th Percentile Value (Preliminary Baseline) (6)(7)
		minimum	maximum		
Index Properties	Bulk Density, pcf (1)	128	137	136	137
Strength & Mechanical Properties	Unconfined Compressive Strength, psi				
	- from tests by ASTM D7012-C and D7012-D (2)	267	2,553	1,410	1,981
	- estimated from axial PLI tests (3)	1,690	1,690	1,690	1,690
	Dynamic Elastic Modulus, E, 10^6 psi (4)(5)(6)	0.12	0.12	0.12	-
	Dynamic Poisson's Ratio, v (4)(5)(6)	0.18	0.18	0.18	-
Abrasiveness & Hardness	Cerchar Abrasiveness Index	0.54	0.54	0.54	0.54
	Rebound Hammer Hardness, H_R	12.0	12.0	12.0	12.0
Slaking Properties	Slake Durability Index, %	40.6	44.2	42.4	41.5

NOTES:
(1) Bulk density is at as-received moisture condition.
(2) UCS tests performed on specimens in as-received moisture condition.
(3) Axial PLI tests performed on specimens in saturated moisture condition.
(4) No data available for static elastic constants.
(5) Dynamic elastic constants from tests pulse velocity and ultrasonic elastic constants by ASTM 2845.
(6) Preliminary baseline values not assigned for elastic constants.
(7) The selected preliminary baseline is the quartile representing the most adverse excavation condition.
(8) Drillability Index classifications are from Dahl et al., 2012.

Table 17. Summary of Bulk Density

	SUMMARY OF RESULTS	
	Bulk Density, pcf	
	LIMESTONE	SHALE
No. Tests	58	3
High	137	137
Low	121	128
Mean	129	134
Median	129	136
75th Percentile	132	137
25th Percentile	126	132
Standard Deviation	4.3	5.0
Coefficient of Variability	0.03	0.04

Table 18. Summary of Unconfined Compressive Strength

A. UCS by ASTM D7012-C and D7012-D

	SUMMARY OF RESULTS Unconfined Compressive Strength, psi by ASTM D7012-C and D7012-D	
	LIMESTONE	SHALE
No. Tests	18	2
High	5,792	2,553
Low	1,543	267
Mean	3,368	1,410
Median	3,238	1,410
75th Percentile	4,255	1,981
25th Percentile	2,367	838
Standard Deviation	1,386	1,616
Coefficient of Variability	0.41	1.15

B. UCS estimated from Point Load Index by ASTM D5731

	SUMMARY OF RESULTS Axial Point Load Index UCS, psi by ASTM D5731	
	LIMESTONE	SHALE
No. Tests	11	1
High	5,410	1,690
Low	3,270	1,690
Mean	4,459	1,690
Median	4,650	1,690
75th Percentile	4,840	1,690
25th Percentile	4,045	1,690
Standard Deviation	660.22	0.00
Coefficient of Variability	0.15	0.00

Table 19. Summary of Elastic Constants (Dynamic)

	SUMMARY OF RESULTS		SUMMARY OF RESULTS	
	Dynamic Elastic Modulus, E, 10^6 psi, by ASTM D2845		Dynamic Poisson's Ratio by ASTM D2845	
	LIMESTONE	SHALE	LIMESTONE	SHALE
No. Tests	14	1	14	1
High	2.94	0.12	0.49	0.18
Low	0.25	0.12	0.15	0.18
Mean	0.68	0.12	0.34	0.18
Median	0.43	0.12	0.39	0.18
75th Percentile	0.58	0.12	0.41	0.18
25th Percentile	0.35	0.12	0.26	0.18
Standard Deviation	0.70	0.00	0.12	0.00
Coefficient of Variability	1.03	0.00	0.35	0.00

Table 20. Summary of Splitting Tensile Strength

	SUMMARY OF RESULTS	
	Splitting Tensile Strength,psi by ASTM D3967	
	LIMESTONE	SHALE
No. Tests	3	0
High	254	-
Low	225	-
Mean	239	-
Median	239	-
75th Percentile	247	-
25th Percentile	232	-
Standard Deviation	14.50	-
Coefficient of Variability	0.06	-

Table 21. Summary of CERCHAR Abrasiveness Index

	SUMMARY OF RESULTS	
	Cerchar Abrasiveness Index by ASTM D7625	
	LIMESTONE	SHALE
No. Tests	15	1
High	0.64	0.54
Low	0.50	0.54
Mean	0.55	0.54
Median	0.53	0.54
75th Percentile	0.59	0.54
25th Percentile	0.51	0.54
Standard Deviation	0.04	0.00
Coefficient of Variability	0.08	0.00

Table 22. Summary of Rebound Hardness (Schmidt Hammer) Test Results

	SUMMARY OF RESULTS	
	Rebound Hardness Number, H_R, by ASTM D5873	
	LIMESTONE	SHALE
No. Tests	6	1
High	23.3	12.0
Low	17.1	12.0
Mean	20.2	12.0
Median	20.7	12.0
75th Percentile	21.6	12.0
25th Percentile	18.1	12.0
Standard Deviation	2.45	0.00
Coefficient of Variability	0.12	0.00

Table 23. Summary of Slake Durability Test Results

	SUMMARY OF RESULTS	
	Slake Durability Index, %	
	LIMESTONE	SHALE
No. Tests	18	2
High	97.8	44.2
Low	86.1	40.6
Mean	96.2	42.4
Median	96.8	42.4
75th Percentile	97.7	43.3
25th Percentile	96.1	41.5
Standard Deviation	2.65	2.55
Coefficient of Variability	0.03	0.06

Table 24. Summary of Drillability Indices

	SUMMARY OF RESULTS		
	Drilling Rate Index (DRI)	Bit Wear Index (BWI)	Cutter Life Index (CLI)
	LIMESTONE		
No. Tests	2	2	2
High	89	8	115.4
Low	88	8	112.6
Mean	88.5	8.0	114.0
Median	88.5	8.0	114.0
75th Percentile	88.8	8.0	114.7
25th Percentile	88.3	8.0	113.3
Standard Deviation	0.71	0.00	1.98
Coefficient of Variability	0.01	0.00	0.02

Table 25. Drillability Indices Classification

Category	DRI™	BWI™	CLI™
Extremely Low	≤ 25	≤ 10	< 5
Very Low	26 - 32	11 - 20	5.0 – 5.9
Low	**33 - 42**	**21 - 30**	**6.0 – 7.9**
Medium	**43 - 57**	**31 - 44**	**8.0 – 14.9**
High	**58 - 69**	**45 - 55**	**15 - 34**
Very High	70 - 82	56 - 69	34 - 74
Extremely High	≥ 83	≥ 70	≥ 75

NOTES:

1. DRI™ = Drilling Rate Index
2. BWI™ = Bit Wear Index
3. CLI™ = Cutter Life Index
4. Classifications are from Dahl et al., 2012.
5. Outlined values are ranges for DART D2 limestone.

Table 26. Preliminary GSI Ranges for DART D2 Rock Types and Ground Classes

	Ground Class					
	I		II		III	
	L-I	S-I	L-II	S-II	L-III	S-III
Rock Type	Limestone	Shale	Limestone	Shale	Limestone	Shale
Preliminary GSI Range [(1)(2)]	50-65	Not applicable [(3)]	40-50	20-30	30-40	10-20

NOTES:
(1) Preliminary Geological Strength Index (GSI) was estimated based on guidelines in Marinos et al., 2005 and limited available data.
(2) Within range, GSI depends on site-specific conditions.
(3) Ground Class S-I shale is sufficiently anisotropic as to make GSI not applicable; shear strength along bedding planes will control rock mass behavior.

Table 27. Summary of Groundwater Level Measurements

Boring Number	Ground Surface Elevation (ft)	Maximum Measured Groundwater Elevation				Minimum Measured Groundwater Elevation			
		Date	Depth (ft)	Elevation (ft)	Measurement Type	Date	Depth (ft)	Elevation (ft)	Measurement Type
B-1	428.44	4/4/2017	20.0	408.4	Measurement during drilling	–	–	–	not recorded
B-2	465.52	4/6/2017	20.2	445.3	Measurement during drilling	–	–	–	not recorded
B-3	435.23	5/2/2017	14.0	421.2	Measurement during drilling	–	–	–	not recorded
B-4	435.05	–	–	–	not recorded	–	–	–	not recorded
B-5	433.39	–	–	–	not recorded	–	–	–	not recorded
P-102	469.61	10/3/2017	14.0	455.6	Measurement during drilling	–	–	–	not recorded
R-2	412.44	–	–	–	not recorded	–	–	–	not recorded
R-3	417.62	–	–	–	not recorded	–	–	–	not recorded
R-8	464.91	–	–	–	not recorded	–	–	–	not recorded
S-1	422.7	6/10/2016	9.0	413.7	Measurement during drilling	–	–	–	not recorded
S-2	427.14	–	–	–	not recorded	–	–	–	not recorded
S-3	428.61	5/4/2016	18.0	410.6	Measurement during drilling	–	–	–	not recorded
T-1	431.15	01/08/19	19.9	411.3	Well measurement	08/20/19	20.5	410.7	Well measurement
T-102	427.65	9/27/2017	18.0	409.7	Measurement during drilling	–	–	–	not recorded
T-103	429.39	10/7/2017	19.0	410.4	Measurement during drilling	–	–	–	not recorded
T-11	429.66	08/23/16	17.15	412.5	Well measurement	08/20/19	19.2	410.5	Well measurement
T-110	464.25	4/9/2018	19.5	444.8	Measurement during drilling	–	–	–	not recorded
T-112	467.46	3/21/2018	19.0	448.5	Measurement during drilling	–	–	–	not recorded
T-201	422.6	10/17/2017	15.5	407.1	Measurement during drilling	–	–	–	not recorded
T-203	438.43	–	–	–	not recorded	–	–	–	not recorded
T-204	448.77	10/27/2018	9.0	439.8	Measurement during drilling	–	–	–	not recorded
T-205	461.02	8/15/2018	21.4	439.6	Measurement during drilling	–	–	–	not recorded
T-24	422.86	4/25/2016	18.0	404.9	Measurement during drilling	–	–	–	not recorded
T-25	423.6	5/25/2016	18.5	405.1	Measurement during drilling	–	–	–	not recorded
T-26	424.36	6/1/2016	18.0	406.4	Measurement during drilling	–	–	–	not recorded
T-27	425.12	6/7/2016	18.0	407.1	Measurement during drilling	–	–	–	not recorded
T-5	429.97	-	–	–	not recorded	–	–	–	not recorded
T-6	430.93	5/23/2016	19.5	411.4	Measurement during drilling	–	–	–	not recorded
TS-104D	427.71	01/08/19	17.25	410.5	Well measurement	08/20/19	22.7	405.0	Well measurement
TS-104S	427.76	01/08/19	18.8	409.0	Well measurement	04/08/19	19.60	408.2	Well measurement
TS-111D	464.79	02/21/19	19.0	445.8	Well measurement	05/10/19	19.75	445.0	Well measurement

Table 27. Summary of Groundwater Level Measurements

Boring Number	Ground Surface Elevation (ft)	Maximum Measured Groundwater Elevation				Minimum Measured Groundwater Elevation			
		Date	Depth (ft)	Elevation (ft)	Measurement Type	Date	Depth (ft)	Elevation (ft)	Measurement Type
TS-111S	464.77	06/17/19	14.50	450.3	Well measurement	10/18/19	18.30	446.5	Well measurement
TS-13A	430.28	–	–	–	not recorded	–	–	–	not recorded
TS-15D	429.29	4/8/2016	21.0	408.3	Measurement during drilling	–	–	–	not recorded
TS-16D	430.18	4/15/2016	18.0	412.2	Measurement during drilling	–	–	–	not recorded
TS-202D	432.67	02/21/19	18.7	414.0	Well measurement	04/24/19	19.8	412.9	Well measurement
TS-202S	432.64	12/31/18	10.31	422.3	Well measurement	04/08/19	12.3	420.3	Well measurement
TS-206D	463.73	12/05/19	18.70	445.0	Well measurement	08/20/19	20.1	443.6	Well measurement
TS-206S	463.75	01/08/19	14.21	449.5	Well measurement	12/05/19	17.2	446.6	Well measurement
TS-207D	458.496	04/24/19	28.0	430.5	Well measurement	08/20/19	30.9	427.6	Well measurement
TS-207S	458.501	05/10/19	23.0	435.5	Well measurement	04/08/19	24.2	434.3	Well measurement
TS-208D	456.985	08/20/19	22.30	434.7	Well measurement	02/21/19	26.2	430.8	Well measurement
TS-208S	457.177	04/24/19	4.5	452.7	Well measurement	08/20/19	5.60	451.6	Well measurement
TS-209D	461.167	05/10/19	9.0	452.2	Well measurement	02/21/19	11.9	449.3	Well measurement
TS-209S	461.209	08/20/19	9.0	452.2	Well measurement	02/21/19	11.9	449.3	Well measurement

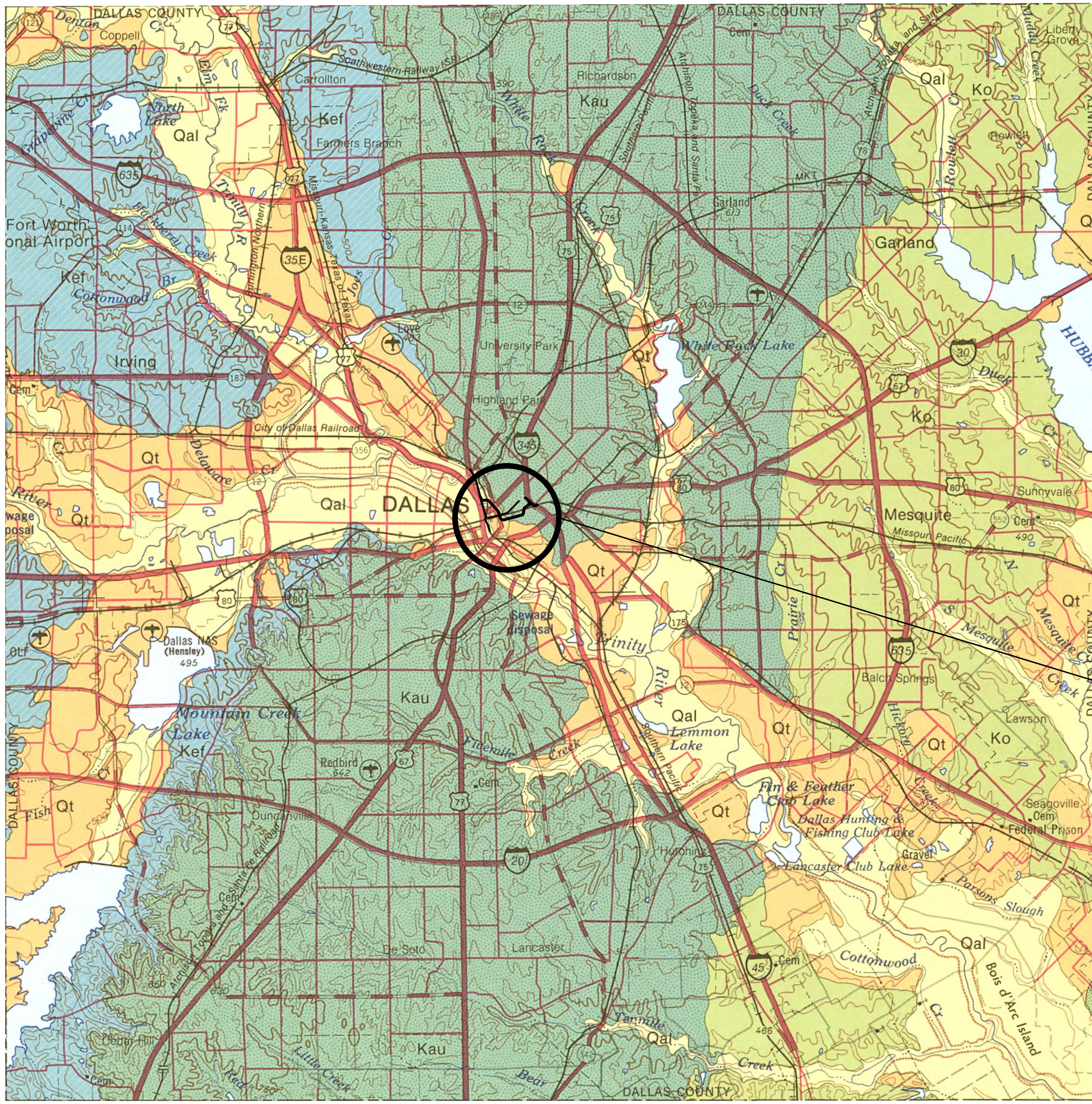
NOTES:

1. Borings in which shallow observation wells were installed have "S" suffix. Borings in which deep observations wells were installed have "D" suffix.

2. For borings in which observation wells were not installed, groundwater levels are based on the level during drilling as shown on boring logs.
3. For borings in which observation wells were installed, maximum/minimum groundwater levels are based on well measurements and do not consider measurements taken during drilling.
5. Extreme high and low groundwater level measurements were excluded from maximum/minimum determinations.
6. Groundwater level measurement details and well installation logs are presented in the GDR (Alliance, 2019).
7. Well measurements were taken between July 2016 and August 2019 for wells T-1 and T-11 and between December 2018 and December 2019 for other wells.
8. Groundwater level measurements for wells TS-202S, TS-202D, TS-206S, TS-202D, TS-111S, TS-111D are not included in the GDR (Alliance, 2019) but were submitted separately by Alliance on December 5, 2019.

FIGURES

DWG No. GC4-0080



DART D2 LPA

SCALE 1:250,000

5 0 5 10

CONTOUR INTERVAL 50 FEET

EXPLANATION

HOLOCENE / PLEISTOCENE	Qal / Qu	ALLUVIUM AND QUATERNARY DEPOSITS UNDIVIDED	QUATERNARY
	Qt	FLUVIATILE TERRACE DEPOSITS	
UPPER CRETACEOUS	Ko	OZAN FORMATION ("LOWER TAYLOR MARL")	CRETACEOUS
	Kau	AUSTIN CHALK	
	Kef	EAGLE FORD FORMATION	

SOURCE: UNIVERSITY OF TEXAS AT AUSTIN, BUREAU OF ECONOMIC GEOLOGY, 1987. GEOLOGIC ATLAS OF TEXAS, DALLAS SHEET, GAYLE SCOTT MEMORIAL EDITION, SCALE 1:250,000.

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DART PROJECT

SCALE	NO SCALE
DRAWN	K SHEFFY
DESIGNED	N CIANCIA
CHECKED	C STONE
IN CHARGE	J FRYE
DATE	03/06/2020

LIGHT RAIL TRANSIT SYSTEM
LINE SECTION CBD-2

FIGURE 1
GEOLOGIC MAP OF DALLAS COUNTY

CONTRACT | DWG No. GC4-0080 | REV

17-FEB-2020 18:19
pw://pwhdruscen01:HDR_US_Central_01/Documents/Dallas_Area_Rapid_Transit_DART_Dallas_TX/DART_General_Planning_CS_VI/6.0_CAD_BIM/6.2_Work_In_Progress/TO_39_D2_Subway_Proj_Dev/6.
ksheffy
Default

pw://pwhdruscen01:HDR_US_Central_01/Documents/Dallas_Area_Rapid_Transit_DART_Dallas_TX/DART_General_Planning_CS_VI/6.0_CAD_BIM/6.2_Work_In_Progress/TO_39_D2_Subway_Proj_Dev/6.2.3_Exhibits/GEOTECH/Borings/18DEC17/8 - DALLAS COUNTY GEOLOGIC MAP

NOTES:

1. BORING LOGS, LABORATORY TEST RESULTS, GROUNDWATER OBSERVATIONS, AND OTHER GEOTECHNICAL DATA ARE PRESENTED IN THE GEOTECHNICAL DATA REPORT (GDR) PREPARED BY ALLIANCE GEOTECHNICAL GROUP (GPC6, 2019).

2. BORINGS DRILLED FOR THE DART D2 PROJECT ARE SHOWN ON THE BORING AND REACH LOCATION PLAN AT THE AS-DRILLED LOCATIONS BASED ON SURVEYED COORDINATES GIVEN IN THE GDR.

3. BORINGS MORE THAN 400 FEET FROM THE ALIGNMENT ARE NOT SHOWN ON THE GEOLOGIC PROFILE.

4. BORINGS MORE THAN 200 FEET FROM THE ALIGNMENT ARE SCREENED ON THE GEOLOGIC PROFILE.

5. ELEVATIONS ARE IN FEET AND ARE BASED ON THE PROJECT VERTICAL DATUM.

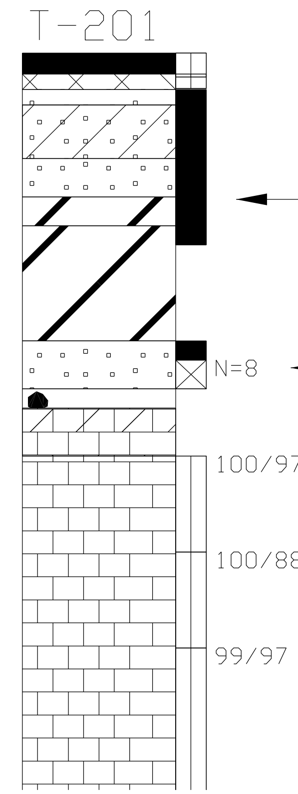
6. PROJECT ALIGNMENT SHOWN IS CURRENT AS OF DECEMBER 20, 2019.

7. PROFILE IS INTENDED TO ILLUSTRATE GROUND CONDITIONS AND IS NOT INTENDED FOR USE FOR DESIGN OR CONSTRUCTION

SURVEY / DATUM:
THE PROJECT VERTICAL DATUM IS THE NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD 88).

ABBREVIATIONS:

CL	CENTERLINE
GDR	GEOTECHNICAL DATA REPORT
LT	OFFSET LEFT OF ALIGNMENT
N	STANDARD PENETRATION TEST BLOWS PER FOOT
ROW	RIGHT OF WAY
RQD	ROCK QUALITY DESIGNATION
RT	OFFSET RIGHT OF ALIGNMENT
EB	EASTBOUND
SPT	STANDARD PENETRATION TEST
STA	STATIONING



RECORDED HIGH GROUNDWATER LEVEL

RECORDED LOW GROUNDWATER LEVEL

B-4 LOCATION OF BORING DRILLED FOR DART D2 INVESTIGATIONS

T-1 BORING NUMBER

101' RT MAGNITUDE AND DIRECTION OF OFFSET FROM ALIGNMENT

LEGEND

CLAY	LIMESTONE	ASPHALTIC PAVING
CLAY, SANDY	LIMESTONE, WEATHERED	CONCRETE
CLAY, SILTY	LIMESTONE, SEVERELY WEATHERED	CONCRETE, LIME-TREATED SOIL
SILTY CLAY, CLAYEY SAND	SANDY, SHALEY, LIMESTONE	FLEXIBLE BASE
SAND	SHALEY LIMESTONE	GRAVELLY
SAND, CLAYEY	SHALE	
SAND, GRAVEL	SANDSTONE	
SAND, SILTY		

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DART gpc six

DART PROJECT

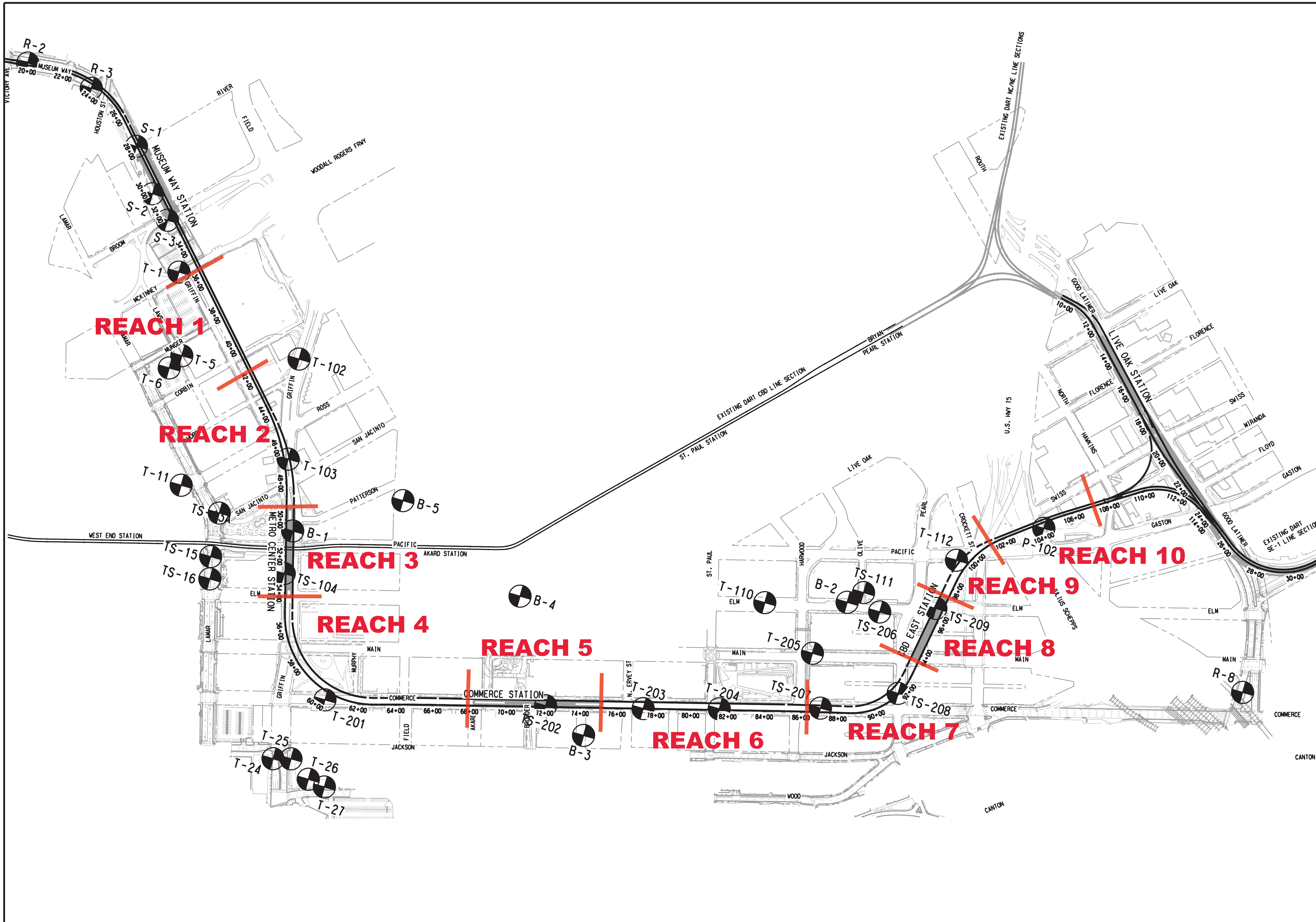
DART

SCALE	NO SCALE
DRAWN	K. SHEFFY
DESIGNED	M. CIANCIA
CHECKED	C. STONE
IN CHARGE	C. STONE
DATE	03/06/2020

CAES

LIGHT RAIL TRANSIT SYSTEM
LINE SECTION CBD-2
FIGURE 2
LEGEND AND NOTES
BORING LOCATION PLAN
AND GEOLOGIC PROFILE

CONTRACT | DWG No. HC1-0001 | REV



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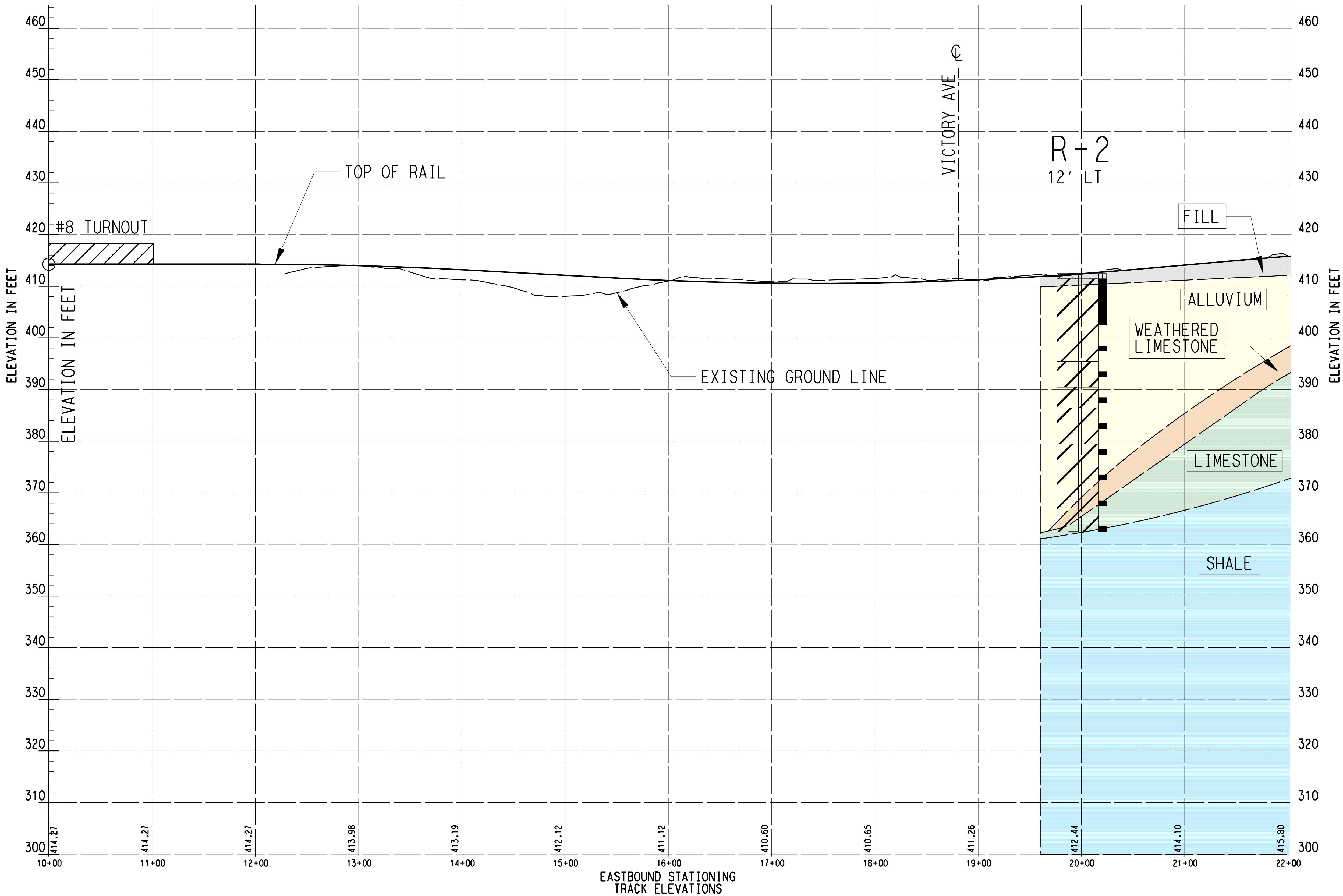
DART

