



Geotechnical Baseline Report for 20% Design

GPC6, C-2012668-02, Task Order #39 Dallas CBD Second Light
Rail Alignment (D2 Subway)

Concept Design
Revision A

Dallas, Texas
February 26, 2020



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1 INTRODUCTION

1.1 General

This preliminary Geotechnical Baseline Report (GBR) for 20% design describes the anticipated subsurface conditions for the construction of the underground portion of the DART D2 Light Rail Transit (LRT) project. The project is an undertaking of Dallas Area Rapid Transit (DART).

This report was prepared by General Planning Consultant Six (GPC6) and managed by HDR on behalf of DART.

The project alignment, configuration, and design addressed in this report are current as of December 20, 2019. Ground characterization is based on geotechnical information current as of August 29, 2019 as presented in the Geotechnical Data Report (GDR) dated August 27, 2019 (GPC6, 2019).

Elevations in this report reference the project vertical datum, NAVD 88.

This report pertains to the underground portion of the DART D2 project, which begins at the start of the U-wall retained cut of the West Portal at Station 35+30 and extends to the end of the U-wall retained cut of the East Portal at Station 107+60. This GBR specifically addresses excavation and support of below-grade structures indicated in Section 2.4. The remaining portions of the project, consisting of surface and aerial structures, are addressed by the Contract Drawings and Specifications.

This report shall be used in conjunction with other Contract Documents.

Square brackets in this report enclose explanatory text describing information that would be incorporated in the final GBR issued as a Contract Document.

[The final GBR will be a Contract Document and will be binding upon DART and the Design-Build Contractor ("Contractor"). In the case of apparent conflicts, discrepancies, or inconsistencies with any other geotechnical data made available to the Contractor for this or other contracts, the final GBR shall take precedence in the reconciliation of the conflict.]

[The data developed during supplemental geotechnical investigations will be documented in Supplemental Geotechnical Data Reports (SGDRs) for the DART D2 project. The final GBR will incorporate site-specific data as they become available.]

[The precedence of Contract Documents will be given in the General Conditions of the Contract.]

1.2 Purpose

The preliminary geotechnical baselines contained in this report were developed from available project geotechnical data, review of existing data, and evaluations of anticipated ground behavior consistent with construction means and methods that are likely to be employed by the Contractor.



Available project geotechnical data are presented in the DART D2 GDR dated August 29, 2019 (GPC6, 2019). Where indicated in this report, the limited site-specific geotechnical data available for the DART D2 project were supplemented by field and laboratory data collected by others for other Dallas-area projects.

This GBR was prepared in general accordance with “Geotechnical Baseline Reports for Construction, Suggested Guidelines” (ASCE, 2007).

This report will be revised as additional project geotechnical data become available and as project design and procurement details are developed. The objectives of the final GBR will be to:

- Set clear realistic baselines for conditions anticipated to be encountered during subsurface construction.
- Provide all bidders with a single contractual interpretation of the subsurface conditions that can be relied upon in developing bids.
- Present geotechnical and construction considerations that are the basis for specific requirements in the Performance and Technical Specifications (“Specifications”).
- Present key project constraints, conditions, and requirements in the Contract Drawings and Specifications that need to be considered during preparation of bids and during performance of the work.
- Provide guidance to DART and/or its agent in administering the Contract and monitoring performance during construction.

The baselines are not intended to be a guarantee or warranty that conditions will in fact be encountered, since the actual subsurface conditions will be variable. Instead, these baselines are intended to identify anticipated subsurface conditions likely to be encountered during execution of the work and are considered a contractual commitment by DART that will be applicable to Contract Differing Site Condition requirements.

2 PROJECT DESCRIPTION

2.1 DART D2 Project Overview

The DART D2 project is a planned light rail project within the central business district of Dallas, Texas. Figure 2-1 shows a project location plan. The 2.34-mile-long Locally Preferred Alternative (LPA) extends generally west-east from Victory Park to Deep Ellum via Commerce Street and downtown Dallas.

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.

[The final GBR will address proposed additional underground structures at Commerce Station, which were not yet included in the design as of December 20, 2019, including entrance and ventilation shafts and station entrances and adits.]

2.2 DART D2 Alignment

The Locally Preferred Alternative (LPA) for the D2 Subway is a 2.34-mile light rail line that will travel at-grade through the Victory development with a proposed station adjacent to the Perot Museum (Museum Way Station). The alignment then travels under Woodall Rodgers Freeway where it transitions from surface-running to below-grade in a tunnel via a portal immediately south of Woodall Rodgers Freeway. From this point the alignment travels southeast in a tunnel below Griffin Street with a proposed Metro Center Subway Station (with connections to the West Transfer Center and West End light rail station) before curving east under Commerce Street.

The alignment continues east under Commerce Street through the heart of Downtown Dallas with a proposed Commerce Subway Station at Akard Street (three blocks south of the existing Akard light rail station) and a proposed CBD East Subway Station on the east end of downtown (one block south of the East Transfer Center). The alignment then turns northeast parallel to Swiss Avenue and begins transitioning from subway to at-grade via a portal under and immediately east of IH-345. The alignment continues parallel to Swiss Avenue at-grade before tying back in to the existing light rail system at Good-Latimer Expressway via a wye alignment configuration, including rebuilding a portion of the existing Green Line track. The alignment will result in the removal of the existing Deep Ellum light rail station.