LIGHT RAIL TRANSIT SYSTEM
LINE SECTION CBD-2
FIGURE 3
BORING AND REACH
LOCATION PLAN
12/20/19

C:\pwworking\central01\d0894629\CBD2-GC2-1000.200

DWG No. GC4-0031



SCALE (IN FEET) HORIZ 0 25 50 100

SCALE (IN FEET) VERT 0 5 10 20

NOTE:

SEE FIGURE 2 FOR LEGEND AND NOTES

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DART PROJECT

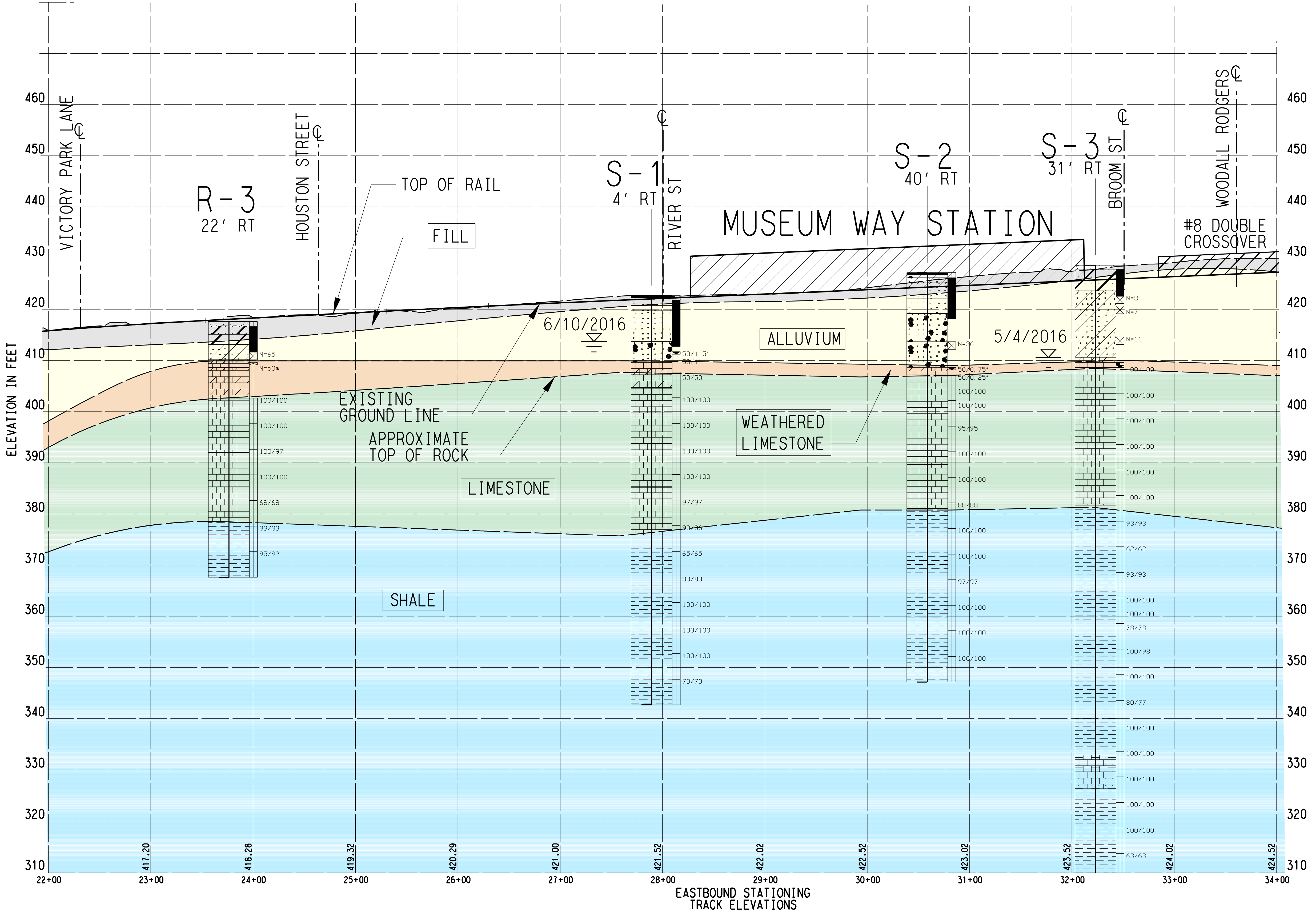
SCALE	1"=50'-0"
DRAWN	K SHEFFY
DESIGNED	M CIANCIA
CHECKED	C STONE
IN CHARGE	C STONE
DATE	03/06/2020

LIGHT RAIL TRANSIT SYSTEM
LINE SECTION CBD-2

FIGURE 4-A
GENERAL GEOLOGIC PROFILE
STA 10+00 TO STA 22+00

CONTRACT | DWG No. GC4-0031 | REV

DWG No. GC4-0032



SCALE (IN FEET) HORIZ 0 25 50 100

SCALE (IN FEET) VERT 0 5 10 20

NOTE:

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DART PROJECT

SCALE	1"-50'-0"
DRAWN	K SHEFFY
DESIGNED	M CIANCIA
CHECKED	C STONE
IN CHARGE	C STONE
DATE	03/06/2020

LIGHT RAIL TRANSIT SYSTEM
LINE SECTION CBD-2

FIGURE 4-B
GENERAL GEOLOGIC PROFILE
STA 22+00 TO STA 34+00

CONTRACT | DWG No. GC4-0032 | REV

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ksheffy
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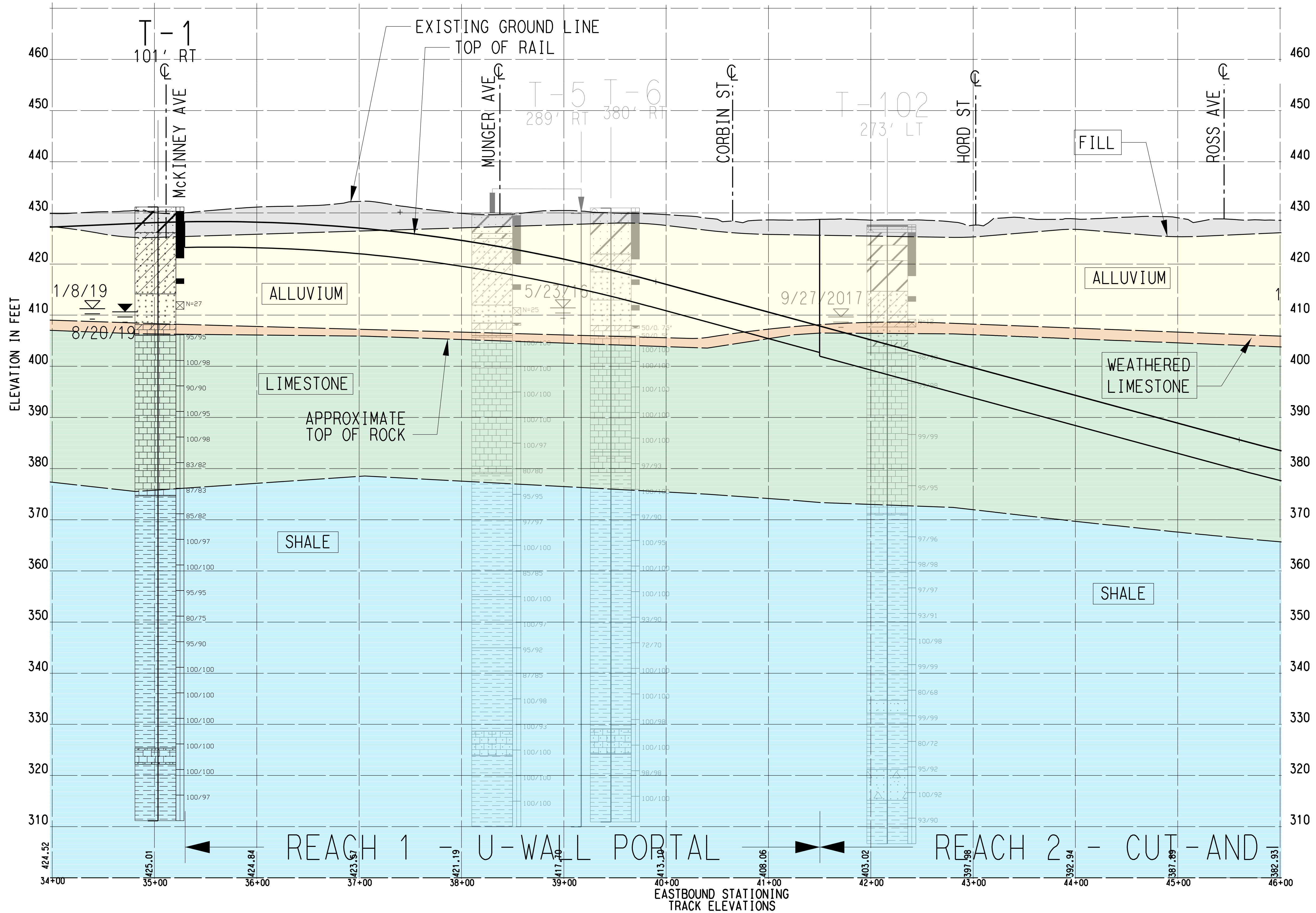

SCALE (IN FEET)
HORIZ 0 25 50 100
VERT 0 5 10 20

NOTE:

SEE FIGURE 2 FOR LEGEND AND NOTES

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DART PROJECT

SCALE	1"=50'-0"
DRAWN	K SHEFFY
DESIGNED	M CIANCIA
CHECKED	C STONE
IN CHARGE	C STONE
DATE	03/06/2020

LIGHT RAIL TRANSIT SYSTEM
LINE SECTION CBD-2

FIGURE 4-C
GENERAL GEOLOGIC PROFILE
STA 34+00 TO STA 46+00

CONTRACT | DWG No. GC4-0033 | REV

DWG No. GC4-0033

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ksheffy
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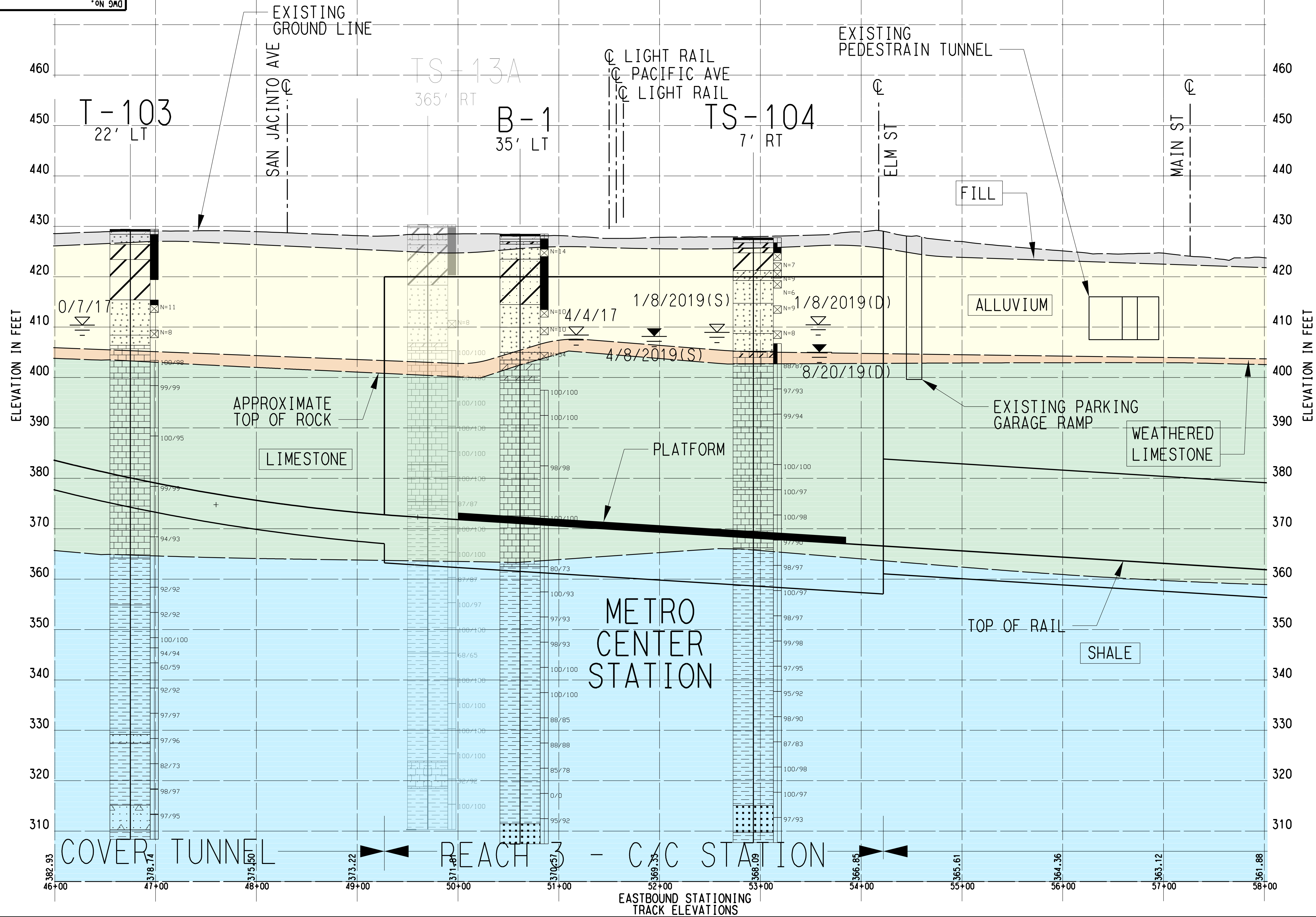

HORIZ SCALE (IN FEET) 0 25 50 100

VERT SCALE (IN FEET) 0 5 10 20

NOTE:
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SCALE	1"=50'-0"
DRAWN	K SHEFFY
DESIGNED	M CIANCIA
CHECKED	C STONE
IN CHARGE	C STONE
DATE	03/06/2020

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LIGHT RAIL TRANSIT SYSTEM
LINE SECTION CBD-2

FIGURE 4-D
GENERAL GEOLOGIC PROFILE
STA 46+00 TO STA 58+00

CONTRACT | DWG No. GC4-0034 | REV

REV	AMEND	CR	DATE	DESCRIPTION	BY	ENG	CHK	APP

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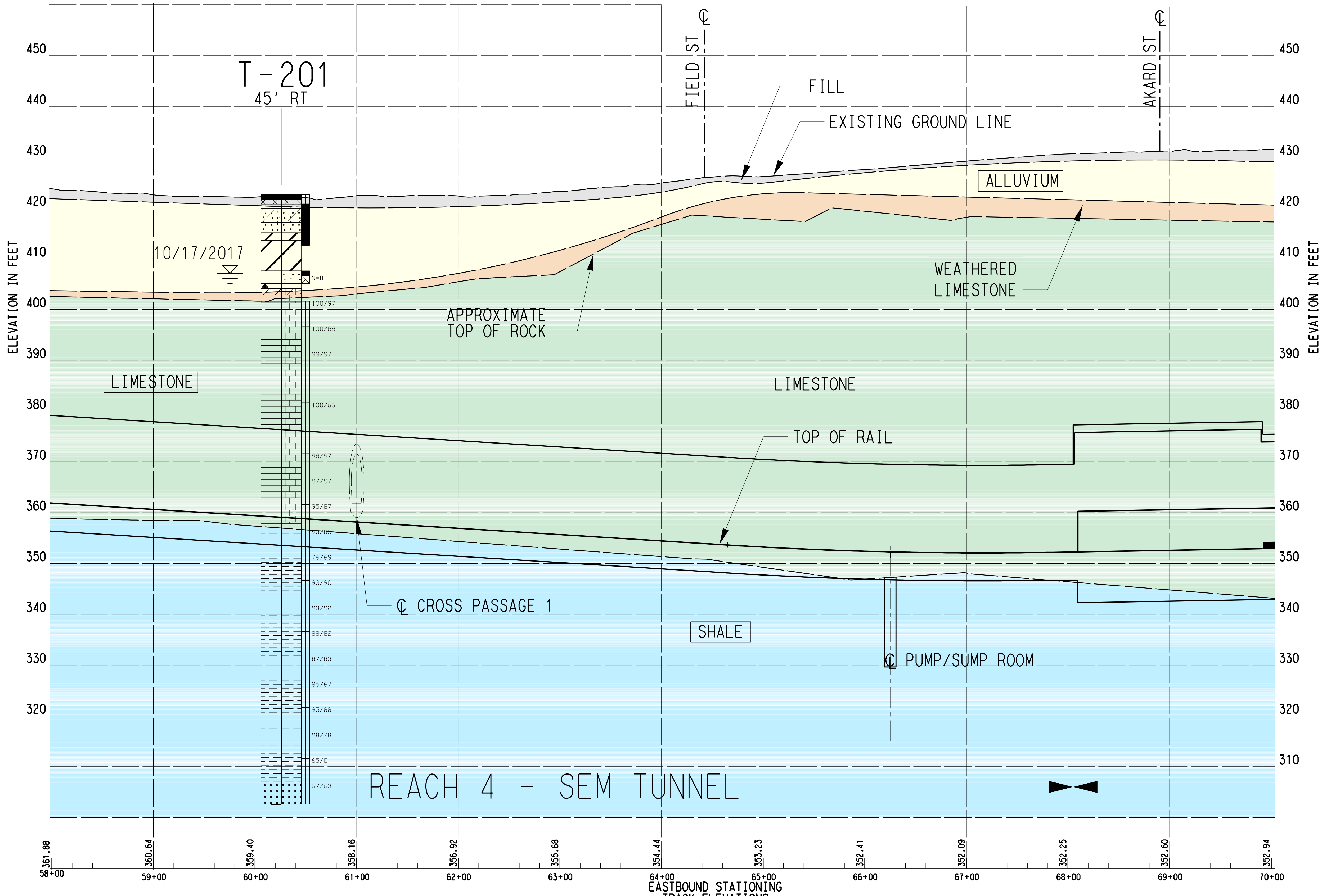
DWG No. GC4-0035



SCALE (IN FEET) HORIZ 0 25 50 100

SCALE (IN FEET) VERT 0 5 10 20

NOTE:

SEE FIGURE 2 FOR LEGEND AND NOTES

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DART PROJECT

SCALE	1"=50'-0"
DRAWN	K SHEFFY
DESIGNED	M CIANCIA
CHECKED	C STONE
IN CHARGE	C STONE
DATE	03/06/2020

LIGHT RAIL TRANSIT SYSTEM
LINE SECTION CBD-2

FIGURE 4-E
GENERAL GEOLOGIC PROFILE
STA 58+00 TO STA 70+00

CONTRACT | DWG No. GC4-0035 | REV

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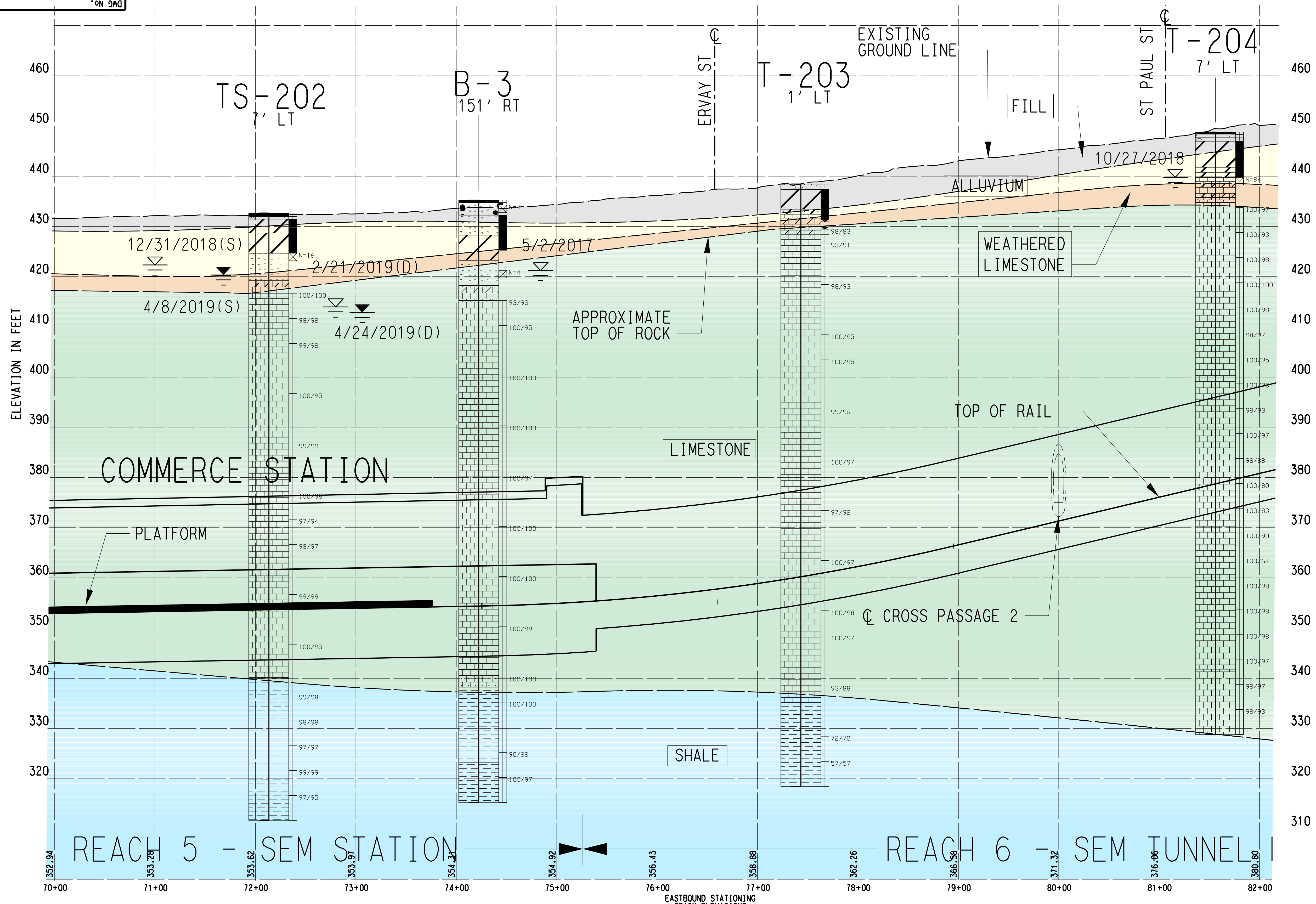
DWG No. GC4-0036



HORIZ SCALE (IN FEET) 0 25 50 100

VERT SCALE (IN FEET) 0 5 10 20

NOTE:

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DART gpc SIX

DART PROJECT

DART

SCALE	1"=50'-0"
DRAWN	K SHEFFY
DESIGNED	M CIANCIA
CHECKED	C STONE
IN CHARGE	C STONE
DATE	03/06/2020

CAES

LIGHT RAIL TRANSIT SYSTEM
LINE SECTION CBD-2

FIGURE 4-F
GENERAL GEOLOGIC PROFILE
STA 70+00 TO STA 82+00

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18-FEB-2020 10:15
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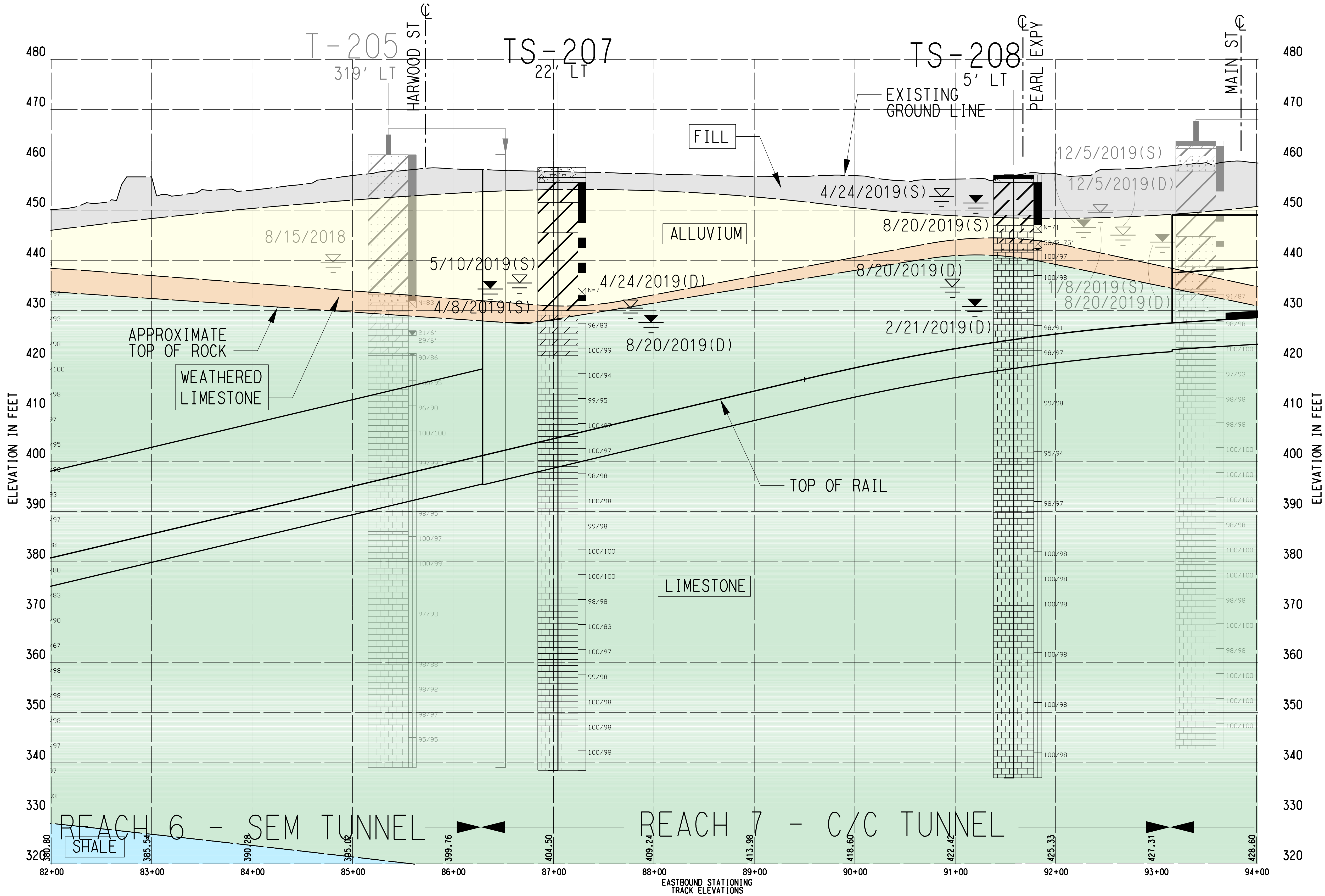

SCALE (IN FEET)
HORIZ 0 25 50 100
VERT 0 5 10 20

NOTE:
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DART PROJECT

SCALE	1"=50'-0"
DRAWN	K SHEFFY
DESIGNED	M CIANCIA
CHECKED	C STONE
IN CHARGE	C STONE
DATE	03/06/2020

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LIGHT RAIL TRANSIT SYSTEM
LINE SECTION CBD-2

FIGURE 4-G
GENERAL GEOLOGIC PROFILE
STA 82+00 TO STA 94+00

CONTRACT	DWG No.	REV
	GC4-0037	

REV	AMEND	CR	DATE	DESCRIPTION	BY	ENG	CHK	APP

DWG No. GC4-0037

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ksheffy
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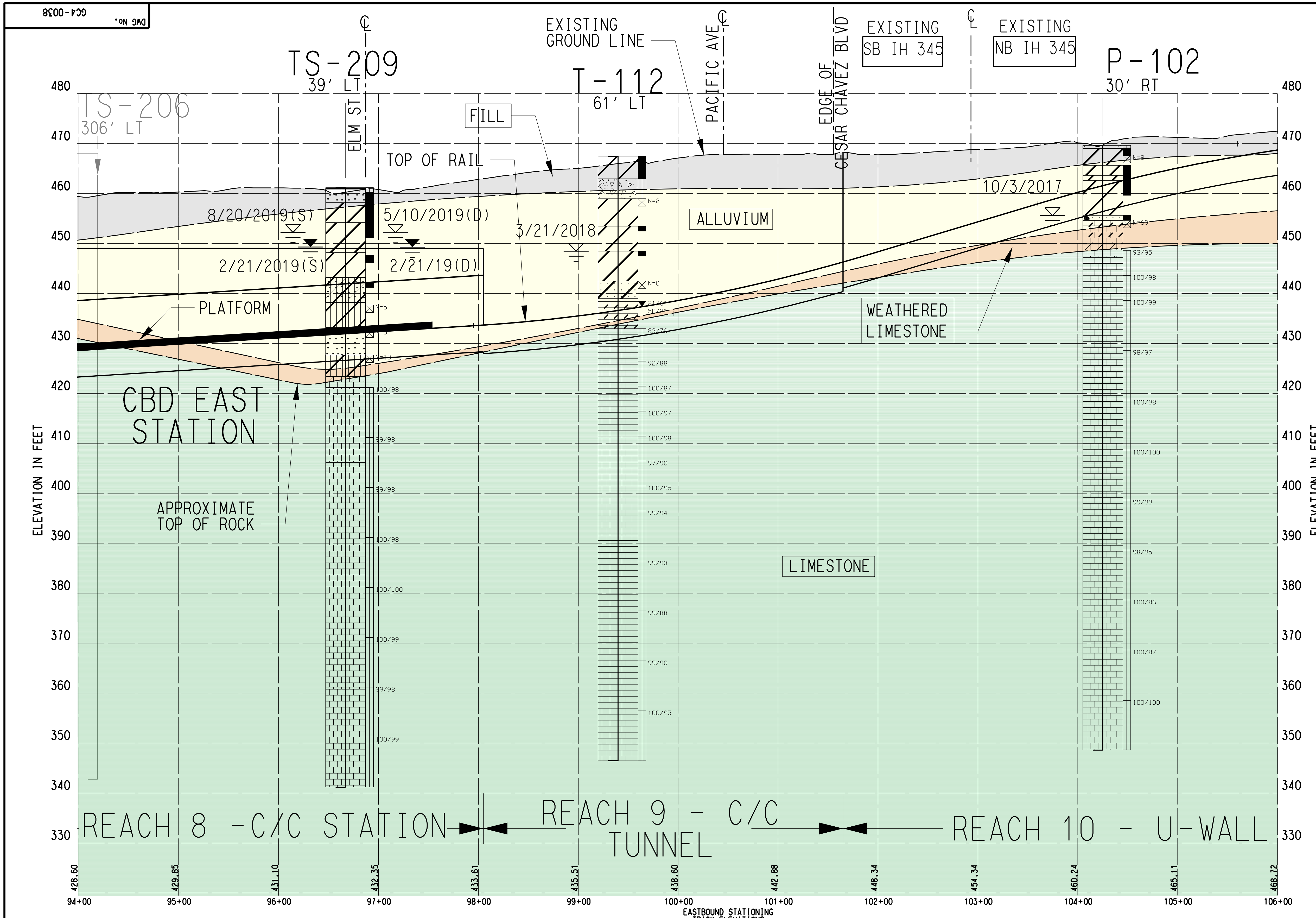

NOTE:

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REV	AMEND	CR	DATE	DESCRIPTION	BY	ENG	CHK	APP

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DART PROJECT

SCALE	1"=50'-0"
DRAWN	K SHEFFY
DESIGNED	M CIANCIA
CHECKED	C STONE
IN CHARGE	C STONE
DATE	03/06/2020

LIGHT RAIL TRANSIT SYSTEM
LINE SECTION CBD-2

FIGURE 4-H
GENERAL GEOLOGIC PROFILE
STA 94+00 TO STA 106+00

CONTRACT | DWG No. GC4-0038 | REV

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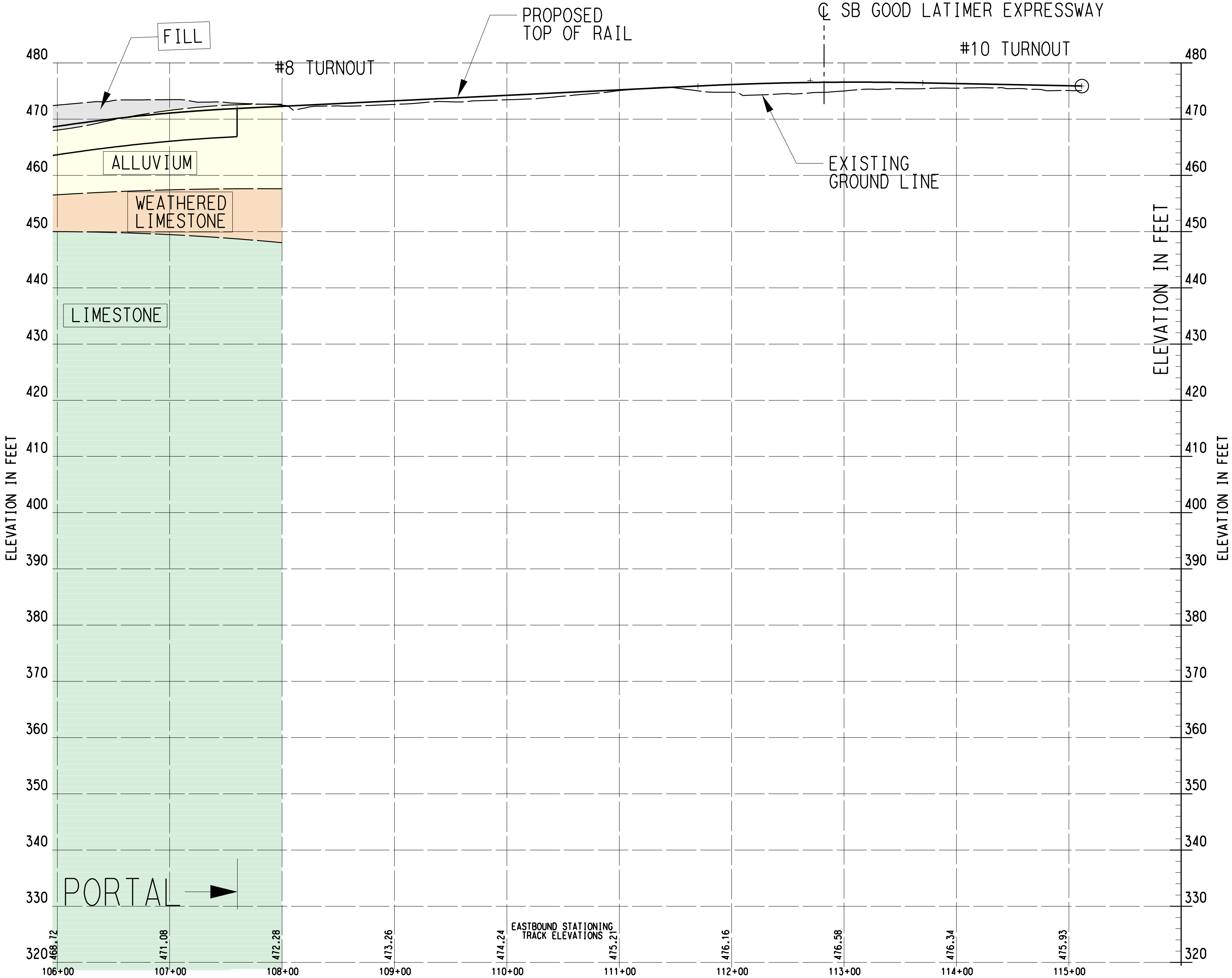
DWG No. GC4-0039



SCALE (IN FEET) HORIZ 0 25 50 100

SCALE (IN FEET) VERT 0 5 10 20

NOTE:
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REV	AMEND	CR	DATE	DESCRIPTION	BY	ENG	CHK	APP

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DART PROJECT

SCALE	1"=50'-0"
DRAWN	K SHEFFY
DESIGNED	M CIANCIA
CHECKED	C STONE
IN CHARGE	C STONE
DATE	03/06/2020

LIGHT RAIL TRANSIT SYSTEM
LINE SECTION CBD-2

FIGURE 4-I
GENERAL GEOLOGIC PROFILE
STA 106+00 TO STA 115+00

CONTRACT | DWG No. GC4-0039 | REV

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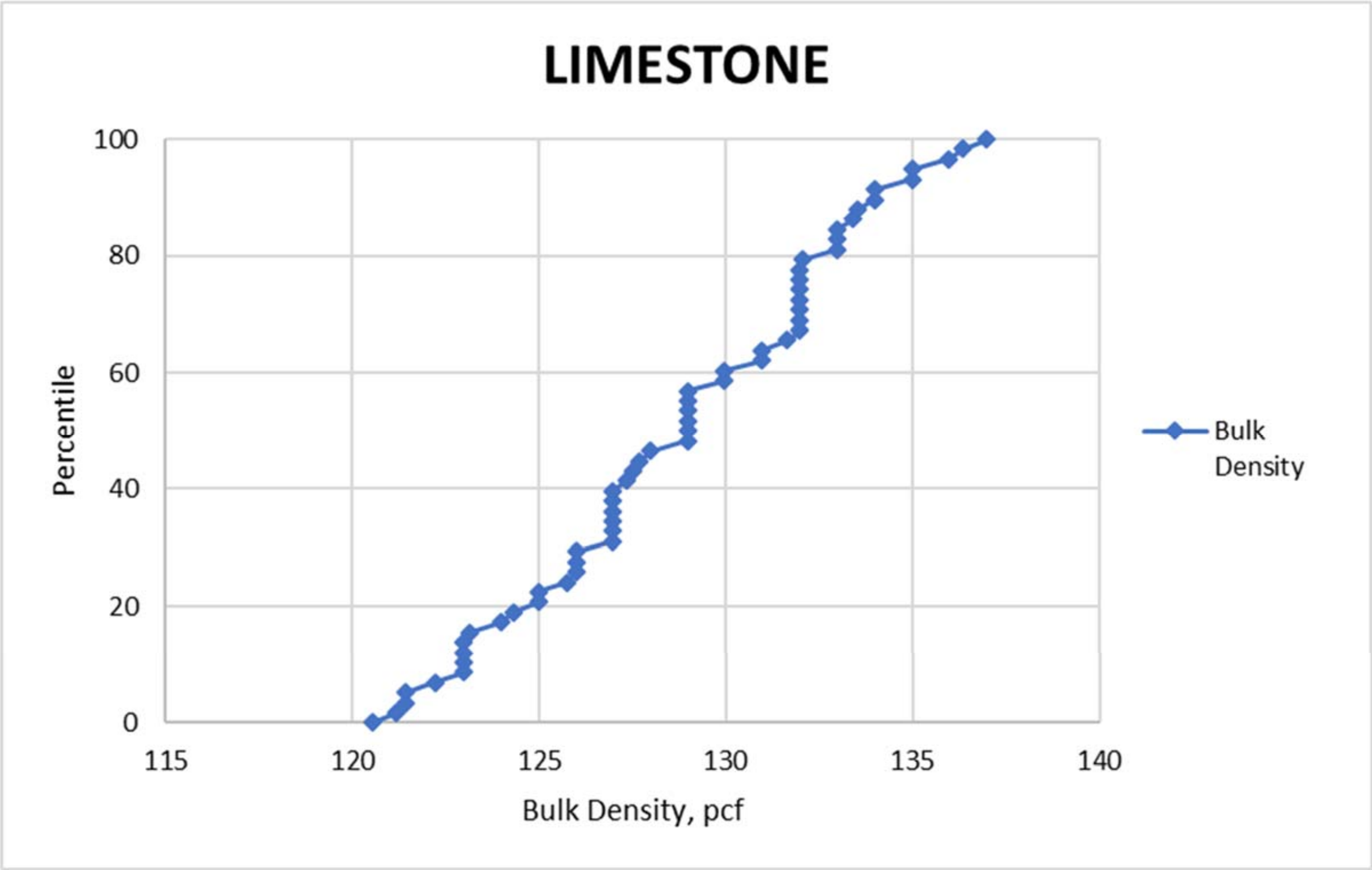
kshefty
Default

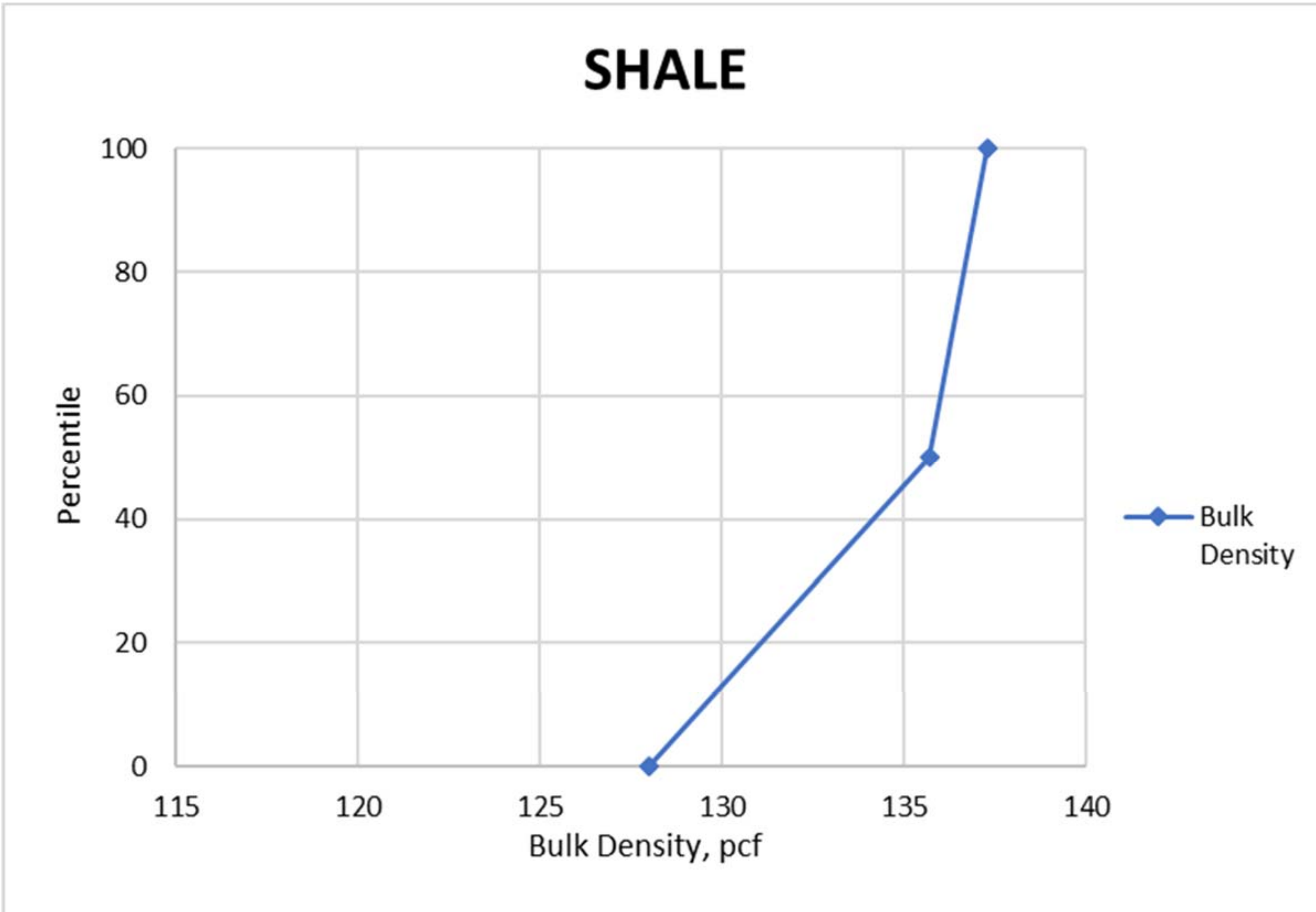
pw://pwhdruscen01:HDR_US_Central_01/Documents/Dallas_Area_Rapid_Transit_DART_Dallas_TX/DART_General_Planning_CS_V1/6.0_CAD_BIM/6.2_Work_In_Progress/TO_39_D2_Subway_Proj_Dev/6.2.3_Exhibits/GEOTECH/SHEETS/GEOTECHNICAL STICK PROFILE FIGURE 4I

Figure 5. Bulk density, limestone



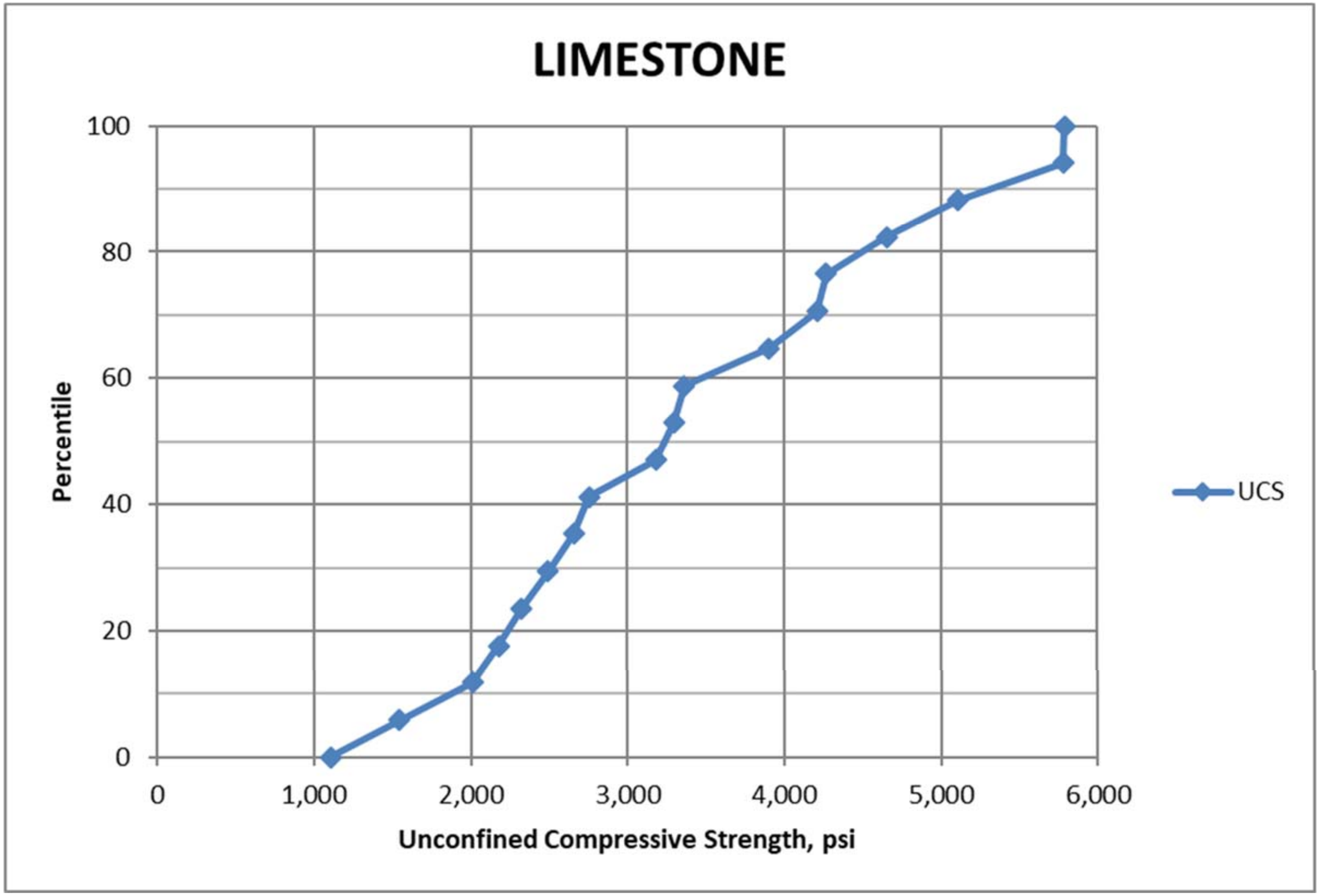
NOTE: Plot shows bulk density at as-received moisture content.

Figure 6. Bulk density, shale



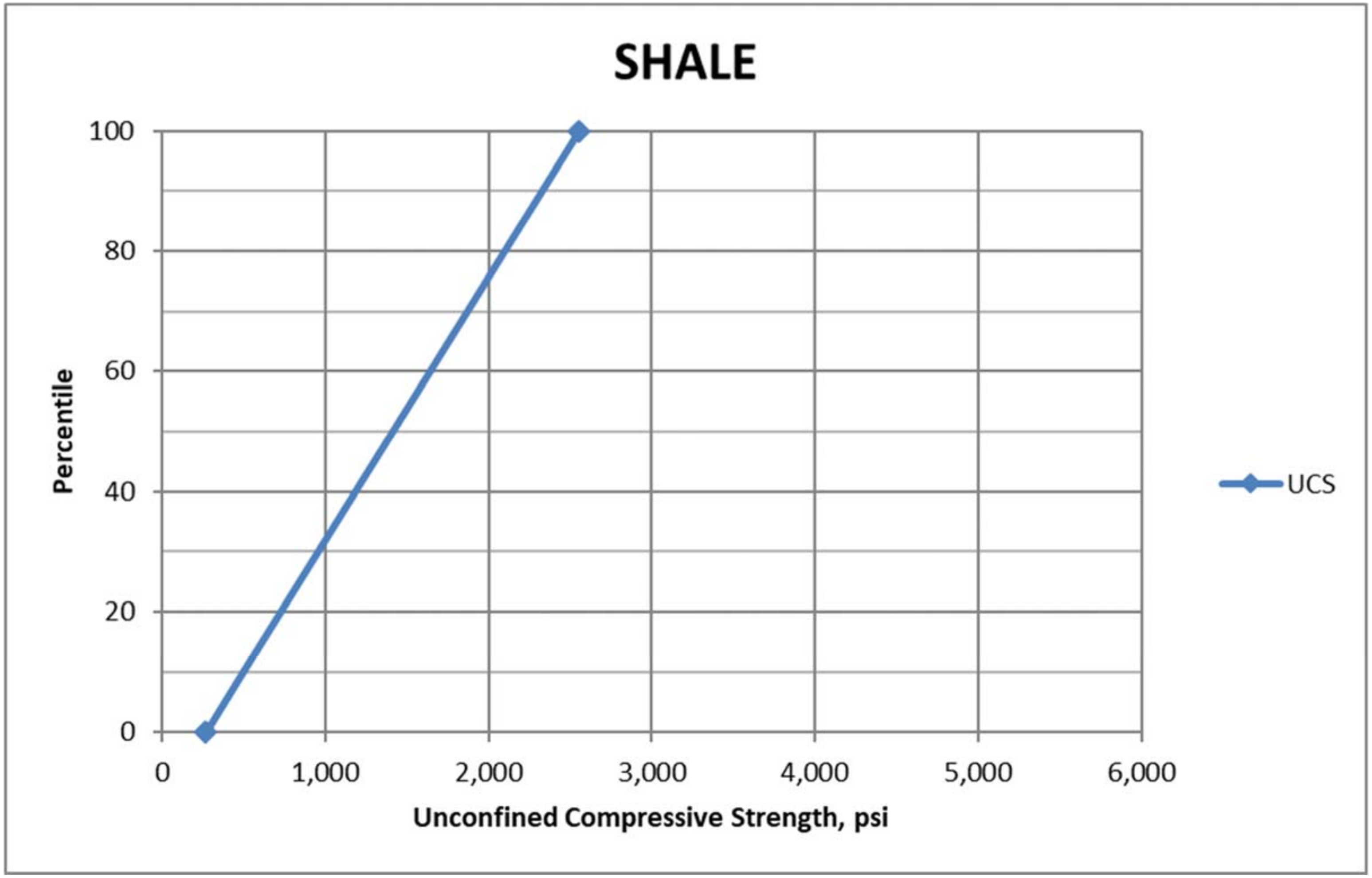
NOTE: Plot shows bulk density at as-received moisture content.