The current LPA current introduces four new stations, one surface station (Museum Way Station) and three underground stations (Metro Center Station, Commerce Station, and CBD East Station). The underground stations will be accessed by stairs, elevators and/or escalators and will include emergency egress and ventilation shafts.

2.3 Contract Description

For this preliminary GBR, it has been assumed that all underground heavy civil work will be procured as one single contract. If the DART D2 underground heavy civil work is procured under multiple contracts, a separate final GBR will be prepared for each contract.

Construction of the underground portions will include cut-and-cover and mined twin tunnels, one mined underground station, two cut-and-cover underground stations, station entrance shafts and ventilation shafts, mined cross passages, a sump/pump room, and U-wall retained excavations for portals.

The alignment is located primarily within the public right-of-way, including the two westernmost underground stations, Metro Center, beneath Griffin Street, and Commerce Station, beneath Commerce Street. East of Commerce Station is a tunnel transition, east of which the alignment weaves beneath properties outside the public right-of-way, including the CBD East Station between Elm and Main Streets.

The existing street grid, the minimum achievable tunnel excavation radius, and the desired maximum speed of LRT trains constrain the horizontal alignment. The presence of adjacent and overlying structures, design and operational requirements, subsurface conditions, and anticipated construction methodologies constrain the vertical alignment.

The underground portion of the DART D2 project, for which this preliminary GBR applies, is assumed to include construction of all underground excavation, temporary and permanent support, and structures. Construction of cross passages and the sump/pump room includes temporary support, waterproofing, and structural lining. Construction of underground stations and portals includes construction of rigid support of excavation (SOE) secant pile or slurry walls or similar waterproof and permanent structures, excavation and support of entrance shafts and ventilation shafts, station excavations with temporary support, waterproofing, and structural concrete up to the finished ground level. Underground construction is also assumed to include invert drains, embedded conduits, penetrations, and sleeves for mechanical, electrical, and plumbing (MEP), temporary power, lighting, and flood control facilities.

Construction of the underground portion of the DART D2 project will interface with work for above-ground structures at station locations and for the vehicles, track, and finishes. It will also interface with construction of at-grade LRT east and west of the underground portion of the project.

[The final GBR will reference the Contract Drawings and Specifications for full details of work included in the contract for construction of the underground portion of the DART D2 project.]

2.4 Contract Elements

Based on the preliminary 20% alignment and design as of December 20, 2019, the contract will include the following major underground elements, as summarized in Table 2-1:

[The final GBR will describe the major underground elements, station configurations and construction methods, excavation methods, and construction sequencing, or options, consistent with other final contract documents.]

- Two portals, each consisting of open-cut construction with a U-wall retaining structure to transition to surface grades.
- Three sections of cut-and-cover tunnels, transitioning from portals or stations. As shown in Table 2-1, SEM construction is an option for two tunnel sections. For baseline purposes, cut-and-cover construction is assumed.
- A three-level cut-and-cover station, Metro Center Station, and a single-level cut-and-cover station, CBD East Station.
- One SEM mined station, Commerce Station, two levels deep but with different heights to accommodate existing utilities. Main access to the station will be via a vertical shaft with headhouse and passenger adit to the mezzanine level. An egress shaft with passenger adit connection will be constructed at the east end of the station. A ventilation shaft is also planned for Commerce Station. *[20% station design was still in progress as of December 20, 2019.]*

- Two sections of SEM-mined tunnels adjacent to the west end and east end of Commerce Station. TBM mining is an option for these tunnel sections. For baseline purposes, SEM mining is assumed.
- Two cross passages and a sump/pump room to be constructed in rock by SEM mining.
- *[Cross passages, shafts for ventilation structures and station entrances, and connecting adits will be included in the contract but are not addressed in detail in this preliminary GBR because locations and design details were not yet defined as of December 20, 2019. They will be included as applicable in the final GBR.]*
- *[Utility relocations, underpinning, mitigations for obstructions in public and private right-of-way, and other related work in the contract will be included as applicable in the final GBR.]*

3 SOURCES OF GEOLOGIC AND GEOTECHNICAL INFORMATION

3.1 Geotechnical Data Reports

The principal sources of geologic and geotechnical information used to evaluate and characterize the subsurface conditions at the site, interpret the geotechnical data, and develop the baseline information presented in the final GBR is the DART D2 GDR (GPC6, 2019) prepared by Alliance Geotechnical Group.

The DART D2 GDR presents methods and results of geotechnical investigations, including:

- Soil and rock drilling and sampling
- Installation of piezometers
- Groundwater level monitoring data
- Laboratory testing of soil and rock

[The final GBR will reference additional project-specific information and data from DART North Central Line design and construction and other relevant Dallas-area projects to be presented as Reference Information Documents or in SGDR(s).]