Figure 7. Unconfined compressive strength, limestone



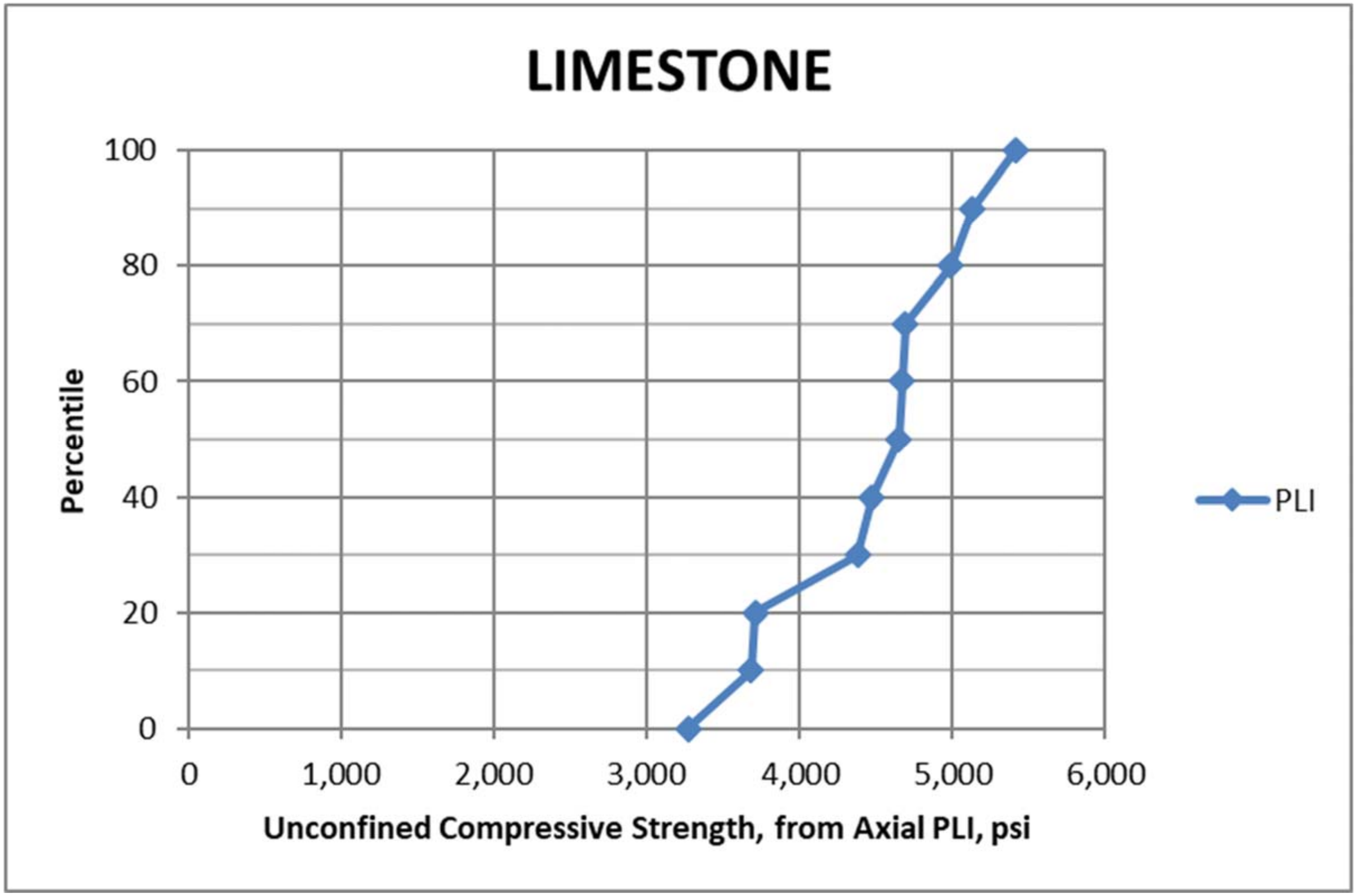
NOTE: Specimens were tested at as-received moisture content by ASTM D7012-C and D-7012-D.

Figure 8. Unconfined compressive strength, shale



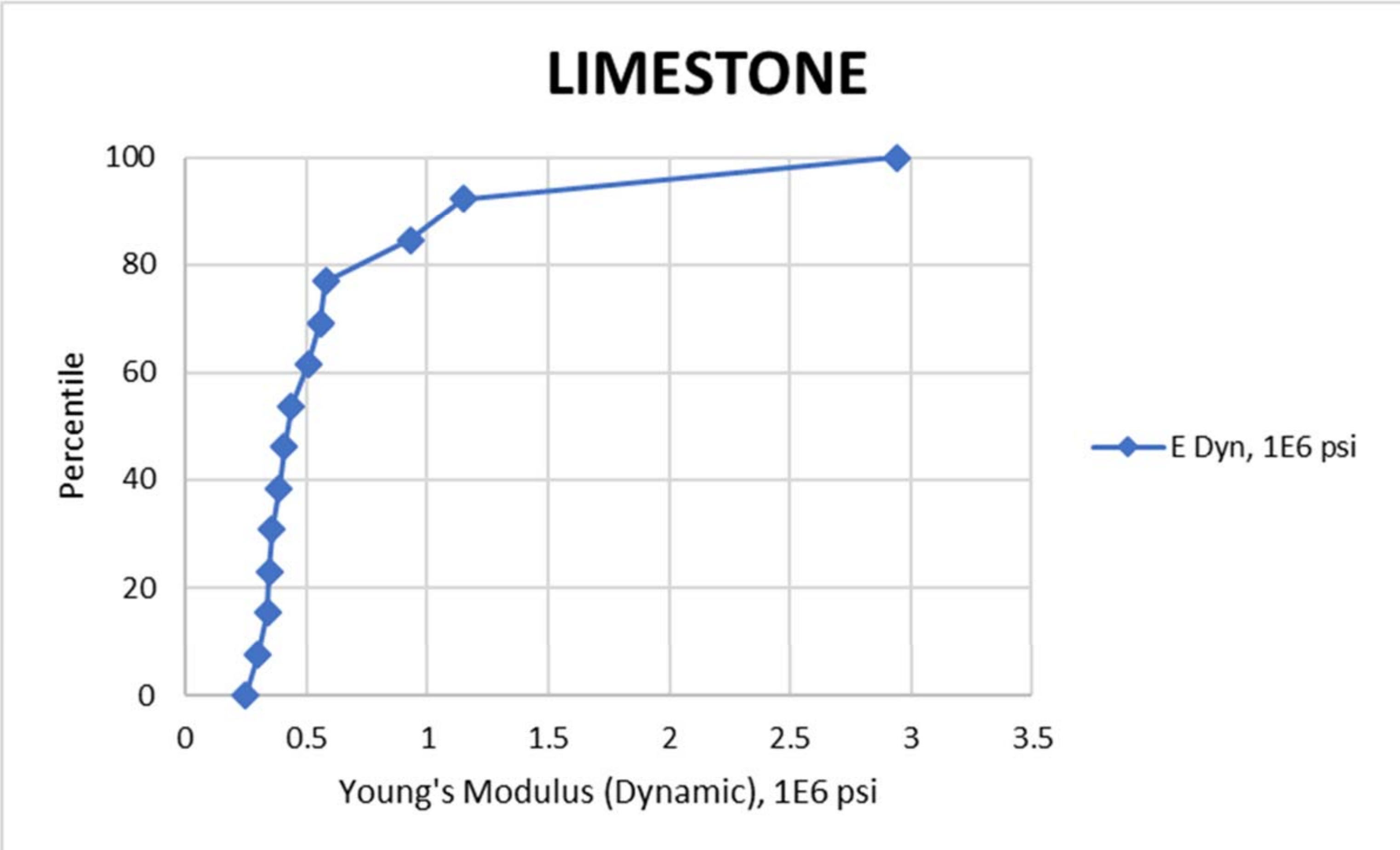
NOTE: Specimens were tested at as-received moisture content by ASTM D7012-C and D-7012-D.

Figure 9. Unconfined compressive strength estimated from axial point load index tests, limestone



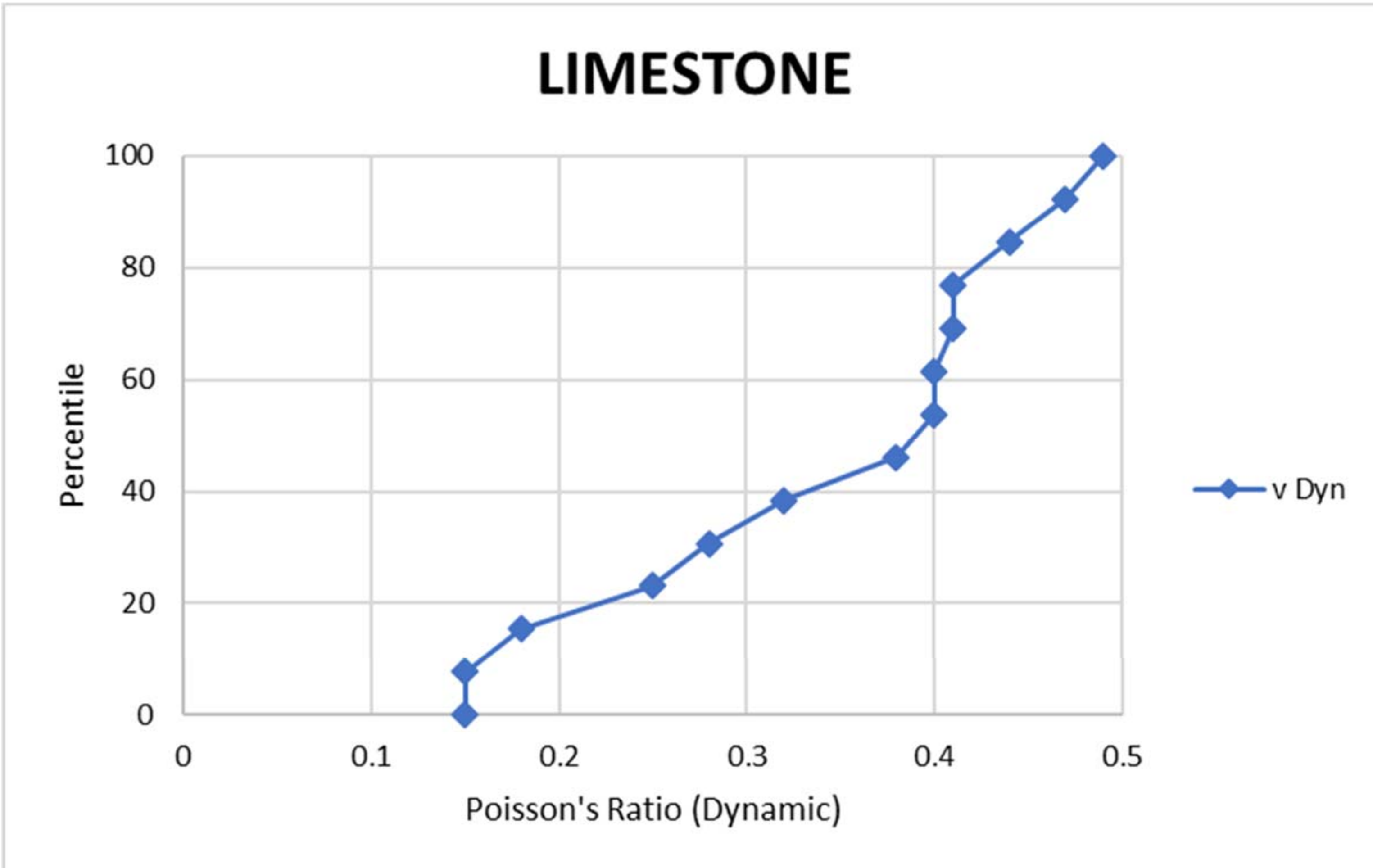
NOTE: Specimens were tested in saturated condition by ASTM D5731.

Figure 10. Dynamic Young's modulus, limestone



NOTE: Data are from tests on intact rock samples for pulse velocities and dynamic modulus, by ASTM D2845.

Figure 11. Dynamic Poisson's ratio, limestone



NOTE: Data are from tests on intact rock samples for pulse velocities and dynamic modulus, by ASTM D2845.

Figure 12. Splitting tensile strength, limestone

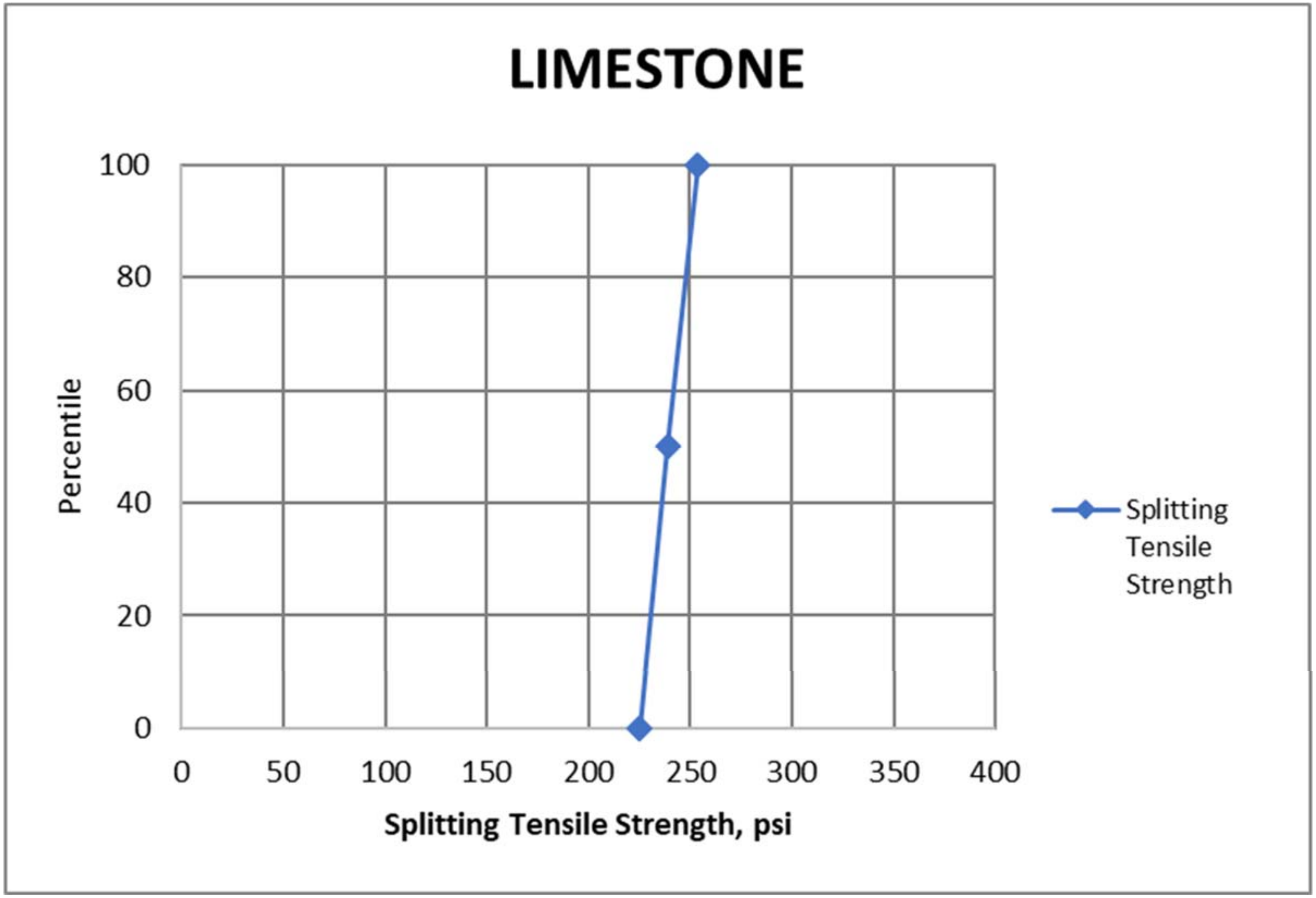


Figure 13. CERCHAR Abrasiveness Index, limestone

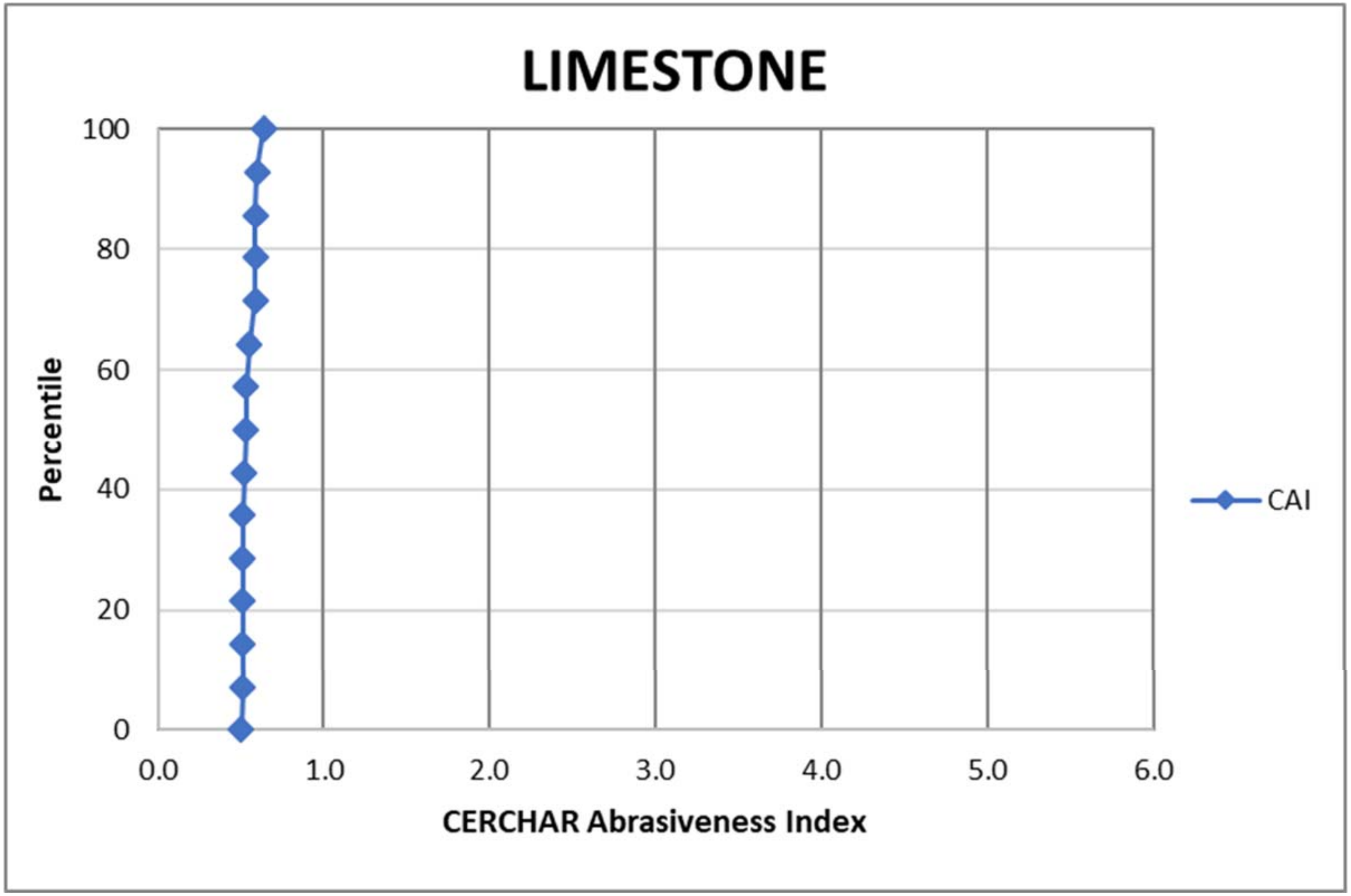
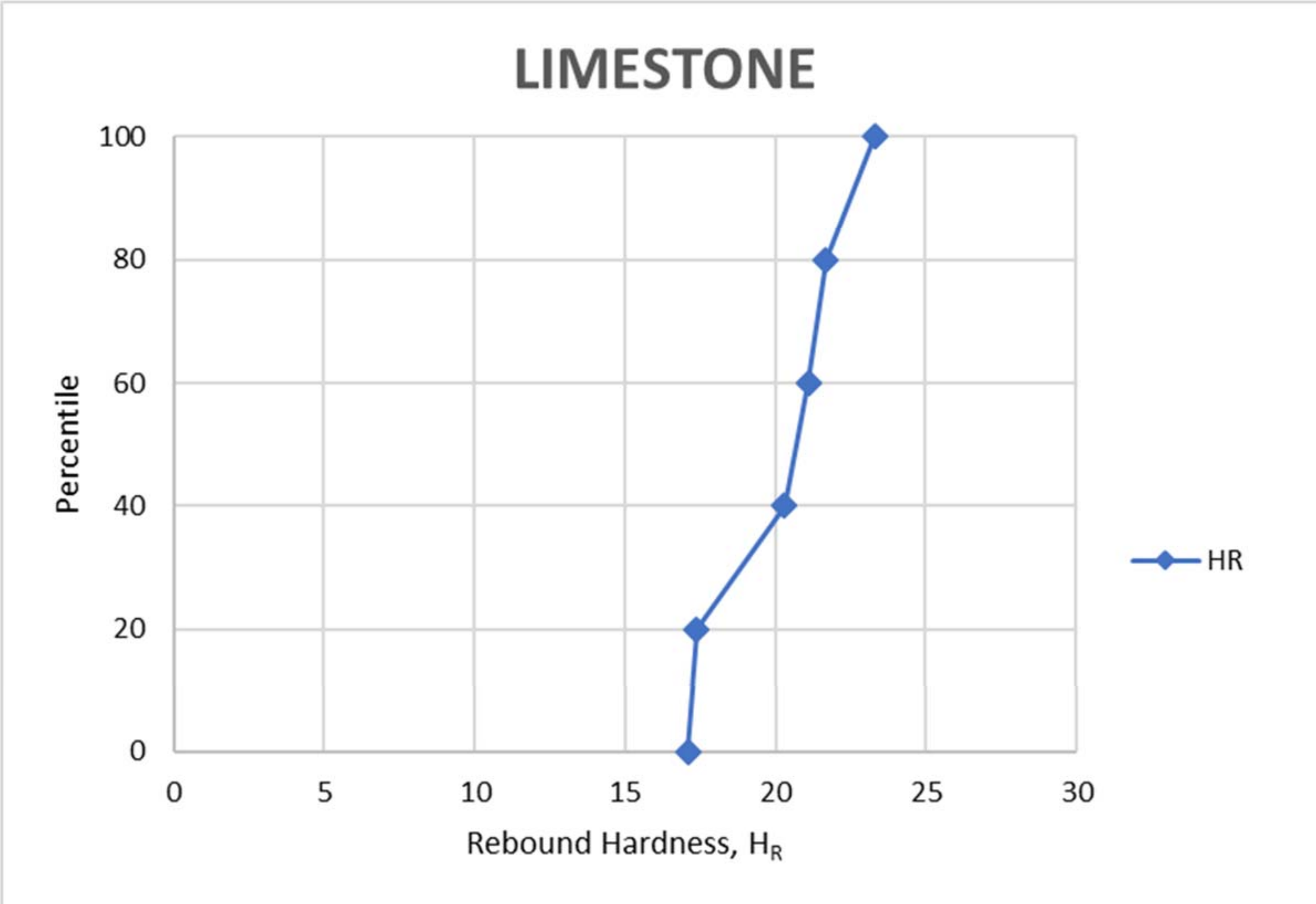


Figure 14. Rebound hardness, limestone



NOTE: Rebound hardness was determined from Schmidt hammer tests by ASTM 5873.

Figure 15. Slake durability, limestone

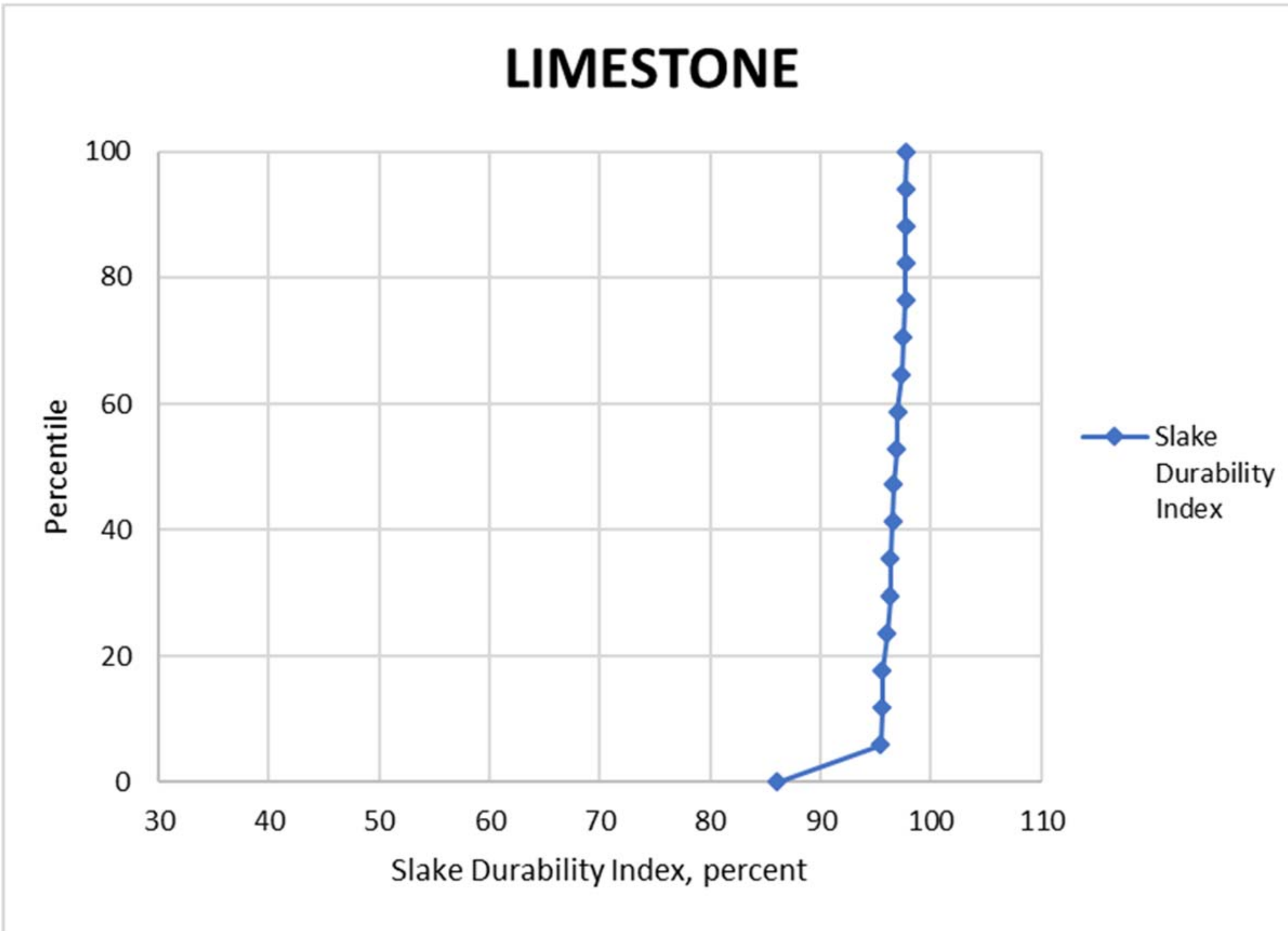


Figure 16. Slake durability, shale

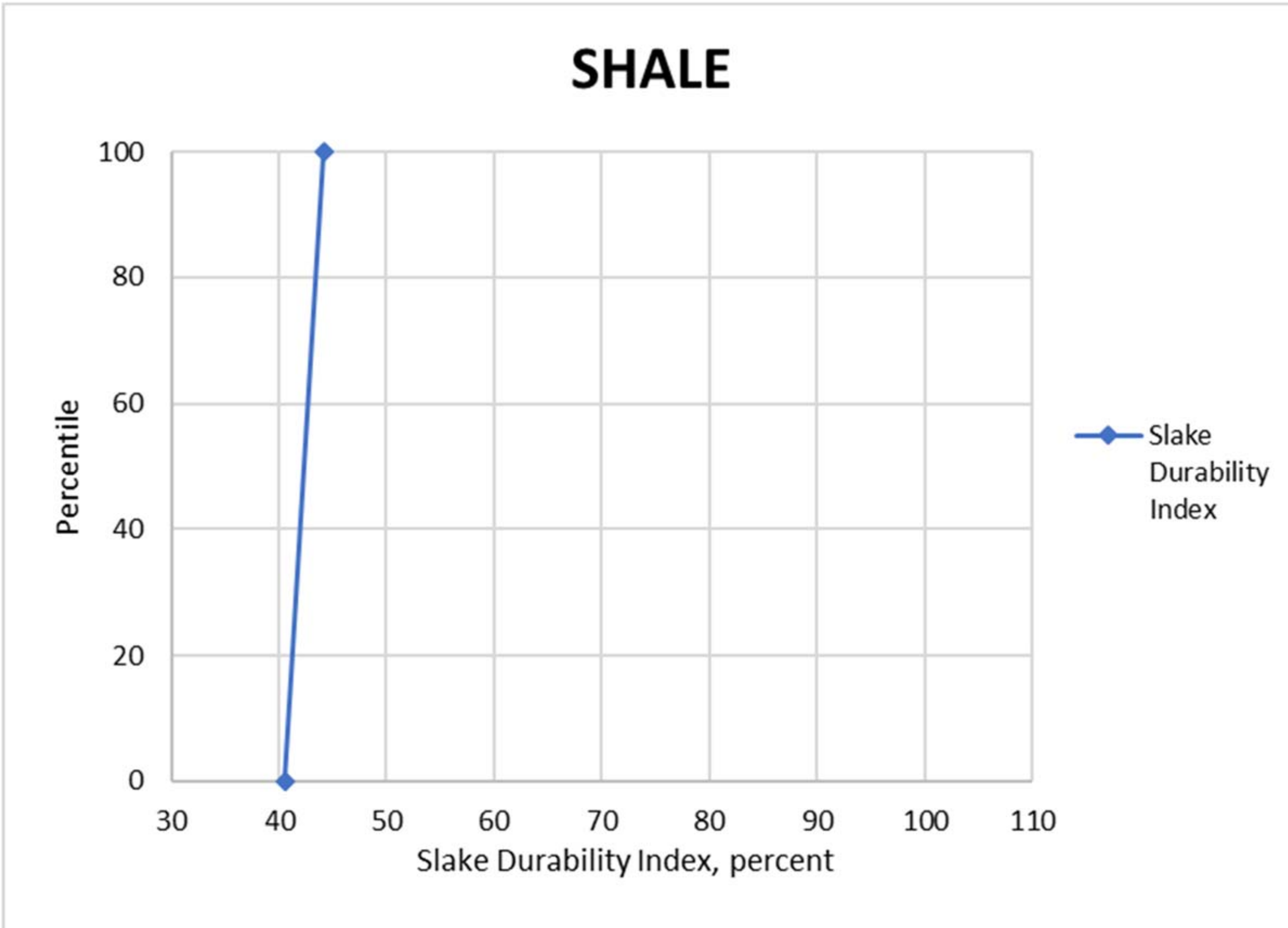
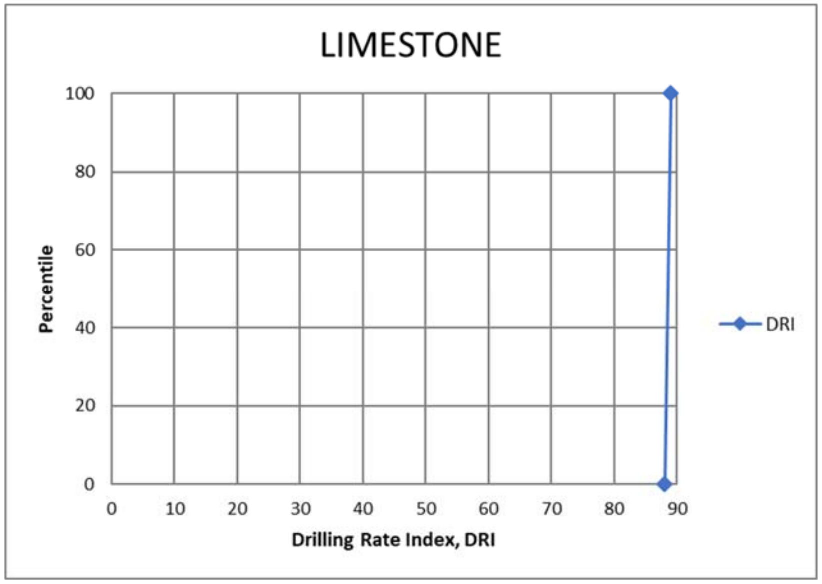
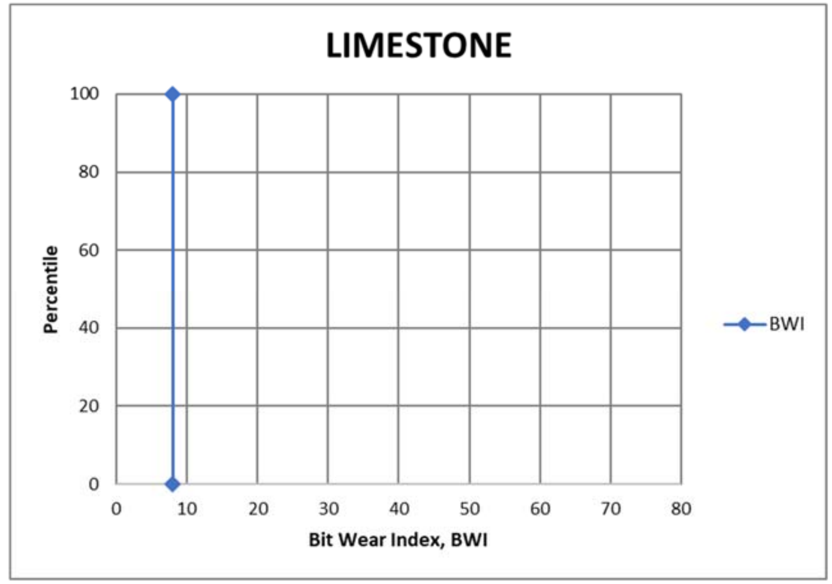
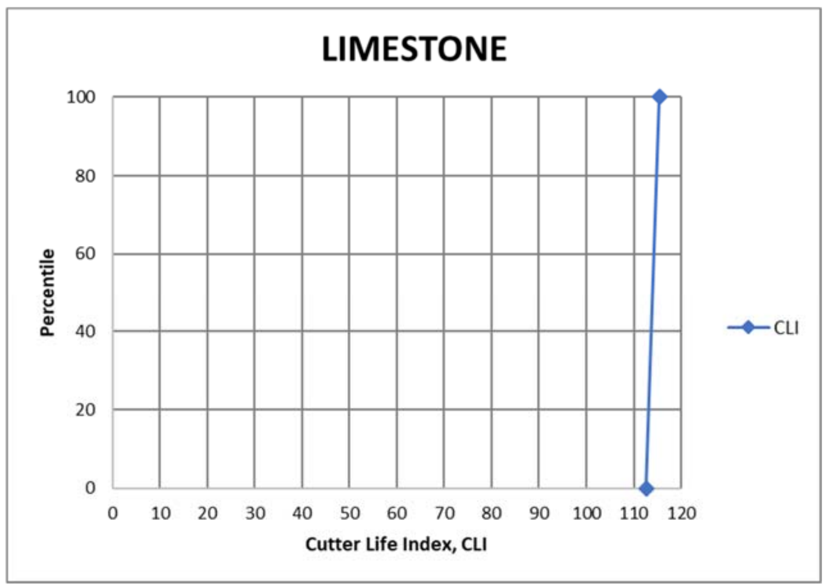


Figure 17. Drillability indices, limestone







APPENDICES

APPENDIX A

EXCERPT FROM DART D2 GROUND CLASS STUDY

1 OBJECTIVE

The objective of this study was to present the ground classification system developed for DART D2 tunnels and to develop design and preliminary baseline ground class distributions for proposed DART D2 excavations, based on the data available presented in the Geotechnical Data Report (GDR) prepared by Alliance Geotechnical Group dated August 29, 2019 (GPC6, 2019).

2 ASSUMPTIONS FOR GROUND CLASSIFICATION AND GROUND CLASS DISTRIBUTION

The following assumptions were made for this study. Changes in these assumptions could affect results of ground classifications and ground class distributions.

1. Tunnel alignment, stationing, and portal and station locations are those established for 20 percent design as of December 20, 2019.
2. Boring locations, depths, and descriptions for all borings are correct as shown in the GDR.
3. In case of conflict between boring logs and laboratory test data, for the purpose of finding ground class distributions, it was assumed that boring logs are correct.
4. It is assumed that the soil and rock descriptions can be used with drilling and sampling information to assign ground classes.
5. International Society for Rock Mechanics (ISRM) weathering grades (Table 1) are appropriate for ground class distinctions for rock. It is assumed that weathering grades shown on draft boring logs are relative grades for this region and not necessarily directly correlated with ISRM grades.
6. Ground class distributions are the same across the full width of tunnels, stations, and portal excavations for purposes of this calculation.
7. Ground class distributions are valid throughout a DART D2 underground alignment reach, even though borings may not be distributed throughout the reach.
8. Vertical test borings representatively sampled rock quality and soil types.
9. Soil samples are representative of in-situ soil.
10. Variations in drilling and sampling methods did not affect sample composition.
11. Soils characteristics are noted and described consistently and correctly in boring logs.
12. Information not shown on boring logs, such as RQD, Recovery, and run depths, can be appropriately obtained from other information in the GDR, such as rock core photos and rock discontinuity logs.

13. Ground class distributions will be reviewed and revised as necessary if there are changes to boring logs or other data in the GDR.
14. Highly and completely weathered rock which was not sampled is correctly described on boring logs based on other observations.
15. All artificial fill is identified on boring logs and can be classified as Ground Class F, Fill.
16. Soils described as clay and clayey on draft boring logs are alluvium.
17. Soils described as sand and sandy on draft boring logs are alluvium.
18. The top of rock can be defined as the level at which rock coring was initiated.
19. Ground classes in rock can be adequately and objectively determined based on Recovery, RQD, weathering, and descriptions of slickensided fracture surfaces recorded on boring logs.
20. All slickensided fractures present in recovered core samples were recorded on boring logs.
21. Unless otherwise noted on boring logs, core recovery loss and low RQD were due to reduced quality of rock.
22. All bentonite layers present in recovered core samples were recorded on boring logs.
23. Mechanical breaks and natural fractures in rock were correctly distinguished on boring logs.
24. RQDs recorded for shale reflect in-situ rock quality and not fractures that were initiated or opened due to handling, slaking, desiccation, stress relief, or swelling after the core was removed from the borehole.
25. Individual ground classes retain their distinct characteristics even when complexly interlayered within underground excavations.
26. Two-dimensional ground class distributions can be extrapolated to three-dimensional ground class distributions which are consistent throughout a defined underground alignment reach.
27. Ground conditions can be appropriately interpreted by orthogonally projecting data to the underground alignment from borings up to 400 feet away.
28. For purposes of defining upper and lower excavation limits, proposed Metro Center and CBD East Stations will be constructed by cut-and-cover method.
29. For purposes of defining upper and lower excavation limits, proposed Commerce Station will be constructed by Sequential Excavation Method (SEM).
30. Tunnel sections adjacent to proposed Commerce Station will be constructed by SEM. Other tunnel sections will be constructed by cut-and-cover method.
31. It is assumed that conditions above excavation crown and below excavation invert do not affect stability or design. These conditions will require re-evaluation when additional geotechnical data become available.

32. It is appropriate to develop preliminary baseline distributions of ground classes based on the data now available. It is assumed that relevant baselines will be evaluated in the context of the additional geotechnical investigations, advancing project design, and development of construction methodologies.

3 METHODOLOGY

The following sections describe the method and approach for development of DART D2 project ground classifications and the distribution of ground classes along the proposed underground alignment.

3.1 Ground Classifications System

1. A ground classification system was established for the DART D2 project based on the following general requirements:
   - Applicable to anticipated possible construction methods, including SEM, cut-and-cover construction, and Tunnel Boring Machine (TBM).
   - Quantitative, objective, and based on subsurface data collected and to be presented in project geotechnical data reports
   - Standardized terminology
   - Unambiguously communicable in terms of baseline values
   - Baseline classifications can be verified during construction
   - Same system can be applied to all DART D2 project underground construction
2. The DART D2 project ground classification criteria consider the project's geologic setting and specific soil and rock features affecting underground construction.
3. Ground Classes and their distinguishing characteristics are summarized in Table 2.
   - For unweathered to moderately weathered rock, classes are linked to International Society for Rock Mechanics (ISRM) weathering grades (See Table 1, from ISRM, 1981), fracture spacing, strength, number of sets of slickensided fractures, number and thickness of planar weakness zones, and presence/absence of inherently weak rock types.
   - Highly to completely weathered rock are here considered Intermediate Geomaterials (IGM). Their classification is linked to ISRM criteria for weathering grades IV and V, including decomposition and disintegration.
   - For soils, two natural soil groups were defined, along with an additional soil unit for fill. It was not possible to distinguish alluvial soils from residual soils corresponding to ISRM weathering grade VI based on information on boring logs and available laboratory test data, but the classification was retained for future use.

4. As shown in Table 2, the 12 defined ground classes were combined into eight Ground Class Groups and three General Ground Class Groups. As additional data are collected, ground classes may be grouped differently depending on baselining needs for construction. For example, it may become more appropriate to group classes by rock type rather than by rock quality and weathering.
5. "Weathered Rock," a term used on draft boring logs to describe uncored rock, was classified as Intermediate Geomaterial (IGM) and constitutes ISRM Weathering Grades IV (highly weathered rock) and V (completely weathered rock).
6. Overburden was defined as the non-lithified material above the "Weathered Rock."

3.2 Reach Definition

1. Ten reaches were defined for the proposed DART D2 project underground alignment. Reach limits were defined on the basis of proposed structures and anticipated construction methods. Reach limits and general ground conditions are shown in Table 3. Reach limits are shown in Figure 1.
2. Limits of Reaches 1 and 10 were defined on the basis of limits of proposed U-wall retained cuts at the West Portal and East Portal, respectively.
3. Limits of Reaches 2 and 9 were defined on the bases of limits of proposed cut-and-cover tunnel construction between adjacent to the West Portal and East Portal, respectively.
4. Limits of Reaches 3 and 8 were defined on the basis of limits of proposed cut-and-cover construction for Metro Center Station and CBD East Station, respectively.
5. Limits of Reach 5 were defined on the basis of limits of proposed SEM station excavation for Commerce Station.
6. Limits of Reaches 4 and 6 were defined on the basis of limits of proposed SEM tunnel excavation adjacent to the west end and east end of Commerce Station, respectively.
7. Limits of Reach 7 were defined on the basis of limits of proposed cut-and-cover tunnel construction adjacent to the west end of CBD East Station.
8. Reach stationing is shown for the reference alignment, which is the eastbound track. General reach descriptions apply to both alignments.

3.3 Excavation Horizon Definition

1. All excavation limits were based on top-of-rail elevations on 20 percent design alignment profile current as of December 20, 2019.
2. Vertical limits of proposed SEM tunnel excavation were defined as extending 22.2 feet upward from the tunnel alignment invert design elevation.
3. Vertical limits of proposed U-wall retained cut sections at the two portals were defined as extending upward from the base of the invert slab to the ground surface.

4. Vertical limits of proposed cut-and-cover tunnel construction were defined as extending upward from the base of the invert slab to the ground surface.
5. Vertical limits of proposed cut-and-cover station construction at Metro Center Station and CBD East Station were defined as extending upward from the base of the invert slab to the ground surface.
6. Vertical limits of excavation for proposed Commerce Station were defined based on SEM construction of a center-platform station extending 44 feet upward from the proposed station invert. The height of the excavation was assumed to be constant across the length of the station.
7. An excavation horizon was not defined for excavations for proposed cross passages or proposed pump and sump structure.
8. General ground conditions within excavation limits are included in the Reach descriptions in shown in Table 3.

3.4 Data for Analysis

1. Data for analysis was from the Geotechnical Data Report (GDR) prepared by Alliance Geotechnical Group dated August 29, 2019 (GPC6, 2019).
2. Borings drilled for the DART D2 project within 400 feet of the proposed excavation limits were considered applicable. Reach limits, proposed project structures, applicable borings, and relevant depths for each reach are presented in Table 4. Boring locations are shown in Figure 1.
3. Ground classes for soil were based on descriptive information and test data shown on boring logs and on laboratory test data. In case of conflicting information, descriptions on boring logs were generally considered correct for purposes of this calculation.
4. Ground classes for rock and highly weathered rock based on descriptions on boring logs and logged measurements of core recovery, RQD, slickensides, and weathering descriptions.
5. Drilling, sampling, logging, and interpretation methods for historical borings for other projects differed from those of BRL GEC. Data from logs of historical borings by others presented in Appendix A of Collier, 2015 was used to supplement D2 data.
6. Supplemental general information about site conditions was obtained from Huitt-Zollars, 1992; Collier, 2015; and HNTB, 2016.

3.5 Ground Class Distributions

1. Ground classification criteria were applied to each foot of depth in each applicable boring in each reach along the proposed underground alignment. This information is presented in the left columns of Attachment A.

2. Upper and lower depths of the excavation horizon at each boring was determined based on the 20 percent design underground alignment drawing current as of December 20, 2019. Boring locations were orthogonally projected to the alignment.
3. For proposed portal U-wall retained excavations and cut-and-cover tunnels and stations, the excavation horizon extends from invert to ground surface (Reaches 1, 2, 3, 7, 8, 9, and 10).
4. The thickness of the excavation horizon for U-wall retained excavation reaches and cut-and-cover reaches was taken as the thickness at the longitudinal midpoint of the reach (Reaches 1, 2, 3, 7, 8, 9, and 10).
5. For proposed SEM tunnels, the excavation horizon extends 22.2 feet upward from invert (Reaches 4 and 6).
6. For the proposed SEM station at Commerce Street, the excavation horizon extends 44 feet upward from invert, over the full length of the station.
7. The proportions of the various ground classes within each boring were calculated as a percentage of boring footage within the excavation horizon. Results are presented in Table 5 and included in Attachment A.

3.5.1 PORTAL U-WALL RETAINED EXCAVATIONS

1. For portal reaches (Reaches 1 and 10), the proportions of each ground class in each boring were calculated as percentages of the total boring footage and as a percentage of boring footage within the proposed portal U-wall excavations. Results are included in Attachment A and presented in Table 5.
2. Results were compiled by reach by finding the maximum, minimum, median, and total percentages of each ground class for the borings within each portal reach. Ground class distributions for excavation of portal Reaches 1 and 10 are summarized in Table 6 and in Table 7.

3.5.2 CUT-AND-COVER TUNNEL EXCAVATION

3. For cut-and-cover tunnel reaches (Reaches 2, 7, and 9), the proportions of each ground class in each boring were calculated as percentages of the total boring footage and as a percentage of boring footage within the tunnel excavation. Results are included in Attachment A and presented in Table 5.
4. Results were compiled by reach by finding the maximum, minimum, median, and total percentages of each ground class for the borings within each cut-and-cover tunnel reach along the underground alignment. Ground class distributions for excavation of cut-and-cover tunnel Reaches 2, 7, and 9 are summarized in Table 6 and in Table 8.

3.5.3 MINED (SEM) TUNNEL EXCAVATION

1. For mined (SEM) tunnel reaches (Reaches 4 and 6), the proportions of each ground class in each boring were calculated as percentages of the total boring footage and as a percentage of boring footage within the tunnel excavation. Results are included in Attachment A and presented in Table 5.
2. Results were compiled by reach by finding the maximum, minimum, median, and total percentages of each ground class for the borings within each SEM tunnel reach along the underground alignment. Ground class distributions for excavation of mined (SEM) tunnel Reaches 4 and 6 are summarized in Table 6 and in Table 9.

3.5.4 CUT-AND-COVER STATION EXCAVATION

1. For cut-and-cover Metro Center and CBD East Station reaches (Reaches 3 and 8), the proportions of each ground class in each boring were calculated as percentages of the total boring footage and as a percentage of boring footage within the proposed station excavation. Results are included in Attachment A and presented in Table 5.
2. Results were compiled by reach by finding the maximum, minimum, median, and total percentages of each ground class for the borings within each cut-and-cover station reach. Ground class distributions for excavation of station Reaches 3 and 8 are summarized in Table 6 and in Table 10.

3.5.5 MINED (SEM) STATION EXCAVATION

3. For the mined (SEM) Commerce Station reach (Reach 5), the proportions of each ground class in each boring were calculated as percentages of the total boring footage and as a percentage of boring footage within the proposed station excavation. Results are included in Attachment A and presented in Table 5.
4. Results were compiled by reach by finding the maximum, minimum, median, and total percentages of each ground class for the borings within the Commerce Station reach. Ground class distributions for excavation of station Reaches 3 and 8 are summarized in Table 6 and in Table 11.

4 RESULTS

1. Table 6 summarizes results for all underground excavations.
2. Reach-specific results are presented in the following tables:

Table 7	Portal U-wall retained excavations	Reaches 1 and 2
Table 8	Cut-and-cover tunnels	Reaches 2, 4, 7, and 9
Table 9	SEM tunnels	Reaches 4 and 6
Table 10	Cut-and-cover stations	Reaches 3 and 8

Table 11 SEM station Reach 5

3. Ranges of estimated volume percentages of each ground class within the proposed excavation for each reach are shown as follows:
   - The maximum/minimum range by reach represents the range of ground class percentages that could be encountered within a vertical slice orthogonal to the alignment anywhere within a given reach.
   - The median percentage by reach represents the median or typical mix of ground classes at the excavation face throughout the length of a given reach.
   - The total percentage by reach represents the estimated mix of ground classes that are anticipated to be excavated throughout the length of a given reach.
4. Tables 12, 13, and 14 present summaries of distributions of Ground Class Groups by excavation method, including open-cut excavation for portals (Table 12), cut-and-cover excavation for tunnels and two stations (Table 13), and SEM excavation for tunnels and one station (Table 14).
5. The generalized geologic profile presented in Attachment B shows the spatial distribution of Ground Class Groups and rock types along the length of the DART D2 underground alignment. It should be noted that this an interpreted profile and that information was extrapolated and interpolated between widely spaced borings. Actual ground conditions may differ from the conditions shown. Levels shown for top of rock and top of shale were estimated from D2 project data supplemented by data from historical boring logs in Collier, 2015.

5 CONCLUSIONS

The ground class descriptions and distributions in this memorandum will require updating after additional site-specific geotechnical data are available.

Although based on the limited data, the ranges and distributions of ground classes shown in Tables 6 through 14 are suggested for use in preliminary design estimates and as preliminary baselines for excavations for DART D2 tunnels, stations, and portals. All percentages discussed below are by volume.

5.1 Portal U-Wall Retained Excavations

1. Based on the limited available data, excavations for the portal U-wall retained cuts will be entirely in fill and alluvium, as shown in Table 12. Because the invert is not far above the overburden-rock contact, a small amount of “weathered rock” could also be present at both the West Portal and the East Portal.
2. No rock excavation at either the West Portal or the East Portal is indicated by the limited available data.

5.2 Cut-and-Cover Tunnels

1. Based on the limited available data, excavations for the proposed cut-and-cover tunnels in Reach 2 and Reach 7 will both encounter rock, constituting about 40 percent of the excavated volume and primarily Ground Class I limestone. The remainder of excavation in Reach 2 and Reach 7 will be small amounts (<10 percent) of other rock, "weathered rock," alluvium, and fill.
2. Excavations for the proposed cut-and-cover tunnel in Reach 9, adjacent to the East Portal, will encounter a small amount (<10 percent) of Ground Class II limestone. The remainder of excavation in Reach 9 will be Fill, Alluvium, and some "weathered rock.

5.3 Mined (SEM) Tunnels

1. All SEM tunnel excavation will be in rock.
2. Excavations for the proposed SEM tunnels in Reach 4 will be mostly (62 percent) in Ground Class I limestone. The remainder of excavation in Reach 4 will be in Ground Class II limestone and Ground Class II shale.
3. Excavations for the proposed SEM tunnels in Reach 6 will be mostly (75 percent) in Ground Class I limestone. The remainder of excavation in Reach 6 will be in Ground Class II limestone.

5.4 Cut-and-Cover Stations

1. Both proposed cut-and-cover stations will be excavated in overburden and rock.
2. Nearly half (49 percent) of the volume of excavated material at Metro Center Station (Reach 3) will be Ground Class I limestone. The remainder of excavation will include Ground Class II limestone, Ground Class I and II shale, "weathered rock," alluvium, and fill.
3. More than two-thirds (68 percent) of the volume of excavated material at CBD East Station (Reach 8) will be clayey alluvium. The remainder of excavation will include fill, sandy alluvium, "weathered rock," and Ground Class I and II limestone. No shale is anticipated to be encountered in Reach 6 based on available information. A 1.5-foot thick bentonite layer is anticipated to be encountered within excavations in limestone for CBD East Station.

5.5 SEM Station

1. All SEM excavation for Commerce Station will be in rock.
2. Almost all (99 percent) of the volume of excavated material at Commerce Station will be Ground Class I limestone.
3. Based on available information, the remaining volume of excavated material will be Ground Class II limestone.

4. Because the proposed Commerce Station invert nearly coincides with the limestone-shale contact, some shale could be encountered in excavations near the invert.

6 REFERENCES

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GPC6, 2019. *Geotechnical Data Report, Dallas CBD Second Light Rail Alignment – DART D-2,* prepared by Alliance Geotechnical Group, August 27, 2019, 899 p.

Huitt-Zollars, Inc., 1992. *DART North Central Line, Routh Street to Mockingbird Lane Line Section NC-1, Design Report.* prepared in association with Sverdrup Corporation, Arredonda; Brunz, & Associates, Inc.; LS Transit Systems, Inc.; Helmuth, Obata & Kasabaum, Inc.; and Campos Engineering, Inc., 142 p.

HNTB Corporation (HNTB), 2016. *Geotechnical Report for Underground Guideway, Rev. 0.* General Planning Consultant VI Task Order #16, Dallas CBD Second Light Rail Alignment (D2), 22 p.

International Society for Rock Mechanics, 1981. "Suggested Methods for the Quantitative Description of Discontinuities in Rock Masses," in ISRM Suggested Methods: Rock Characterization, Testing and Monitoring, E. T. Brown, editor, Pergamon Press, Oxford, p. 31.

ATTACHMENT A

GROUND CLASSIFICATIONS BY BORING

DART D2 Tunnel Alignment
Ground Classifications by Boring

NOTES:
1. All classifications were based on draft or incomplete boring logs without laboratory test data
2. Generalized Ground Classes:
   a. F Ground Class includes only Ground Class F.
   b. Alluvium Ground Class Group includes Ground Classes A1 and A2
   c. Residual Soil Ground Class Group includes only Ground Class RS.
   d. "Weathered Rock" Ground Class Group includes only Ground Class IGM.
   e. Ground Class Group III includes Ground Classes L-III and S-III.
   f. Ground Class Group II includes Ground Classes L-II and S-II.
   g. Ground Class Group I includes Ground Classes L-II and S-I.
   h. Bentonite Ground Class Group includes layers of bentonite and bentonitic shale >6 inches thick (Ground Class B).
3. Top of Rock (GC I, II, or III) assumed to be at level of start of coring.
4. Material logged as rock above level of start of coring, sometimes described as "Weathered Rock" on logs, is assumed to be highly to completely weathered rock (GC IGM).
5. Rock Ground Class determinations are based primarily on RQD, slickensides, and weathering descriptions on draft boring logs. (I=RQD >90; II=RQD 50-90; III=RQD<50)
6. Excavation horizon shown only for borings within 400 feet of alignment.
7. For portal, cut-and-cover tunnels, and cut-and-cover stations, top of excavation is ground surface.
8. For borings at portals, Excavation Horizon extends from invert, which is 5.0 feet below Top of Rail, to ground surface.
9. For borings along proposed cut-and-cover tunnels, Excavation Horizon extends from invert, which is 5.7 feet below Top of Rail, to ground surface.
10. For borings along proposed mined (SEM) tunnels, Excavation Horizon extends from invert, which is 5.5 feet below Top of Rail, to crown, which is 22.2 feet above invert.
11. For borings at proposed cut-and-cover stations, Excavation Horizon extends from invert, which is 9.5 feet below Top of Rail at Metro Center Station and 5.3 feet below Top of Rail at CBD East Station, to ground surface.
12. For borings at mined (SEM) Commerce Station, Excavation Horizon extends 44.0 feet upward from invert, which is 10.0 feet below Top of Rail. Assume same horizon height across station length.

Boring No.	Soil Type/Ground Class	Vertical Extent		Vertical Thickness (ft)	Ground Class Group	Comments	Depth to Top of Excavation, ft	Depth to Excavation Invert, ft	Reach and Structure
		Top Depth (ft)	Bottom Depth (ft)						
B-1	F	0.0	1.5	1.5	Fill		0.00	67.94	3
	A1	1.5	2.0	0.5	Alluvium				Metro Center Sta
	A2	2.0	5.0	3.0					
	A1	5.0	14.0	9.0					
	A2	14.0	25.0	11.0					
	IGM	25.0	31.0	6.0	"Weathered Rock"				
	L-I	31.0	66.0	35.0	I				
	S-II	66.0	71.0	5.0	II		1.94		
	S-I	71.0	96.0	25.0	I				
	S-II	96.0	117.0	21.0	II				
	S-I	117.0	121.0	4.0	I				
				121.0					

Boring No.	Soil Type/Ground Class	Vertical Thickness (ft)	Percentage for boring	Whole unit thickness in Excavation Horizon	Partial unit thickness in Excavation Horizon	Thickness within Excavation, ft	Percentage within Excavation
B-1	F	1.5	1.2%	1.5	0.0	1.5	2.2%
	A1	9.5	7.9%	9.5	0.0	9.5	14.0%
	A2	14.0	11.6%	14.0	0.0	14.0	20.6%
	RS	0.0	0.0%	0.0	0.0	0.0	0.0%
	IGM	6.0	5.0%	6.0	0.0	6.0	8.8%
	L-III	0.0	0.0%	0.0	0.0	0.0	0.0%
	S-III	0.0	0.0%	0.0	0.0	0.0	0.0%
	L-II	0.0	0.0%	0.0	0.0	0.0	0.0%
	S-II	26.0	21.5%	0.0	1.9	1.9	2.9%
	L-I	35.0	28.9%	35.0	0.0	35.0	51.5%
	S-I	29.0	24.0%	0.0	0.0	0.0	0.0%
	B	0.0	0.0%	0.0	0.0	0.0	0.0%
		121.0	100.0%	66.0	1.9	67.9	100.0%

Boring No.	Ground Class Group	Vertical Thickness (ft)	Percentage for boring	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
B-1	Fill	1.5	1.2%	1.5	2.2%
	Alluvium	23.5	19.4%	23.5	34.6%
	Residual Soil	0.0	0.0%	0.0	0.0%
	'Weathered Rock'	6.0	5.0%	6.0	8.8%
	III	0.0	0.0%	0.0	0.0%
	II	26.0	21.5%	1.9	2.9%
	I	64.0	52.9%	35.0	51.5%
	Bentonite	0.0	0.0%	0.0	0.0%
		121.0	100.0%	67.9	100.0%

Boring No.	Ground Class	Vertical Extent		Vertical Thickness (ft)	Ground Class Group	Comments	Depth to Top of Excavation, ft	Depth to Excavation Invert, ft	Reach and Structure
		Top Depth (ft)	Bottom Depth (ft)						
B-2	F	0.0	5.0	5.0	Fill				
	A1	5.0	35.5	30.5	Alluvium				
	IGM	35.5	40.0	4.5	"Weathered Rock"				
	L-I	40.0	120.0	80.0	I				
				0.0					
				0.0					
				0.0					
				0.0					
				0.0					
				0.0					
				0.0					
				0.0					
				0.0					
				0.0					
				0.0					
			0.0	120.0					

Boring No.	Soil Type/Ground Class	Vertical Thickness (ft)	Percentage for boring	Whole unit thickness in Excavation Horizon	Partial unit thickness in Excavation Horizon	Thickness within Excavation, ft	Percentage within Excavation
B-2	F	5.0	4.2%	0.0	0.0	0.0	0.0%
	A1	30.5	25.4%	0.0	0.0	0.0	0.0%
	A2	0.0	0.0%	0.0	0.0	0.0	0.0%
	RS	0.0	0.0%	0.0	0.0	0.0	0.0%
	IGM	4.5	3.8%	0.0	0.0	0.0	0.0%
	L-III	0.0	0.0%	0.0	0.0	0.0	0.0%
	S-III	0.0	0.0%	0.0	0.0	0.0	0.0%
	L-II	0.0	0.0%	0.0	0.0	0.0	0.0%
	S-II	0.0	0.0%	0.0	0.0	0.0	0.0%
	L-I	80.0	66.7%	0.0	0.0	0.0	0.0%
	S-I	0.0	0.0%	0.0	0.0	0.0	0.0%
	B	0.0	0.0%	0.0	0.0	0.0	0.0%
		120.0	100.0%	0.0	0.0	0.0	0.0%

Boring No.	Generalized Ground Class	Vertical Thickness (ft)	Percentage for boring	Thickness within Excavation, ft	Percentage within Excavation
B-2	Fill	5.0	4.2%	0.0	0.0%
	Alluvium	30.5	25.4%	0.0	0.0%
	Residual Soil	0.0	0.0%	0.0	0.0%
	'Weathered Rock'	4.5	3.8%	0.0	0.0%
	III	0.0	0.0%	0.0	0.0%
	II	0.0	0.0%	0.0	0.0%
	I	80.0	66.7%	0.0	0.0%
	Bentonite	0.0	0.0%	0.0	0.0%
		120.0	100.0%	0.0	0.0%

Boring No.	Soil Type/Ground Class	Vertical Extent		Vertical Thickness (ft)	Ground Class Group	Comments	Depth to Top of Excavation, ft	Depth to Excavation Invert, ft	Reach and Structure
		Top Depth (ft)	Bottom Depth (ft)						
B-3	F	0.0	3.0	3.0	Fill		44.13	90.23	5
	A2	3.0	7.0	4.0	Alluvium				Commerce Sta
	A1	7.0	12.0	5.0					
	A2	12.0	17.0	5.0					
	IGM	17.0	20.0	3.0	"Weathered Rock"				
	L-I	20.0	97.0	77.0	I		46.10		
	S-I	97.0	112.0	15.0					
	S-II	112.0	120.0	8.0	II				
				0.0					
				0.0					
				0.0					
				0.0					
				0.0					
				0.0					
				0.0					
				120.0					

Boring No.	Soil Type/Ground Class	Vertical Thickness (ft)	Percentage for boring	Whole unit thickness in Tunnel Horizon	Partial unit thickness in Excavation Horizon	Thickness within Excavation, ft	Percentage within Excavation
B-3	F	3.0	2.5%	0.0	0.0	0.0	0.0%
	A1	5.0	4.2%	0.0	0.0	0.0	0.0%
	A2	9.0	7.5%	0.0	0.0	0.0	0.0%
	RS	0.0	0.0%	0.0	0.0	0.0	0.0%
	IGM	3.0	2.5%	0.0	0.0	0.0	0.0%
	L-III	0.0	0.0%	0.0	0.0	0.0	0.0%
	S-III	0.0	0.0%	0.0	0.0	0.0	0.0%
	L-II	0.0	0.0%	0.0	0.0	0.0	0.0%
	S-II	8.0	6.7%	0.0	0.0	0.0	0.0%
	L-I	77.0	64.2%	0.0	46.1	46.1	100.0%
	S-I	15.0	12.5%	0.0	0.0	0.0	0.0%
	B	0.0	0.0%	0.0	0.0	0.0	0.0%
		120.0	100.0%	0.0	46.1	46.1	100.0%

Boring No.	Ground Class Group	Vertical Thickness (ft)	Percentage for boring	Thickness within Excavation, ft	Percentage within Excavation
B-3	Fill	3.0	2.5%	0.0	0.0%
	Alluvium	14.0	11.7%	0.0	0.0%
	Residual Soil	0.0	0.0%	0.0	0.0%
	'Weathered Rock'	3.0	2.5%	0.0	0.0%
	III	0.0	0.0%	0.0	0.0%
	II	8.0	6.7%	0.0	0.0%
	I	92.0	76.7%	46.1	100.0%
	Bentonite	0.0	0.0%	0.0	0.0%
		120.0	100.0%	46.1	100.0%

Ground Classifications by Boring

Boring No.	Soil Type/Ground Class	Vertical Extent		Vertical Thickness (ft)	Ground Class Group	Comments	Depth to Top of Excavation, ft	Depth to Excavation Invert, ft	Reach and Structure
		Top Depth (ft)	Bottom Depth (ft)						
P-102	F	0.0	4.0	4.0	Fill		0.00	13.61	9
	A1	4.0	14.0	10.0	Alluvium		9.61		East Portal
	A2	14.0	15.0	1.0					
	IGM	15.0	21.0	6.0	"Weathered Rock"				
	L-I	21.0	26.0	5.0	I				
	L-II	26.0	31.0	5.0	II	45o slicks			
	L-I	31.0	51.0	20.0	I				
	L-II	51.0	61.0	10.0	II	45o slicks			
	L-I	61.0	91.0	30.0	I				
	L-II	91.0	121	30.0	II	45o slicks			
				0.0					
				0.0					
				0.0					
				0.0					
				121.0					

Boring No.	Soil Type/Ground Class	Vertical Thickness (ft)	Percentage for boring	Whole unit thickness in Excavation Horizon	Partial unit thickness in Excavation Horizon	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
P-102	F	4.0	3.3%	4.0	0.0	4.0	29.4%
	A1	10.0	8.3%	0.0	9.6	9.6	70.6%
	A2	1.0	0.8%	0.0	0.0	0.0	0.0%
	RS	0.0	0.0%	0.0	0.0	0.0	0.0%
	IGM	6.0	5.0%	0.0	0.0	0.0	0.0%
	L-III	0.0	0.0%	0.0	0.0	0.0	0.0%
	S-III	0.0	0.0%	0.0	0.0	0.0	0.0%
	L-II	45.0	37.2%	0.0	0.0	0.0	0.0%
	S-II	0.0	0.0%	0.0	0.0	0.0	0.0%
	L-I	55.0	45.5%	0.0	0.0	0.0	0.0%
	S-I	0.0	0.0%	0.0	0.0	0.0	0.0%
	B	0.0	0.0%	0.0	0.0	0.0	0.0%
		121.0	100.0%	4.0	9.6	13.6	100.0%

Boring No.	Ground Class Group	Vertical Thickness (ft)	Percentage for boring	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
P-102	Fill	4.0	3.3%	4.0	29.4%
	Alluvium	11.0	9.1%	9.6	70.6%
	Residual Soil	0.0	0.0%	0.0	0.0%
	'Weathered Rock'	6.0	5.0%	0.0	0.0%
	III	0.0	0.0%	0.0	0.0%
	II	45.0	37.2%	0.0	0.0%
	I	55.0	45.5%	0.0	0.0%
	Bentonite	0.0	0.0%	0.0	0.0%
		121.0	100.0%	13.6	100.0%

Boring No.	Soil Type/Ground Class	Vertical Extent		Vertical Thickness (ft)	Ground Class Group	Comments	Depth to Top of Excavation, ft	Depth to Excavation Invert, ft	Reach and Structure
		Top Depth (ft)	Bottom Depth (ft)						
T-1	F	0.0	5.0	5.0	Fill		0.00	11.15	1
	A2	5.0	23.0	18.0	Alluvium		6.15		West Portal
	IGM	23.0	25.0	2.0	'Weathered Rock'				
	L-I	25.0	50.0	25.0	I				
	L-II	50.0	56.8	6.8	II				
	S-II	56.8	65.0	8.2					
	S-I	65.0	80.0	15.0	I				
	S-II	80.0	85.0	5.0	II				
	S-I	85.0	106.0	21.0					
	L-I	106.0	109.0	3.0	I	LS @ 106-109			
	S-I	109.0	120	11.0					
				0.0					
				0.0					
				0.0					
				120.0					

Boring No.	Soil Type/Ground Class	Vertical Thickness (ft)	Percentage for boring	Whole unit thickness in Excavation Horizon	Partial unit thickness in Excavation Horizon	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
T-1	F	5.0	4.2%	5.0	0.0	5.0	44.8%
	A1	0.0	0.0%	0.0	0.0	0.0	0.0%
	A2	18.0	15.0%	0.0	6.1	6.1	55.2%
	RS	0.0	0.0%	0.0	0.0	0.0	0.0%
	IGM	2.0	1.7%	0.0	0.0	0.0	0.0%
	L-III	0.0	0.0%	0.0	0.0	0.0	0.0%
	S-III	0.0	0.0%	0.0	0.0	0.0	0.0%
	L-II	6.8	5.7%	0.0	0.0	0.0	0.0%
	S-II	13.2	11.0%	0.0	0.0	0.0	0.0%
	L-I	28.0	23.3%	0.0	0.0	0.0	0.0%
	S-I	47.0	39.2%	0.0	0.0	0.0	0.0%
	B	0.0	0.0%	0.0	0.0	0.0	0.0%
		120.0	100.0%	5.0	6.1	11.2	100.0%

Boring No.	Ground Class Group	Vertical Thickness (ft)	Percentage for boring	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
T-1	Fill	5.0	4.2%	5.0	44.8%
	Alluvium	18.0	15.0%	6.1	55.2%
	Residual Soil	0.0	0.0%	0.0	0.0%
	'Weathered Rock'	2.0	1.7%	0.0	0.0%
	III	0.0	0.0%	0.0	0.0%
	II	20.0	16.7%	0.0	0.0%
	I	75.0	62.5%	0.0	0.0%
	Bentonite	0.0	0.0%	0.0	0.0%
		120.0	100.0%	11.2	100.0%

Boring No.	Soil Type/Ground Class	Vertical Extent		Vertical Thickness (ft)	Ground Class Group	Comments	Depth to Top of Excavation, ft	Depth to Excavation Invert, ft	Reach and Structure
		Top Depth (ft)	Bottom Depth (ft)						
T-5	F	0.0	0.5	0.5	Fill		0.00	17.97	1
	A1	0.5	5.0	4.5	Alluvium				West Portal
	A2	5.0	21.5	16.5			12.97		
	IGM	21.5	25.0	3.5	'Weathered Rock'				
	L-I	25.0	51.0	26.0	I				
	S-II	51.0	55.0	4.0	II				
	S-I	55.0	70.0	15.0	I				
	S-II	70.0	75.0	5.0	II				
	S-I	75.0	90.0	15.0	I				
	S-II	90.0	95	5.0	II				
	S-I	95.0	101.3	6.3					
	L-I	101.3	106.0	4.7	I	LS @ 101.3-106			
	S-I	106.0	120.0	14.0					
				0.0					
				120.0					

Boring No.	Soil Type/Ground Class	Vertical Thickness (ft)	Percentage for boring	Whole unit thickness in Excavation Horizon	Partial unit thickness in Excavation Horizon	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
T-5	F	0.5	0.4%	0.5	0.0	0.5	2.8%
	A1	4.5	3.8%	4.5	0.0	4.5	25.0%
	A2	16.5	13.8%	0.0	13.0	13.0	72.2%
	RS	0.0	0.0%	0.0	0.0	0.0	0.0%
	IGM	3.5	2.9%	0.0	0.0	0.0	0.0%
	L-III	0.0	0.0%	0.0	0.0	0.0	0.0%
	S-III	0.0	0.0%	0.0	0.0	0.0	0.0%
	L-II	0.0	0.0%	0.0	0.0	0.0	0.0%
	S-II	14.0	11.7%	0.0	0.0	0.0	0.0%
	L-I	30.7	25.6%	0.0	0.0	0.0	0.0%
	S-I	50.3	41.9%	0.0	0.0	0.0	0.0%
	B	0.0	0.0%	0.0	0.0	0.0	0.0%
		120.0	100.0%	5.0	13.0	18.0	100.0%

Boring No.	Ground Class Group	Vertical Thickness (ft)	Percentage for boring	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
T-5	Fill	0.5	0.4%	0.5	2.8%
	Alluvium	21.0	17.5%	17.5	97.2%
	Residual Soil	0.0	0.0%	0.0	0.0%
	'Weathered Rock'	3.5	2.9%	0.0	0.0%
	III	0.0	0.0%	0.0	0.0%
	II	14.0	11.7%	0.0	0.0%
	I	81.0	67.5%	0.0	0.0%
	Bentonite	0.0	0.0%	0.0	0.0%
		120.0	100.0%	18.0	100.0%

Boring No.	Soil Type/Ground Class	Vertical Extent		Vertical Thickness (ft)	Ground Class Group	Comments	Depth to Top of Excavation, ft	Depth to Excavation Invert, ft	Reach and Structure
		Top Depth (ft)	Bottom Depth (ft)						
T-6	F	0.0	3.0	3.0			0.00	19.93	1
	A1	3.0	9.0	6.0					West Portal
	A2	9.0	23.0	14.0			10.93		
	IGM	23.0	25.0	2.0					
	L-I	25.0	52.0	27.0					
	S-I	52.0	80.0	28.0					
	S-II	80.0	90.0	10.0					
	S-I	90.0	120.0	30.0		LS @ 103-107			
				0.0					
				0.0					
				0.0					
				0.0					
				0.0					
				0.0					
				120.0					

Boring No.	Soil Type/Ground Class	Vertical Thickness (ft)	Percentage for boring	Whole unit thickness in Excavation Horizon	Partial unit thickness in Excavation Horizon	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
T-6	F	3.0	2.5%	3.0	0.0	3.0	15.1%
	A1	6.0	5.0%	6.0	0.0	6.0	30.1%
	A2	14.0	11.7%	0.0	10.9	10.9	54.8%
	RS	0.0	0.0%	0.0	0.0	0.0	0.0%
	IGM	2.0	1.7%	0.0	0.0	0.0	0.0%
	L-III	0.0	0.0%	0.0	0.0	0.0	0.0%
	S-III	0.0	0.0%	0.0	0.0	0.0	0.0%
	L-II	0.0	0.0%	0.0	0.0	0.0	0.0%
	S-II	10.0	8.3%	0.0	0.0	0.0	0.0%
	L-I	27.0	22.5%	0.0	0.0	0.0	0.0%
	S-I	58.0	48.3%	0.0	0.0	0.0	0.0%
	B	0.0	0.0%	0.0	0.0	0.0	0.0%
		120.0	100.0%	9.0	10.9	19.9	100.0%

Boring No.	Ground Class Group	Vertical Thickness (ft)	Percentage for boring	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
T-6	Fill	3.0	2.5%	3.0	15.1%
	Alluvium	20.0	16.7%	16.9	84.9%
	Residual Soil	0.0	0.0%	0.0	0.0%
	'Weathered Rock'	2.0	1.7%	0.0	0.0%
	III	0.0	0.0%	0.0	0.0%
	II	10.0	8.3%	0.0	0.0%
	I	85.0	70.8%	0.0	0.0%
	Bentonite	0.0	0.0%	0.0	0.0%
		120.0	100.0%	19.9	100.0%

Ground Classifications by Boring

Boring No.	Soil Type/Ground Class	Vertical Extent		Vertical Thickness (ft)	Ground Class Group	Comments	Depth to Top of Excavation, ft	Depth to Excavation Invert, ft	Reach and Structure
		Top Depth (ft)	Bottom Depth (ft)						
T-102	F	0.0	1.5	1.5	Fill		0.00	31.35	2
	A1	1.5	13.0	11.5	Alluvium				C&C Tunnel
	A2	13.0	22.5	9.5					
	IGM	22.5	25.5	3.0	"Weathered Rock"				
	L-I	25.5	31.0	5.5	I				
	L-II	31.0	41.0	10.0	II	35o slicks	0.35		
	L-I	41.0	56.5	15.5	I				
	S-I	56.5	85.5	29.0					
	S-II	85.5	93.0	7.5	II	20o & 30o slicks			
	S-II	93.0	95.5	2.5		mudstone			
	S-I	95.5	101.0	5.5	I				
	S-II	101.0	105.5	4.5	II				
	S-I	105.5	121.0	15.5	I				
				0.0					
				121.0					

Boring No.	Soil Type/Ground Class	Vertical Thickness (ft)	Percentage for boring	Whole unit thickness in Excavation Horizon	Partial unit thickness in Excavation Horizon	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
T-102	F	1.5	1.2%	1.5	0.0	1.5	4.8%
	A1	11.5	9.5%	11.5	0.0	11.5	36.7%
	A2	9.5	7.9%	9.5	0.0	9.5	30.3%
	RS	0.0	0.0%	0.0	0.0	0.0	0.0%
	IGM	3.0	2.5%	3.0	0.0	3.0	9.6%
	L-III	0.0	0.0%	0.0	0.0	0.0	0.0%
	S-III	0.0	0.0%	0.0	0.0	0.0	0.0%
	L-II	10.0	8.3%	0.0	0.3	0.3	1.1%
	S-II	14.5	12.0%	0.0	0.0	0.0	0.0%
	L-I	21.0	17.4%	5.5	0.0	5.5	17.5%
	S-I	50.0	41.3%	0.0	0.0	0.0	0.0%
	B	0.0	0.0%	0.0	0.0	0.0	0.0%
		121.0	100.0%	31.0	0.3	31.4	100.0%

Boring No.	Ground Class Group	Vertical Thickness (ft)	Percentage for boring	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
T-102	Fill	1.5	1.2%	1.5	4.8%
	Alluvium	21.0	17.4%	21.0	67.0%
	Residual Soil	0.0	0.0%	0.0	0.0%
	'Weathered Rock'	3.0	2.5%	3.0	9.6%
	III	0.0	0.0%	0.0	0.0%
	II	24.5	20.2%	0.3	1.1%
	I	71.0	58.7%	5.5	17.5%
	Bentonite	0.0	0.0%	0.0	0.0%
		121.0	100.0%	31.4	100.0%

Boring No.	Soil Type/Ground Class	Vertical Extent		Vertical Thickness (ft)	Ground Class Group	Comments	Depth to Top of Excavation, ft	Depth to Excavation Invert, ft	Reach and Structure
		Top Depth (ft)	Bottom Depth (ft)						
T-103	F	0.0	3.0	3.0	Fill		0.00	55.09	2
	A1	3.0	14.0	11.0	Alluvium				C&C Tunnel
	A2	14.0	23.0	9.0					
	IGM	23.0	26.0	3.0	"Weathered Rock"				
	L-I	26.0	65.0	39.0	I		29.09		
	S-I	65.0	86.0	21.0		mudstone @ 100.5-102			
	S-II	86.0	111.0	25.0	II				
	S-I	111.0	121.0	10.0	I				
				0.0					
				0					
				0.0					
				0.0					
				0.0					
				0.0					
				121.0					

Boring No.	Soil Type/Ground Class	Vertical Thickness (ft)	Percentage for boring	Whole unit thickness in Excavation Horizon	Partial unit thickness in Excavation Horizon	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
T-103	F	3.0	2.5%	3.0	0.0	3.0	5.4%
	A1	11.0	9.1%	11.0	0.0	11.0	20.0%
	A2	9.0	7.4%	9.0	0.0	9.0	16.3%
	RS	0.0	0.0%	0.0	0.0	0.0	0.0%
	IGM	3.0	2.5%	3.0	0.0	3.0	5.4%
	L-III	0.0	0.0%	0.0	0.0	0.0	0.0%
	S-III	0.0	0.0%	0.0	0.0	0.0	0.0%
	L-II	0.0	0.0%	0.0	0.0	0.0	0.0%
	S-II	25.0	20.7%	0.0	0.0	0.0	0.0%
	L-I	39.0	32.2%	0.0	29.1	29.1	52.8%
	S-I	31.0	25.6%	0.0	0.0	0.0	0.0%
	B	0.0	0.0%	0.0	0.0	0.0	0.0%
		121.0	100.0%	26.0	29.1	55.1	100.0%

Boring No.	Ground Class Group	Vertical Thickness (ft)	Percentage for boring	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
T-103	Fill	3.0	2.5%	3.0	5.4%
	Alluvium	20.0	16.5%	20.0	36.3%
	Residual Soil	0.0	0.0%	0.0	0.0%
	'Weathered Rock'	3.0	2.5%	3.0	5.4%
	III	0.0	0.0%	0.0	0.0%
	II	25.0	20.7%	0.0	0.0%
	I	70.0	57.9%	29.1	52.8%
	Bentonite	0.0	0.0%	0.0	0.0%
		121.0	100.0%	55.1	100.0%

Boring No.	Soil Type/Ground Class	Vertical Extent		Vertical Thickness (ft)	Ground Class Group	Comments	Depth to Top of Excavation, ft	Depth to Excavation Invert, ft	Reach and Structure
		Top Depth (ft)	Bottom Depth (ft)						
T-112	F	0.0	9.5	9.5	Fill		0.00	36.16	9
	A1	9.5	28.5	19.0	Alluvium				C&C Tunnel
	IGM	28.5	34.5	6.0	'Weathered Rock'				
	L-II	34.5	51.0	16.5	II		1.66		
	L-I	51.0	91.0	40.0	I				
	L-II	91.0	101.0	10.0	II				
	L-I	101.0	121.0	20.0	I				
				0.0					
				0.0					
				0					
				0.0					
				0.0					
				0.0					
				0.0					
				121.0					

Boring No.	Soil Type/Ground Class	Vertical Thickness (ft)	Percentage for boring	Whole unit thickness in Excavation Horizon	Partial unit thickness in Excavation Horizon	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
T-112	F	9.5	7.9%	9.5		9.5	26.3%
	A1	19.0	15.7%	19.0		19.0	52.5%
	A2	0.0	0.0%	0.0		0.0	0.0%
	RS	0.0	0.0%	0.0		0.0	0.0%
	IGM	6.0	5.0%	6.0		6.0	16.6%
	L-III	0.0	0.0%	0.0		0.0	0.0%
	S-III	0.0	0.0%	0.0		0.0	0.0%
	L-II	26.5	21.9%	0.0	1.7	1.7	4.6%
	S-II	0.0	0.0%	0.0		0.0	0.0%
	L-I	60.0	49.6%	0.0		0.0	0.0%
	S-I	0.0	0.0%	0.0		0.0	0.0%
	B	0.0	0.0%	0.0		0.0	0.0%
		121.0	100.0%	34.5	1.7	36.2	100.0%

Boring No.	Ground Class Group	Vertical Thickness (ft)	Percentage for boring	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
T-112	Fill	9.5	7.9%	9.5	26.3%
	Alluvium	19.0	15.7%	19.0	52.5%
	Residual Soil	0.0	0.0%	0.0	0.0%
	'Weathered Rock'	6.0	5.0%	6.0	16.6%
	III	0.0	0.0%	0.0	0.0%
	II	26.5	21.9%	1.7	4.6%
	I	60.0	49.6%	0.0	0.0%
	Bentonite	0.0	0.0%	0.0	0.0%
		121.0	100.0%	36.2	100.0%

Boring No.	Soil Type/Ground Class	Vertical Extent		Vertical Thickness (ft)	Ground Class Group	Comments	Depth to Top of Excavation, ft	Depth to Excavation Invert, ft	Reach and Structure
		Top Depth (ft)	Bottom Depth (ft)						
T-201	F	0.0	2.5	2.5	Fill		46.90	69.10	4
	A2	2.5	7.5	5.0	Alluvium				SEM Tunnel
	A1	7.5	15.0	7.5					
	A2	15.0	18.5	3.5					
	IGM	18.5	21.0	2.5	"Weathered Rock"				
	L-I	21.0	26.0	5.0	I				
	L-II	26.0	31.0	5.0	II				
	L-I	31.0	41.0	10.0	I				
	L-II	41.0	51.0	10.0	II		4.10		
	L-I	51.0	64.8	13.8	I				
	S-II	64.8	76.0	11.2	II		4.30		
	S-I	76.0	86.0	10.0	I				
	S-II	86.0	120.0	34.0	II	SS @116-120			
				120.0					

Boring No.	Soil Type/Ground Class	Vertical Thickness (ft)	Percentage for boring	Whole unit thickness in Tunnel Horizon	Partial unit thickness in Excavation Horizon	Thickness within Excavation, ft	Percentage within Excavation
T-201	F	2.5	2.1%	0.0	0.0	0.0	0.0%
	A1	7.5	6.3%	0.0	0.0	0.0	0.0%
	A2	8.5	7.1%	0.0	0.0	0.0	0.0%
	RS	0.0	0.0%	0.0	0.0	0.0	0.0%
	IGM	2.5	2.1%	0.0	0.0	0.0	0.0%
	L-III	0.0	0.0%	0.0	0.0	0.0	0.0%
	S-III	0.0	0.0%	0.0	0.0	0.0	0.0%
	L-II	15.0	12.5%	0.0	4.1	4.1	18.5%
	S-II	45.2	37.7%	0.0	4.3	4.3	19.4%
	L-I	28.8	24.0%	13.8	0.0	13.8	62.2%
	S-I	10.0	8.3%	0.0	0.0	0.0	0.0%
	B	0.0	0.0%	0.0	0.0	0.0	0.0%
		120.0	100.0%	13.8	8.4	22.2	100.0%

Boring No.	Ground Class Group	Vertical Thickness (ft)	Percentage for boring	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
T-201	Fill	2.5	2.1%	0.0	0.0%
	Alluvium	16.0	13.3%	0.0	0.0%
	Residual Soil	0.0	0.0%	0.0	0.0%
	'Weathered Rock'	2.5	2.1%	0.0	0.0%
	III	0.0	0.0%	0.0	0.0%
	II	60.2	50.2%	8.4	37.8%
	I	38.8	32.3%	13.8	62.2%
	Bentonite	0.0	0.0%	0.0	0.0%
		120.0	100.0%	22.2	100.0%

Ground Classifications by Boring

Boring No.	Soil Type/Ground Class	Vertical Extent		Vertical Thickness (ft)	Ground Class Group	Comments	Depth to Top of Excavation, ft	Depth to Excavation Invert, ft	Reach and Structure
		Top Depth (ft)	Bottom Depth (ft)						
T-203	F	0.0	5.0	5.0	Fill		61.73	83.93	6
	A1	5.0	6.0	1.0	Alluvium				SEM Tunnel
	IGM	6.0	9.0	3.0	"Weathered Rock"				
	L-II	9.0	10.0	1.0	II				
	L-I	10.0	103.5	93.5	I		22.20		
	S-II	103.5	120.0	16.5	II				
				0.0					
				0.0					
				0.0					
				0.0					
				0.0					
				0.0					
				0.0					
				0.0					
				120.0					

Boring No.	Soil Type/Ground Class	Vertical Thickness (ft)	Percentage for boring	Whole unit thickness in Excavation Horizon	Partial unit thickness in Excavation Horizon	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
T-203	F	5.0	4.2%	0.0	0.0	0.0	0.0%
	A1	1.0	0.8%	0.0	0.0	0.0	0.0%
	A2	0.0	0.0%	0.0	0.0	0.0	0.0%
	RS	0.0	0.0%	0.0	0.0	0.0	0.0%
	IGM	3.0	2.5%	0.0	0.0	0.0	0.0%
	L-III	0.0	0.0%	0.0	0.0	0.0	0.0%
	S-III	0.0	0.0%	0.0	0.0	0.0	0.0%
	L-II	1.0	0.8%	0.0	0.0	0.0	0.0%
	S-II	16.5	13.8%	0.0	0.0	0.0	0.0%
	L-I	93.5	77.9%	0.0	22.2	22.2	100.0%
	S-I	0.0	0.0%	0.0	0.0	0.0	0.0%
	B	0.0	0.0%	0.0	0.0	0.0	0.0%
		120.0	100.0%	0.0	22.2	22.2	100.0%

Boring No.	Ground Class Group	Vertical Thickness (ft)	Percentage for boring	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
T-203	Fill	5.0	4.2%	0.0	0.0%
	Alluvium	1.0	0.8%	0.0	0.0%
	Residual Soil	0.0	0.0%	0.0	0.0%
	'Weathered Rock'	3.0	2.5%	0.0	0.0%
	III	0.0	0.0%	0.0	0.0%
	II	17.5	14.6%	0.0	0.0%
	I	93.5	77.9%	22.2	100.0%
	Bentonite	0.0	0.0%	0.0	0.0%
		120.0	100.0%	22.2	100.0%

Boring No.	Soil Type/Ground Class	Vertical Extent		Vertical Thickness (ft)	Ground Class Group	Comments	Depth to Top of Excavation, ft	Depth to Excavation Invert, ft	Reach and Structure
		Top Depth (ft)	Bottom Depth (ft)						
T-204	F	0.0	2.0	2.0	Fill		54.07	76.27	6
	A1	2.0	9.0	7.0	Alluvium				SEM Tunnel
	IGM	9.0	15.0	6.0	"Weathered Rock"				
	L-I	15.0	65.0	50.0	I		10.93		
	L-II	65.0	90.0	25.0	II		11.27		
	L-I	90.0	120.0	30.0	I				
				0.0					
				0.0					
				0.0					
				0.0					
				0.0					
				0.0					
				0.0					
				120.0					

Boring No.	Soil Type/Ground Class	Vertical Thickness (ft)	Percentage for boring	Whole unit thickness in Excavation Horizon	Partial unit thickness in Excavation Horizon	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
T-204	F	2.0	1.7%	0.0	0.0	0.0	0.0%
	A1	7.0	5.8%	0.0	0.0	0.0	0.0%
	A2	0.0	0.0%	0.0	0.0	0.0	0.0%
	RS	0.0	0.0%	0.0	0.0	0.0	0.0%
	IGM	6.0	5.0%	0.0	0.0	0.0	0.0%
	L-III	0.0	0.0%	0.0	0.0	0.0	0.0%
	S-III	0.0	0.0%	0.0	0.0	0.0	0.0%
	L-II	25.0	20.8%	0.0	11.3	11.3	50.8%
	S-II	0.0	0.0%	0.0	0.0	0.0	0.0%
	L-I	80.0	66.7%	0.0	10.9	10.9	49.2%
	S-I	0.0	0.0%	0.0	0.0	0.0	0.0%
	B	0.0	0.0%	0.0	0.0	0.0	0.0%
		120.0	100.0%	0.0	22.2	22.2	100.0%

Boring No.	Ground Class Group	Vertical Thickness (ft)	Percentage for boring	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
T-204	Fill	2.0	1.7%	0.0	0.0%
	Alluvium	7.0	5.8%	0.0	0.0%
	Residual Soil	0.0	0.0%	0.0	0.0%
	'Weathered Rock'	6.0	5.0%	0.0	0.0%
	III	0.0	0.0%	0.0	0.0%
	II	25.0	20.8%	11.3	50.8%
	I	80.0	66.7%	10.9	49.2%
	Bentonite	0.0	0.0%	0.0	0.0%
		120.0	100.0%	22.2	100.0%

Boring No.	Soil Type/Ground Class	Vertical Extent		Vertical Thickness (ft)	Ground Class Group	Comments	Depth to Top of Excavation, ft	Depth to Excavation Invert, ft	Reach and Structure
		Top Depth (ft)	Bottom Depth (ft)						
T-205	A1	0.0	27.8	27.8	Alluvium		0.00	64.72	7
	A2	27.8	29.5	1.7					C&C Tunnel
	IGM	29.5	40.0	10.5	"Weathered Rock"				
	L-II	40.0	45.0	5.0	II				
	L-I	45.0	101.0	56.0	I		19.72		
	L-II	101.0	106.0	5.0					
	L-I	106.0	122.0	16.0					
				0.0					
				0.0					
				0.0					
				0.0					
				0.0					
				0.0					
				122.0					

Boring No.	Soil Type/Ground Class	Vertical Thickness (ft)	Percentage for boring	Whole unit thickness in Excavation Horizon	Partial unit thickness in Excavation Horizon	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
T-205	F	0.0	0.0%	0.0	0.0	0.0	0.0%
	A1	27.8	22.8%	27.8	0.0	27.8	43.0%
	A2	1.7	1.4%	1.7	0.0	1.7	2.6%
	RS	0.0	0.0%	0.0	0.0	0.0	0.0%
	IGM	10.5	8.6%	10.5	0.0	10.5	16.2%
	L-III	0.0	0.0%	0.0	0.0	0.0	0.0%
	S-III	0.0	0.0%	0.0	0.0	0.0	0.0%
	L-II	10.0	8.2%	5.0	0.0	5.0	7.7%
	S-II	0.0	0.0%	0.0	0.0	0.0	0.0%
	L-I	72.0	59.0%	0.0	19.7	19.7	30.5%
	S-I	0.0	0.0%	0.0	0.0	0.0	0.0%
	B	0.0	0.0%	0.0	0.0	0.0	0.0%
		122.0	100.0%	45.0	19.7	64.7	100.0%

Boring No.	Ground Class Group	Vertical Thickness (ft)	Percentage for boring	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
T-205	Fill	0.0	0.0%	0.0	0.0%
	Alluvium	29.5	24.2%	29.5	45.6%
	Residual Soil	0.0	0.0%	0.0	0.0%
	'Weathered Rock'	10.5	8.6%	10.5	16.2%
	III	0.0	0.0%	0.0	0.0%
	II	10.0	8.2%	5.0	7.7%
	I	72.0	59.0%	19.7	30.5%
	Bentonite	0.0	0.0%	0.0	0.0%
		122.0	100.0%	64.7	100.0%

Boring No.	Soil Type/Ground Class	Vertical Extent		Vertical Thickness (ft)	Ground Class Group	Comments	Depth to Top of Excavation, ft	Depth to Excavation Invert, ft	Reach and Structure
		Top Depth (ft)	Bottom Depth (ft)						
TS-13A	F	0.0	3.0	3.0	Fill		0.00	67.78	3
	A2	3.0	4.0	1.0					Metro Center Sta
	A1	4.0	12.0	8.0	Alluvium				
	A2	12.0	23.5	11.5					
	IGM	23.5	25.0	1.5	'Weathered Rock'				
	L-I	25.0	56.5	31.5	I				
	S-II	56.5	60.0	3.5	II				
	S-I	60.0	70.0	10.0	I	12" ls layer at 70.	7.78		
	S-II	70.0	75.0	5.0	II				
	S-I	75.0	85.0	10.0	I				
	S-II	85.0	90	5.0	II				
	S-I	90.0	106.5	16.5		ls @ 93.6-95.0			
	L-I	106.5	112.0	5.5	I	ls @ 106.5-112.0			
	S-I	112.0	120.0	8.0					
				120.0					

Boring No.	Soil Type/Ground Class	Vertical Thickness (ft)	Percentage for boring	Whole unit thickness in Excavation Horizon	Partial unit thickness in Excavation Horizon	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
TS-13A	F	3.0	2.5%	3.0	0.0	3.0	4.4%
	A1	8.0	6.7%	8.0	0.0	8.0	11.8%
	A2	12.5	10.4%	12.5	0.0	12.5	18.4%
	RS	0.0	0.0%	0.0	0.0	0.0	0.0%
	IGM	1.5	1.3%	1.5	0.0	1.5	2.2%
	L-III	0.0	0.0%	0.0	0.0	0.0	0.0%
	S-III	0.0	0.0%	0.0	0.0	0.0	0.0%
	L-II	0.0	0.0%	0.0	0.0	0.0	0.0%
	S-II	13.5	11.3%	3.5	0.0	3.5	5.2%
	L-I	37.0	30.8%	31.5	0.0	31.5	46.5%
	S-I	44.5	37.1%	0.0	7.8	7.8	11.5%
	B	0.0	0.0%	0.0	0.0	0.0	0.0%
		120.0	100.0%	60.0	7.8	67.8	100.0%

Boring No.	Ground Class Group	Vertical Thickness (ft)	Percentage for boring	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
TS-13A	Fill	3.0	2.5%	3.0	4.4%
	Alluvium	20.5	17.1%	20.5	30.2%
	Residual Soil	0.0	0.0%	0.0	0.0%
	'Weathered Rock'	1.5	1.3%	1.5	2.2%
	III	0.0	0.0%	0.0	0.0%
	II	13.5	11.3%	3.5	5.2%
	I	81.5	67.9%	39.3	58.0%
	Bentonite	0.0	0.0%	0.0	0.0%
		120.0	100.0%	67.8	100.0%

Ground Classifications by Boring

Boring No.	Soil Type/Ground Class	Vertical Extent Top Depth (ft)	Vertical Extent Bottom Depth (ft)	Vertical Thickness (ft)	Ground Class Group	Comments	Depth to Top of Excavation, ft	Depth to Excavation Invert, ft	Reach and Structure
TS-104	F	0.0	1.0	1.0	Fill		0.00	69.21	3
	A1	1.0	6.5	5.5	Alluvium				Metro Center Sta
	A2	6.5	22.5	16.0					
	IGM	22.5	25.0	2.5	"Weathered Rock"				
	L-II	25.0	30.0	5.0	II				
	L-I	30.0	61.5	31.5	I				
	S-I	61.5	100.0	38.5			7.71		
	S-II	100.0	105.0	5.0	II	SS @ 112.5-118			
	S-I	105.0	120.0	15.0	I				
				0.0					
				0.0					
				0.0					
				0.0					
				0.0					
				120.0					

Boring No.	Soil Type/Ground Class	Vertical Thickness (ft)	Percentage for boring	Whole unit thickness in Excavation Horizon	Partial unit thickness in Excavation Horizon	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
TS-104	F	1.0	0.8%	1.0	0.0	1.0	1.4%
	A1	5.5	4.6%	5.5	0.0	5.5	7.9%
	A2	16.0	13.3%	16.0	0.0	16.0	23.1%
	RS	0.0	0.0%	0.0	0.0	0.0	0.0%
	IGM	2.5	2.1%	2.5	0.0	2.5	3.6%
	L-III	0.0	0.0%	0.0	0.0	0.0	0.0%
	S-III	0.0	0.0%	0.0	0.0	0.0	0.0%
	L-II	5.0	4.2%	5.0	0.0	5.0	7.2%
	S-II	5.0	4.2%	0.0	0.0	0.0	0.0%
	L-I	31.5	26.3%	31.5	0.0	31.5	45.5%
	S-I	53.5	44.6%	0.0	7.7	7.7	11.1%
	B	0.0	0.0%	0.0	0.0	0.0	0.0%
		120.0	100.0%	61.5	7.7	69.2	100.0%

Boring No.	Ground Class Group	Vertical Thickness (ft)	Percentage for boring	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
TS-104	Fill	1.0	0.8%	1.0	1.4%
	Alluvium	21.5	17.9%	21.5	31.1%
	Residual Soil	0.0	0.0%	0.0	0.0%
	'Weathered Rock'	2.5	2.1%	2.5	3.6%
	III	0.0	0.0%	0.0	0.0%
	II	10.0	8.3%	5.0	7.2%
	I	85.0	70.8%	39.2	56.7%
	Bentonite	0.0	0.0%	0.0	0.0%
		120.0	100.0%	69.2	100.0%

Boring No.	Soil Type/Ground Class	Vertical Extent Top Depth (ft)	Vertical Extent Bottom Depth (ft)	Vertical Thickness (ft)	Ground Class Group	Comments	Depth to Top of Excavation, ft	Depth to Excavation Invert, ft	Reach and Structure
TS-111	F	0.0	1.0	1.0					
	A1	1.0	31.0	30.0					
	A2	31.0	41.5	10.5					
	IGM	41.5	45.0	3.5					
	L-I	45.0	95.0	50.0					
	L-III	95.0	101.5	6.5		55o slicks @ 97.2; 45o slicks @ 99.5			
	L-I	101.5	120.0	18.5					
				0.0					
				0.0					
				0.0					
				0.0					
				0.0					
				0.0					
				0.0					
				120.0					

Boring No.	Soil Type/Ground Class	Vertical Thickness (ft)	Percentage for boring	Whole unit thickness in Excavation Horizon	Partial unit thickness in Excavation Horizon	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
TS-111	F	1.0	0.8%	0.0	0.0	0.0	0.0%
	A1	30.0	25.0%	0.0	0.0	0.0	0.0%
	A2	10.5	8.8%	0.0	0.0	0.0	0.0%
	RS	0.0	0.0%	0.0	0.0	0.0	0.0%
	IGM	3.5	2.9%	0.0	0.0	0.0	0.0%
	L-III	6.5	5.4%	0.0	0.0	0.0	0.0%
	S-III	0.0	0.0%	0.0	0.0	0.0	0.0%
	L-II	0.0	0.0%	0.0	0.0	0.0	0.0%
	S-II	0.0	0.0%	0.0	0.0	0.0	0.0%
	L-I	68.5	57.1%	0.0	0.0	0.0	0.0%
	S-I	0.0	0.0%	0.0	0.0	0.0	0.0%
	B	0.0	0.0%	0.0	0.0	0.0	0.0%
		120.0	100.0%	0.0	0.0	0.0	0.0%

Boring No.	Ground Class Group	Vertical Thickness (ft)	Percentage for boring	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
TS-111	Fill	1.0	0.8%	0.0	0.0%
	Alluvium	40.5	33.8%	0.0	0.0%
	Residual Soil	0.0	0.0%	0.0	0.0%
	'Weathered Rock'	3.5	2.9%	0.0	0.0%
	III	6.5	5.4%	0.0	0.0%
	II	0.0	0.0%	0.0	0.0%
	I	68.5	57.1%	0.0	0.0%
	Bentonite	0.0	0.0%	0.0	0.0%
		120.0	100.0%	0.0	0.0%

Boring No.	Soil Type/Ground Class	Vertical Extent Top Depth (ft)	Vertical Extent Bottom Depth (ft)	Vertical Thickness (ft)	Ground Class Group	Comments	Depth to Top of Excavation, ft	Depth to Excavation Invert, ft	Reach and Structure
TS-202	F	0.0	1.2	1.2	Fill		44.67	88.67	5
	A1	1.2	8.0	6.8	Alluvium				Commerce Sta
	A2	8.0	13.5	5.5					
	IGM	13.5	16.0	2.5	"Weathered Rock"				
	L-I	16.0	26.0	10.0	I				
	L-III	26.0	36.0	10.0	III	45o slicks @33; 60o slicks @ 35.1; 50o slcks @ 35.7			
	L-II	36.0	46.0	10.0	II	60o slicks @ 42.3, 43.2, & 43.4		1.33	
	L-I	46.0	92.5	46.5	I			42.67	
	S-I	92.5	101.0	8.5					
	S-II	101.0	106	5.0	II	40o slicks @ 105			
	S-I	106.0	121.0	15.0	Bentonite				
				0.0					
				0.0					
				0.0					
				121.0					

Boring No.	Soil Type/Ground Class	Vertical Thickness (ft)	Percentage for boring	Whole unit thickness in Excavation Horizon	Partial unit thickness in Excavation Horizon	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
TS-202	F	1.2	1.0%	0.0	0.0	0.0	0.0%
	A1	6.8	5.6%	0.0	0.0	0.0	0.0%
	A2	5.5	4.5%	0.0	0.0	0.0	0.0%
	RS	0.0	0.0%	0.0	0.0	0.0	0.0%
	IGM	2.5	2.1%	0.0	0.0	0.0	0.0%
	L-III	10.0	8.3%	0.0	0.0	0.0	0.0%
	S-III	0.0	0.0%	0.0	0.0	0.0	0.0%
	L-II	10.0	8.3%	0.0	1.3	1.3	3.0%
	S-II	5.0	4.1%	0.0	0.0	0.0	0.0%
	L-I	56.5	46.7%	0.0	42.7	42.7	97.0%
	S-I	23.5	19.4%	0.0	0.0	0.0	0.0%
	B	0.0	0.0%	0.0	0.0	0.0	0.0%
		121.0	100.0%	0.0	44.0	44.0	100.0%

Boring No.	Ground Class Group	Vertical Thickness (ft)	Percentage for boring	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
TS-202	Fill	1.2	1.0%	0.0	0.0%
	Alluvium	12.3	10.2%	0.0	0.0%
	Residual Soil	0.0	0.0%	0.0	0.0%
	'Weathered Rock'	2.5	2.1%	0.0	0.0%
	III	10.0	8.3%	0.0	0.0%
	II	15.0	12.4%	1.3	3.0%
	I	80.0	66.1%	42.7	97.0%
	Bentonite	0.0	0.0%	0.0	0.0%
		121.0	100.0%	44.0	100.0%

Boring No.	Soil Type/Ground Class	Vertical Extent Top Depth (ft)	Vertical Extent Bottom Depth (ft)	Vertical Thickness (ft)	Ground Class Group	Comments	Depth to Top of Excavation, ft	Depth to Excavation Invert, ft	Reach and Structure
TS-206	F	0.0	3.0	3.0	Fill		0.00	40.03	7
	A2	3.0	6.0	3.0	Alluvium				CBD East Sta
	A1	6.0	29.5	23.5					
	IGM	29.5	30.5	1.0	"Weathered Rock"				
12.0	L-II	30.5	36.0	5.5	II				
	L-I	36.0	36.6	0.6	I				
	B	36.6	37.8	1.2	Bentonite				
	L-I	37.8	121.0	83.2	I		2.23		
				0.0					
				0.0					
				0.0					
				0.0					
				0.0					
				0.0					
				121.0					

Boring No.	Soil Type/Ground Class	Vertical Thickness (ft)	Percentage for boring	Whole unit thickness in Excavation Horizon	Partial unit thickness in Excavation Horizon	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
TS-206	F	3.0	2.5%	3.0	0.0	3.0	7.5%
	A1	23.5	19.4%	23.5	0.0	23.5	58.7%
	A2	3.0	2.5%	3.0	0.0	3.0	7.5%
	RS	0.0	0.0%	0.0	0.0	0.0	0.0%
	IGM	1.0	0.8%	1.0	0.0	1.0	2.5%
	L-III	0.0	0.0%	0.0	0.0	0.0	0.0%
	S-III	0.0	0.0%	0.0	0.0	0.0	0.0%
	L-II	5.5	4.5%	5.5	0.0	5.5	13.7%
	S-II	0.0	0.0%	0.0	0.0	0.0	0.0%
	L-I	83.8	69.3%	0.6	2.2	2.8	7.1%
	S-I	0.0	0.0%	0.0	0.0	0.0	0.0%
	B	1.2	1.0%	1.2	0.0	1.2	3.0%
		121.0	100.0%	37.8	2.2	40.0	100.0%

Boring No.	Ground Class Group	Vertical Thickness (ft)	Percentage for boring	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
TS-206	Fill	3.0	2.5%	3.0	7.5%
	Alluvium	26.5	21.9%	26.5	66.2%
	Residual Soil	0.0	0.0%	0.0	0.0%
	'Weathered Rock'	1.0	0.8%	1.0	2.5%
	III	0.0	0.0%	0.0	0.0%
	II	5.5	4.5%	5.5	13.7%
	I	83.8	69.3%	2.8	7.1%
	Bentonite	1.2	1.0%	1.2	3.0%
		121.0	100.0%	40.0	100.0%

Ground Classifications by Boring

Boring No.	Soil Type/Ground Class	Vertical Extent		Vertical Thickness (ft)	Ground Class Group	Comments	Depth to Top of Excavation, ft	Depth to Excavation Invert, ft	Reach and Structure
		Top Depth (ft)	Bottom Depth (ft)						
TS-207	F	0.0	3.0	3.0	Fill		0.00	59.20	7
	A1	3.0	28.5	25.5	Alluvium				C&C Tunnel
	IGM	28.5	31.0	2.5	'Weathered Rock'				
	L-II	31.0	41.0	10.0	II				
	L-I	41.0	91.0	50.0	I		18.20		
	L-II	91.0	96.0	5.0	II				
	L-I	96.0	120.0	24.0	I				
				0.0					
				0.0					
				0.0					
				0.0					
				0.0					
				0.0					
				120.0					

Boring No.	Soil Type/Ground Class	Vertical Thickness (ft)	Percentage for boring	Whole unit thickness in Excavation Horizon	Partial unit thickness in Excavation Horizon	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
TS-207	F	3.0	2.5%	3.0	0.0	3.0	5.1%
	A1	25.5	21.3%	25.5	0.0	25.5	43.1%
	A2	0.0	0.0%	0.0	0.0	0.0	0.0%
	RS	0.0	0.0%	0.0	0.0	0.0	0.0%
	IGM	2.5	2.1%	2.5	0.0	2.5	4.2%
	L-III	0.0	0.0%	0.0	0.0	0.0	0.0%
	S-III	0.0	0.0%	0.0	0.0	0.0	0.0%
	L-II	15.0	12.5%	10.0	0.0	10.0	16.9%
	S-II	0.0	0.0%	0.0	0.0	0.0	0.0%
	L-I	74.0	61.7%	0.0	18.2	18.2	30.7%
	S-I	0.0	0.0%	0.0	0.0	0.0	0.0%
	B	0.0	0.0%	0.0	0.0	0.0	0.0%
		120.0	100.0%	41.0	18.2	59.2	100.0%

Boring No.	Ground Class Group	Vertical Thickness (ft)	Percentage for boring	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
TS-207	Fill	3.0	2.5%	3.0	5.1%
	Alluvium	25.5	21.3%	25.5	43.1%
	Residual Soil	0.0	0.0%	0.0	0.0%
	'Weathered Rock'	2.5	2.1%	2.5	4.2%
	III	0.0	0.0%	0.0	0.0%
	II	15.0	12.5%	10.0	16.9%
	I	74.0	61.7%	18.2	30.7%
	Bentonite	0.0	0.0%	0.0	0.0%
		120.0	100.0%	59.2	100.0%

Boring No.	Soil Type/Ground Class	Vertical Extent		Vertical Thickness (ft)	Ground Class Group	Comments	Depth to Top of Excavation, ft	Depth to Excavation Invert, ft	Reach and Structure
		Top Depth (ft)	Bottom Depth (ft)						
TS-208	F	0.0	8.0	8.0	Fill		0.00	38.69	7
	A1	8.0	10.0	2.0	Alluvium				C&C Tunnel
	IGM	10.0	15.0	5.0	'Weathered Rock'				
	L-I	15.0	120.0	105.0	I		23.69		
				120.0					

Boring No.	Soil Type/Ground Class	Vertical Thickness (ft)	Percentage for boring	Whole unit thickness in Excavation Horizon	Partial unit thickness in Excavation Horizon	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
TS-208	F	8.0	6.7%	8.0	0.0	8.0	20.7%
	A1	2.0	1.7%	2.0	0.0	2.0	5.2%
	A2	0.0	0.0%	0.0	0.0	0.0	0.0%
	RS	0.0	0.0%	0.0	0.0	0.0	0.0%
	IGM	5.0	4.2%	5.0	0.0	5.0	12.9%
	L-III	0.0	0.0%	0.0	0.0	0.0	0.0%
	S-III	0.0	0.0%	0.0	0.0	0.0	0.0%
	L-II	0.0	0.0%	0.0	0.0	0.0	0.0%
	S-II	0.0	0.0%	0.0	0.0	0.0	0.0%
	L-I	105.0	87.5%	0.0	23.7	23.7	61.2%
	S-I	0.0	0.0%	0.0	0.0	0.0	0.0%
	B	0.0	0.0%	0.0	0.0	0.0	0.0%
		120.0	100.0%	15.0	23.7	38.7	100.0%

Boring No.	Ground Class Group	Vertical Thickness (ft)	Percentage for boring	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
TS-208	Fill	8.0	6.7%	8.0	20.7%
	Alluvium	2.0	1.7%	2.0	5.2%
	Residual Soil	0.0	0.0%	0.0	0.0%
	'Weathered Rock'	5.0	4.2%	5.0	12.9%
	III	0.0	0.0%	0.0	0.0%
	II	0.0	0.0%	0.0	0.0%
	I	105.0	87.5%	23.7	61.2%
	Bentonite	0.0	0.0%	0.0	0.0%
		120.0	100.0%	38.7	100.0%

Boring No.	Soil Type/Ground Class	Vertical Extent		Vertical Thickness (ft)	Ground Class Group	Comments	Depth to Top of Excavation, ft	Depth to Excavation Invert, ft	Reach and Structure
		Top Depth (ft)	Bottom Depth (ft)						
TS-209	F	0.0	3.0	3.0	Fill		0.00	34.47	9
	A1	3.0	28.0	25.0					C&C Tunnel
	A2	28.0	33.0	5.0	Alluvium				
	A1	33.0	38.0	5.0			1.47		
	IGM	38.0	40.0	2.0	'Weathered Rock'				
	L-I	40.0	120.0	80.0	I				
				120.0					

Boring No.	Soil Type/Ground Class	Vertical Thickness (ft)	Percentage for boring	Whole unit thickness in Excavation Horizon	Partial unit thickness in Excavation Horizon	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
TS-209	F	3.0	2.5%	3.0	0.0	3.0	8.7%
	A1	30.0	25.0%	25.0	1.5	26.5	76.8%
	A2	5.0	4.2%	5.0	0.0	5.0	14.5%
	RS	0.0	0.0%	0.0	0.0	0.0	0.0%
	IGM	2.0	1.7%	0.0	0.0	0.0	0.0%
	L-III	0.0	0.0%	0.0	0.0	0.0	0.0%
	S-III	0.0	0.0%	0.0	0.0	0.0	0.0%
	L-II	0.0	0.0%	0.0	0.0	0.0	0.0%
	S-II	0.0	0.0%	0.0	0.0	0.0	0.0%
	L-I	80.0	66.7%	0.0	0.0	0.0	0.0%
	S-I	0.0	0.0%	0.0	0.0	0.0	0.0%
	B	0.0	0.0%	0.0	0.0	0.0	0.0%
		120.0	100.0%	33.0	1.5	34.5	100.0%

Boring No.	Ground Class Group	Vertical Thickness (ft)	Percentage for boring	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
TS-209	Fill	3.0	2.5%	3.0	8.7%
	Alluvium	35.0	29.2%	31.5	91.3%
	Residual Soil	0.0	0.0%	0.0	0.0%
	'Weathered Rock'	2.0	1.7%	0.0	0.0%
	III	0.0	0.0%	0.0	0.0%
	II	0.0	0.0%	0.0	0.0%
	I	80.0	66.7%	0.0	0.0%
	Bentonite	0.0	0.0%	0.0	0.0%
		120.0	100.0%	34.5	100.0%

Following borings are west of underground portion of alignment:

Boring No.	Soil Type/Ground Class	Vertical Extent		Vertical Thickness (ft)	Ground Class Group	Comments	Depth to Top of Excavation, ft	Depth to Excavation Invert, ft	Reach and Structure
		Top Depth (ft)	Bottom Depth (ft)						
R-2	F	0.0	1.0	1.0	Fill				
	A1	1.0	50.0	49.0	Alluvium				
				0.0					
				0.0					
				0.0					
				0.0					
				50.0					

Boring No.	Soil Type/Ground Class	Vertical Thickness (ft)	Percentage for boring	Whole unit thickness in Excavation Horizon	Partial unit thickness in Excavation Horizon	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
R-2	F	1.0	2.0%	0.0	0.0	0.0	#DIV/0!
	A1	49.0	98.0%	0.0	0.0	0.0	#DIV/0!
	A2	0.0	0.0%	0.0	0.0	0.0	#DIV/0!
	RS	0.0	0.0%	0.0	0.0	0.0	#DIV/0!
	IGM	0.0	0.0%	0.0	0.0	0.0	#DIV/0!
	L-III	0.0	0.0%	0.0	0.0	0.0	#DIV/0!
	S-III	0.0	0.0%	0.0	0.0	0.0	#DIV/0!
	L-II	0.0	0.0%	0.0	0.0	0.0	#DIV/0!
	S-II	0.0	0.0%	0.0	0.0	0.0	#DIV/0!
	L-I	0.0	0.0%	0.0	0.0	0.0	#DIV/0!
	S-I	0.0	0.0%	0.0	0.0	0.0	#DIV/0!
	B	0.0	0.0%	0.0	0.0	0.0	#DIV/0!
		50.0	100.0%	0.0	0.0	0.0	#DIV/0!

Boring No.	Ground Class Group	Vertical Thickness (ft)	Percentage for boring	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
R-2	Fill	1.0	2.0%	0.0	#DIV/0!
	Alluvium	49.0	98.0%	0.0	#DIV/0!
	Residual Soil	0.0	0.0%	0.0	#DIV/0!
	'Weathered Rock'	0.0	0.0%	0.0	#DIV/0!
	III	0.0	0.0%	0.0	#DIV/0!
	II	0.0	0.0%	0.0	#DIV/0!
	I	0.0	0.0%	0.0	#DIV/0!
	Bentonite	0.0	0.0%	0.0	#DIV/0!
		50.0	100.0%	0.0	#DIV/0!

Ground Classifications by Boring

Boring No.	Soil Type/Ground Class	Vertical Extent Top Depth (ft)	Vertical Extent Bottom Depth (ft)	Vertical Thickness (ft)	Ground Class Group	Comments	Depth to Top of Excavation, ft	Depth to Excavation Invert, ft	Reach and Structure
R-3	F	0.0	4.5	4.5	Fill				
	A2	4.5	7.5	3.0	Alluvium				
	IGM	7.5	15.0	7.5	'Weathered Rock'				
	L-I	15.0	35.0	20.0	I				
	L-II	35.0	37.0	2.0	II				
	L-I	37.0	50.0	13.0	I				
				50.0					

Boring No.	Soil Type/Ground Class	Vertical Thickness (ft)	Percentage for boring	Whole unit thickness in Excavation Horizon	Partial unit thickness in Excavation Horizon	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
R-3	F	4.5	9.0%	0.0	0.0	0.0	#DIV/0!
	A1	0.0	0.0%	0.0	0.0	0.0	#DIV/0!
	A2	3.0	6.0%	0.0	0.0	0.0	#DIV/0!
	RS	0.0	0.0%	0.0	0.0	0.0	#DIV/0!
	IGM	7.5	15.0%	0.0	0.0	0.0	#DIV/0!
	L-III	0.0	0.0%	0.0	0.0	0.0	#DIV/0!
	S-III	0.0	0.0%	0.0	0.0	0.0	#DIV/0!
	L-II	2.0	4.0%	0.0	0.0	0.0	#DIV/0!
	S-II	0.0	0.0%	0.0	0.0	0.0	#DIV/0!
	L-I	33.0	66.0%	0.0	0.0	0.0	#DIV/0!
	S-I	0.0	0.0%	0.0	0.0	0.0	#DIV/0!
	B	0.0	0.0%	0.0	0.0	0.0	#DIV/0!
		50.0	100.0%	0.0	0.0	0.0	#DIV/0!

Boring No.	Ground Class Group	Vertical Thickness (ft)	Percentage for boring	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
R-3	Fill	4.5	3.8%	0.0	#DIV/0!
	Alluvium	3.0	2.5%	0.0	#DIV/0!
	Residual Soil	0.0	0.0%	0.0	#DIV/0!
	'Weathered Rock'	7.5	6.3%	0.0	#DIV/0!
	III	0.0	0.0%	0.0	#DIV/0!
	II	2.0	1.7%	0.0	#DIV/0!
	I	33.0	27.5%	0.0	#DIV/0!
	Bentonite	0.0	0.0%	0.0	#DIV/0!
		50.0	41.7%	0.0	#DIV/0!

Boring No.	Soil Type/Ground Class	Vertical Extent Top Depth (ft)	Vertical Extent Bottom Depth (ft)	Vertical Thickness (ft)	Ground Class Group	Comments	Depth to Top of Excavation, ft	Depth to Excavation Invert, ft	Reach and Structure
S-1	F	0.0	0.5	0.5	Fill				
	A2	0.5	13.0	12.5	Alluvium				
	IGM	13.0	15.0	2.0	'Weathered Rock'				
	L-II	15.0	20.0	5.0	II				
	L-I	20.0	47.0	27.0	I				
	S-II	47.0	60.0	13.0	II				
	S-I	60.0	75.0	15.0	I				
	S-II	75.0	80.0	5.0	II				
				80.0					

Boring No.	Soil Type/Ground Class	Vertical Thickness (ft)	Percentage for boring	Whole unit thickness in Excavation Horizon	Partial unit thickness in Excavation Horizon	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
S-1	F	0.5	0.6%	0.0	0.0	0.0	#DIV/0!
	A1	0.0	0.0%	0.0	0.0	0.0	#DIV/0!
	A2	12.5	15.6%	0.0	0.0	0.0	#DIV/0!
	RS	0.0	0.0%	0.0	0.0	0.0	#DIV/0!
	IGM	2.0	2.5%	0.0	0.0	0.0	#DIV/0!
	L-III	0.0	0.0%	0.0	0.0	0.0	#DIV/0!
	S-III	0.0	0.0%	0.0	0.0	0.0	#DIV/0!
	L-II	5.0	6.3%	0.0	0.0	0.0	#DIV/0!
	S-II	18.0	22.5%	0.0	0.0	0.0	#DIV/0!
	L-I	27.0	33.8%	0.0	0.0	0.0	#DIV/0!
	S-I	15.0	18.8%	0.0	0.0	0.0	#DIV/0!
	B	0.0	0.0%	0.0	0.0	0.0	#DIV/0!
		80.0	100.0%	0.0	0.0	0.0	#DIV/0!

Boring No.	Ground Class Group	Vertical Thickness (ft)	Percentage for boring	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
S-1	Fill	0.5	0.4%	0.0	#DIV/0!
	Alluvium	12.5	10.4%	0.0	#DIV/0!
	Residual Soil	0.0	0.0%	0.0	#DIV/0!
	'Weathered Rock'	2.0	1.7%	0.0	#DIV/0!
	III	0.0	0.0%	0.0	#DIV/0!
	II	23.0	19.2%	0.0	#DIV/0!
	I	42.0	35.0%	0.0	#DIV/0!
	Bentonite	0.0	0.0%	0.0	#DIV/0!
		80.0	66.7%	0.0	#DIV/0!

Boring No.	Soil Type/Ground Class	Vertical Extent Top Depth (ft)	Vertical Extent Bottom Depth (ft)	Vertical Thickness (ft)	Ground Class Group	Comments	Depth to Top of Excavation, ft	Depth to Excavation Invert, ft	Reach and Structure
S-2	F	0.0	2.0	2.0	Fill				
	A2	2.0	18.5	16.5	Alluvium				
	IGM	18.5	20.0	1.5	'Weathered Rock'				
	L-I	20.0	46.0	26.0	I				
	S-II	46.0	50.0	4.0	II				
	L-I	50.0	80.0	30.0	I				
				80.0					

Boring No.	Soil Type/Ground Class	Vertical Thickness (ft)	Percentage for boring	Whole unit thickness in Excavation Horizon	Partial unit thickness in Excavation Horizon	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
S-2	F	2.0	2.5%	0.0	0.0	0.0	#DIV/0!
	A1	0.0	0.0%	0.0	0.0	0.0	#DIV/0!
	A2	16.5	20.6%	0.0	0.0	0.0	#DIV/0!
	RS	0.0	0.0%	0.0	0.0	0.0	#DIV/0!
	IGM	1.5	1.9%	0.0	0.0	0.0	#DIV/0!
	L-III	0.0	0.0%	0.0	0.0	0.0	#DIV/0!
	S-III	0.0	0.0%	0.0	0.0	0.0	#DIV/0!
	L-II	0.0	0.0%	0.0	0.0	0.0	#DIV/0!
	S-II	4.0	5.0%	0.0	0.0	0.0	#DIV/0!
	L-I	56.0	70.0%	0.0	0.0	0.0	#DIV/0!
	S-I	0.0	0.0%	0.0	0.0	0.0	#DIV/0!
	B	0.0	0.0%	0.0	0.0	0.0	#DIV/0!
		80.0	100.0%	0.0	0.0	0.0	#DIV/0!

Boring No.	Ground Class Group	Vertical Thickness (ft)	Percentage for boring	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
S-2	Fill	2.0	2.5%	0.0	#DIV/0!
	Alluvium	16.5	20.6%	0.0	#DIV/0!
	Residual Soil	0.0	0.0%	0.0	#DIV/0!
	'Weathered Rock'	1.5	1.9%	0.0	#DIV/0!
	III	0.0	0.0%	0.0	#DIV/0!
	II	4.0	5.0%	0.0	#DIV/0!
	I	56.0	70.0%	0.0	#DIV/0!
	Bentonite	0.0	0.0%	0.0	#DIV/0!
		80.0	100.0%	0.0	#DIV/0!

Boring No.	Soil Type/Ground Class	Vertical Extent Top Depth (ft)	Vertical Extent Bottom Depth (ft)	Vertical Thickness (ft)	Ground Class Group	Comments	Depth to Top of Excavation, ft	Depth to Excavation Invert, ft	Reach and Structure
S-3	F	0.0	1.0	1.0	Fill				
	A1	1.0	18.0	17.0	Alluvium				
	IGM	18.0	20.0	2.0	'Weathered Rock'				
	L-I	20.0	47.0	27.0	I				
	S-I	47.0	55.0	8.0					
	S-II	55.0	60.0	5.0	II				
	S-I	60.0	70.0	10.0	I				
	S-II	70.0	75.0	5.0	II				
	S-I	75.0	85.0	10.0	I				
	S-II	85.0	90.0	5.0	II				
	S-I	90.0	96.0	6.0	I				
	L-I	96.0	102.5	6.5			Is @ 96-102.5		
	S-I	102.5	115.0	12.5					
	S-II	115.0	120.0	5.0	II				
				120.0					

Boring No.	Soil Type/Ground Class	Vertical Thickness (ft)	Percentage for boring	Whole unit thickness in Excavation Horizon	Partial unit thickness in Excavation Horizon	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
S-3	F	1.0	0.8%	0.0	0.0	0.0	#DIV/0!
	A1	17.0	14.2%	0.0	0.0	0.0	#DIV/0!
	A2	0.0	0.0%	0.0	0.0	0.0	#DIV/0!
	RS	0.0	0.0%	0.0	0.0	0.0	#DIV/0!
	IGM	2.0	1.7%	0.0	0.0	0.0	#DIV/0!
	L-III	0.0	0.0%	0.0	0.0	0.0	#DIV/0!
	S-III	0.0	0.0%	0.0	0.0	0.0	#DIV/0!
	L-II	0.0	0.0%	0.0	0.0	0.0	#DIV/0!
	S-II	20.0	16.7%	0.0	0.0	0.0	#DIV/0!
	L-I	33.5	27.9%	0.0	0.0	0.0	#DIV/0!
	S-I	46.5	38.8%	0.0	0.0	0.0	#DIV/0!
	B	0.0	0.0%	0.0	0.0	0.0	#DIV/0!
		120.0	100.0%	0.0	0.0	0.0	#DIV/0!

Boring No.	Ground Class Group	Vertical Thickness (ft)	Percentage for boring	Thickness within Excavation Horizon, ft	Percentage within Excavation Horizon
S-3	Fill	1.0	0.8%	0.0	#DIV/0!
	Alluvium	17.0	14.2%	0.0	#DIV/0!
	Residual Soil	0.0	0.0%	0.0	#DIV/0!
	'Weathered Rock'	2.0	1.7%	0.0	#DIV/0!
	III	0.0	0.0%	0.0	#DIV/0!
	II	20.0	16.7%	0.0	#DIV/0!
	I	80.0	66.7%	0.0	#DIV/0!
	Bentonite	0.0	0.0%	0.0	#DIV/0!
		120.0	100.0%	0.0	#DIV/0!

APPENDIX B

EXCERPT FROM DART D2 INTACT ROCK PROPERTIES STUDY

1 OBJECTIVE

The objective of this study was to evaluate the range and variability of intact rock properties of the two major rock types along the proposed DART D2 underground alignment and to develop geotechnical parameters and preliminary baselines based on data presented in the Geotechnical Data Report (GDR) prepared by Alliance Geotechnical Group dated August 29, 2019 (GPC6, 2019a).

2 ASSUMPTIONS FOR INTACT ROCK PROPERTY DETERMINATIONS

The following assumptions were made for this study. Changes in these assumptions could affect selection of intact rock properties for design or baselines.

1. Tunnel alignment, stationing, and portal and station locations are those established for 20 percent design as of December 20, 2019.
2. Boring locations, depths, and descriptions for all borings are correct as shown in the GDR (GPC6, 2019a).
3. Reported data from field and laboratory testing are correct, and reported lithologies of tested specimens are correct as shown on boring logs.
4. The number of tested samples is sufficient to characterize intact rock properties for each rock type.
5. The tested specimens appropriately represent the range and distribution of intact rock properties for each rock type.
6. Results of laboratory tests on intact rock samples are representative of intact rock in situ.
7. Median values (50th percentile values) based on laboratory test data are appropriate for use in geotechnical design.
8. Upper quartile values (75th percentiles) are more appropriate to use as preliminary baseline values than median values (50th percentiles) in order to consider possible extreme values not reflected in available laboratory test results. For Drilling Rate Index, Cutter Life Index, and slake durability, lower quartile values (25th percentiles) are appropriate baseline values.
9. Laboratory tests were performed in general accordance with cited test standards.
10. Irregular and inconsistent laboratory test data presented in the GDR (GPC6, 2019a) have been appropriately excluded from determinations of design properties and baseline properties.
11. In case of conflict between rock descriptions on boring logs and laboratory test data, for the purpose of determining intact rock properties, it was assumed that laboratory test data are correct.

12. Preliminary baseline properties will be evaluated in the context of development of a final Geotechnical Baseline Report.
13. It is appropriate to develop design parameters and preliminary baseline properties of intact rock based on the data now available.
14. It is assumed that parameters and baselines will be re-evaluated and revised as data from additional geotechnical investigations become available.

3 METHODOLOGY

The following sections describe the method and approach for determination of properties of intact rock properties along the proposed DART D2 underground alignment current as of December 20, 2019.

3.1 Data for Analysis

1. Two geologic formations will be encountered in rock excavation along the DART D2 alignment (GPC6, 2019b):
   - Late Cretaceous-age Austin Group, also known as Austin Chalk, consisting of recrystallized, fossiliferous, interbedded chalk and marl, and
   - Late Cretaceous-age Eagle Ford Shale, which underlies the Austin Group, consisting of shale with sandstone, limestone, and clay shale.
2. Drilling, sampling, and laboratory test results in the GDR (GPC6, 2019a) indicate that limestone and shale are the two main rock types present along the alignment.
3. Within these two main rock types, variations in mineralogy, grain size, and bedding occur. These variations can cause differences in intact rock properties.
4. Boring logs in the GDR (GPC6, 2019a) indicate that along the DART D2 underground alignment, the two formations include the following lithologic variations:
   - The Austin Chalk formation consists primarily of limestone and includes argillaceous layers, calcareous layers, calcareous stringers and nodules, and occasional shale seams, all generally less than about 3 inches thick. Frequency and thickness of shale layers increases near the underlying shale.
   - The Eagle Ford Shale formation consists primarily of shale and includes seams of calcareous shale, calcareous nodules and stringers, sandy mudstone, and fine-grained sandstone.
   - Bentonite layers up to about 1.2 feet thick occur within both limestone and shale.
5. Within the two rock general types, three different ground classes have been defined (GPC6, 2019b) which reflect rock mass properties related to weathering, fractures, and faults.

6. Laboratory testing was performed only on rock samples that were slightly weathered to unweathered. Based on the boring logs, testing was performed on samples with generally uniform lithology, i.e., testing was not performed on shale layers within the limestone formation or limestone or sandstone layers within the shale formation.
7. The available laboratory test data indicate that intact rock properties are more likely to vary by rock type than by ground class. In most cases, the level of detail on boring logs and rock laboratory test data sheets was not sufficient to differentiate among minor variations within the two main rock types. Test data were therefore grouped into data for either limestone or shale and include only Ground Class Groups I and II.
8. Laboratory test data evaluated for purposes of developing geotechnical design parameters and preliminary baselines were from the following tests performed on core samples from DART D2 borings:
   - Bulk density
   - Uniaxial compressive strength (UCS) without moduli (ASTM D7012 Method C)
   - Uniaxial compressive strength (UCS) with moduli (ASTM D7012 Method D)
   - Point load index (PLI) strength test, axial (ASTM D5731)
   - Splitting tensile strength (Brazilian) (ASTM D3967)
   - Pulse Velocity and Ultrasonic Elastic Constants (ASTM D2845)
   - Cerchar Abrasiveness Index (ASTM D7625)
   - Rebound hardness number (by Schmidt hammer) (ASTM D5873
   - Slake durability (ASTM D4644)
   - Thin section petrographic analysis
   - Drillability indices (Bruland, 1998)

Test data and details are presented in the GDR (GPC6, 2019a).

9. Data tables were compiled, summarizing test sample location and depth, rock type, and laboratory test results for bulk density, unconfined compressive strength, elastic constants, splitting tensile strength, CERCHAR Abrasiveness Index, rebound hammer hardness, slake durability, and drillability indices. Data tables are presented in Attachments A through H.
10. Information from thin section petrographic analyses were evaluated qualitatively.
11. The following conventions were followed:
    a) Unconfined compressive strength

i. Only axial PLI test results were considered for this study. As presented in the GDR (GPC6, 2019a), unconfined compressive strengths estimated from diametral PLI test results were not calculated in accordance with ASTM D5731 and so were excluded from this study.

ii. UCS values estimated from axial PLI tests by ASTM D5731 were not combined with UCS results from tests by ASTM D7012 Methods C and D because of differences in test specimen moisture content. UCS test specimens were tested at as-received water content. Axial PLI test specimens were saturated for testing, with test specimens saturated by overnight soaking in water and then surface-dried before testing.

b) Elastic constants

i. Only dynamic elastic constants were considered for this study. Values are from results of tests for pulse velocities and ultrasonic elastic constants by ASTM D2845 are presented in the GDR (GPC6, 2019a). Specimens were tested at as-received moisture content.

ii. Static elastic constants developed from results of tests by ASTM D7012-D were not considered for this study because test data plots in the GDR (GPC6, 2019a) show testing irregularities. Static elastic constants from tests by ASTM D7012-D were therefor not considered reliable and were excluded from this study.

c) More than half of the Schmidt hammer rebound hardness test results in the GDR (GPC6, 2019a) include tests performed on specimens which were shorter than the minimum length specified in ASTM standard D5873 for rebound hardness. Results from non-compliant tests were excluded from this study.

d) Bulk density was determined from measurements on samples in as-received moisture condition.

e) Slake durability index was based on second test cycle.

f) Drillability indices were classified according to criteria in Dahl et al., 2012.

12. Statistical analysis for this study considered only results from tests on rock specimens which were slightly weathered to unweathered.

13. Only one strength test failure is reported in the GDR (GPC6, 2019a) to have occurred along a discontinuity. All other test failures occurred through intact material.

14. Test results were sorted by rock type. Maximum, minimum, mean, median, and standard deviation were calculated.

15. For parameters for which geotechnical baseline values may be required (unconfined compressive strength, splitting tensile strength, Cerchar Abrasiveness Index, bulk density, elastic constants, and drillability indices), 75th and 25th percentiles were also calculated.

16. Percentile values were calculated in Excel as:

$$p_i = (i-1) * (100/(n-1))$$

Where

p = percentile
i = sorted data point series number, and
n = total number of data points

17. Test results for each parameter for which there were two or more test results were prepared as percentile plots for each rock type (Figures 1 through 10).
18. For tests for which there were too few reliable results in the GDR (GPC6, 2019a) to permit statistical analyses, maximum, minimum, and mean values were estimated for the summary table, Table 1. Where noted in Table 1, DART D2 data were supplemented by data from tests on similar rock for other Dallas-area projects.

3.2 Development of Ranges, Design Values, and Preliminary Baseline Values

1. For rock type and properties for which data were sufficient to determine ranges and medians, median values were selected as design values.
2. For rock type and properties for which data were sufficient to determine ranges, medians, and quartiles, 75th quartile values were generally selected as preliminary baseline values, to assume that the worst-case excavation condition had not been encountered in testing and to consider possible extreme values not reflected in laboratory test results.
3. For Drilling Rate Index (DRI) and Cutter Life Index (CLI), the 25th quartile was selected as a preliminary baseline value. For these parameters, the quartile values represent a more difficult excavation condition than the median values. No DART D2 drillability test data were available for shale.
4. Preliminary baseline values shown are based on currently available data. For final baselines, values could be revised to eliminate potentially conflicting baseline parameters or parameters with a small number of supporting test results.
5. Ranges, medians, and baseline values were generally rounded up.

3.3 Petrographic Analysis

Thin section petrographic data in the GDR (GPC6, 2019a) were not sufficiently complete for quantitative analysis. The following paragraphs present qualitative assessments.

3.3.1 LIMESTONE

As expected, thin section petrographic analysis in the GDR (GPC6, 2019a) indicate that the primary mineral in DART D2 limestone is calcite, constituting 86 to 94 percent by volume. The calcite includes ferroan calcite, a variety which contains iron. The limestone samples were found to be generally composed of coiled and uncoiled microfossil fragments, with a faint fabric due to parallel alignment of elongated fragments.

Small amounts of smectite, 5 to 10 percent by volume, were present in each of the 15 analyzed limestone thin sections. The smectite group of clay minerals, which includes montmorillonite, have a high capacity for expansion in the presence of water. They are a primary constituent of bentonite.

Fish bone and scale fragments in the limestone are indicated by small amounts (2 to 10 percent) of collophane, a cryptocrystalline apatite mineral with Mohs' hardness of 5.

Opaque minerals, probably pyrite based on boring logs, were found to constitute between 1 and 5 percent of the limestone by volume.

3.3.2 SHALE

The single shale thin section was 84 percent smectite by volume. This high smectite content confirms the reported swelling behavior commonly observed in Eagle Ford shale.

Also present in the shale thin section were quartz (12 percent), as quartz silt and very fine sand. Opaque minerals were reported at 4 percent, and as recorded in boring logs in the GDR (GPC6, 2019a), were probably pyrite. These results indicate that despite the high content of soft clay, the shale may be somewhat abrasive and that hydrogen sulfide and acid groundwater are to be expected.

4 RESULTS

Table 1, Summary of Intact Rock Properties, presents a summary of ranges, design values, and preliminary baseline values for each of the two rock types.

Summaries of statistical information and percentile plots for studied properties are presented in Tables 2 through 9 and Figures 1 through 13. NTNU classifications for ranges of Drillability Indices are shown in Table 14 and are based on Bruland, 1998.

Petrographic analysis indicated high calcite content for limestone and high smectite content for shale.

Laboratory test data sets and plots are presented in Attachments A through L. Laboratory test details and results are presented in the GDR (GPC6, 2019a).

5 CONCLUSIONS

1. Intact rock properties based on data in the GDR (GPC6, 2019a) are summarized in Table 1.
2. Based on data in the GDR (GPC6, 2019a), properties of DART D2 intact limestone fall within a defined range and are generally consistent with published and unpublished data for Austin Chalk (Lachel and Felice, 2006).
3. According to ISRM criteria (ISRM, 1981), tested limestone samples were generally weak, soft, non-abrasive, and not prone to slaking.
4. Only limited test data are available for DART D2 intact shale properties, but data in the GDR (GPC6, 2019a) indicate that according to ISRM criteria, tested shale samples were generally weak to very weak, soft, and prone to slaking.
5. Intact rock properties reported for Austin Chalk limestone and Eagle Ford shale from testing for other Dallas-area underground projects are generally similar to those for the same formations reported in the DART D2 GDR (GPC6, 2019a). These projects include the Cole Park Detention Vault (Fugro Consultants, 2004), Mill Creek Drainage Relief Tunnel (HNTB, 2014), IH-635 (LBJ Freeway) Corridor, Section 4-West (Fugro, 2005), and the IH-635 Managed Lanes Project (Lachel Felice, 2006).
6. Unconfined compressive strengths of Austin Chalk limestone and Eagle Ford Shale samples from the Superconducting Super Collider Site in Waxahachie, about 35 miles southeast of Dallas (Earth Tech, 1990), are both slightly lower than those for the same formations reported in the DART D2 GDR (GPC6, 2019a).
7. Unconfined compressive strength of Austin Chalk limestone samples from DART's Light Rail Transit System NC-1B Tunnel Project in Dallas (Huitt-Zollars, 1991) was also slightly lower than those for the same formation reported in the DART D2 GDR (GPC6, 2019a).
8. Intact rock properties will require updating after additional site-specific boring and laboratory test data become available.
9. The set of DART D2 laboratory test data currently available is not yet sufficiently robust, especially for shale, to confidently assign contractually-binding baseline values. If no additional project-specific data become available, the limited data set could be supplemented by data from another Dallas-area tunnel projects in the same formations.

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