This GBR for 20% Design is based on DART D2 project geotechnical information available as of August 29, 2019, and the 20% design alignment and configuration current as of December 20, 2019. This configuration did not identify site layouts, stations, entrances, and ancillary facilities, including ventilation plants.

Data used for development of most preliminary geotechnical ground characterization and geotechnical design parameters presented in this GBR were from logs of borings drilled for the DART D2 Project and DART D2 project geotechnical laboratory test data presented in the GDR (GPC6, 2019).

For this GBR for 20% Design, field and laboratory geotechnical data collected for the following Dallas-area projects were used to supplement the limited geotechnical data currently available for the DART D2 project:

- DART North Central Transit Tunnels and Cityplace Station (Section NC-1B) (DART, 1992a; 1992b)
- 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)

3.2 Published Geologic and Geotechnical Reports

Readily available published geologic and geotechnical reports, construction records, and record drawings from nearby projects were reviewed for this GBR for 20% Design. Relevant details of previous construction experience are discussed in Section 6. Where appropriate, information from previous construction projects was considered in developing the baselines in this preliminary GBR. References for this information are listed in Section 14 of this report.

The information listed will not necessarily be complete, and other sources of data may exist. References and sources of information are provided as reference information only.

[The final GBR will reference additional published geologic and historical references which will be listed or included in their entirety as Reference Information Documents or in SGDR(s).]

4 PROJECT GEOLOGIC SETTING

For this preliminary GBR for 20% Design, the DART D2 project geologic setting is as described in detail in Geotechnical Design Memorandum (GDM) 3 (GPC6, 2020). A geologic map of the Dallas County is presented in Figure 4-1.

[The final GBR will refer to Reference Information Documents, the GDR, and/or an SGDR for the details of the DART D2 project geologic setting.]

4.1 Physiography and Regional Geology

The 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 area is within the Blackland Prairies of the West Gulf Coastal Plain Section of the Coastal Plain Physiographic Province of the Atlantic Plain Division (Fenneman, 1938). The Blackland Prairies extend across Texas from the Red River southwestward to San Antonio and are underlain by chinks and marls which weather to deep, black, fertile clay soils.

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 overlain by thousands of feet of Cretaceous-age sedimentary rocks. Due to post-Cretaceous tilting, bedding in the Cretaceous sedimentary rocks dips gently east or southeast toward the East Texas Embayment at 50 to 100 feet per mile (Allen and Flanigan, 1986).

Rock in the DART D2 project area consists of the late-Cretaceous age Eagle Ford Shale, Austin Chalk, and Ozan Formation. Belts of weaker shale have been worn down more rapidly than the relatively resistant Austin Chalk, producing a series of escarpments trending generally north-south across the region. 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.

Erosion during the Pleistocene epoch entrenched major streams into rock, including the Trinity River in Dallas, leaving former flood plains elevated above the current flood plain. The resulting terraced sediments and alluvium were deposited along Trinity River and its three Dallas-area tributaries during Pleistocene and Holocene time.

[The final GBR will reference the Reference Information Documents, GDR, and/or SGDR for additional detail.]

4.2 Topography and Drainage

From sea level at the Gulf of Mexico, the elevation of the Gulf Coastal Plain increases northward and westward toward Dallas. 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.

The DART D2 project site is within the Upper Trinity River watershed. The Trinity River is a 710-mile-long river rising in northern Texas and flowing southeast through downtown Dallas, west of the DART D2 alignment, to drain into Galveston Bay. Two tributaries, Elm Fork and West Fork, join the Trinity River just west of Dallas, and East Fork joins 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).

[The final GBR will reference the Reference Information Documents and/or SGDR for additional detail.]

4.3 Regional Groundwater Conditions

Major aquifers in the Dallas area are the Early Cretaceous-age Trinity and Paluxy sands, the Late Cretaceous-age Woodbine sands, and the Holocene and Pleistocene sands and gravels of the flood plains and terraces. The city's surface water storage system provides most of the public water supply, with groundwater only a minor source used by local industries and agriculture.

[The final GBR will reference the Reference Information Documents and/or SGDR for additional detail.]

4.4 Seismicity

Like most of North America east of the Rocky Mountains, damaging earthquakes are rare in the Dallas region, and most occur at 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).

Earthquake events of magnitude 3.4 and 3.2 were recorded in 2015 and 2019, respectively, in Johnson County, Texas, 25 to 30 miles southwest of Dallas, and are believed to be related to effects of wastewater injection (Hennings et al., 2019).

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 final GBR will reference the Reference Information Documents and/or SGDR for additional detail.]

4.5 Site Geology

Soil and rock units in the Dallas region are described below in order from youngest to oldest. Figure 4-1 presents a geologic map of Dallas County. Section 9 presents site-specific engineering properties of these materials, and Section 10 describes site geotechnical conditions by specific reaches of the DART D2 underground alignment. A general geologic profile of the underground portion of the DART D2 project is presented in Figures 8-1A through 8-1I based on the alignment and design current as of December 20, 2019.

4.5.1 OVERBURDEN GEOLOGY

Overburden is here defined as all non-lithified material above weathered rock. In the DART D2 project area, overburden is composed of fill, alluvium, and residual soil.

Near the Trinity River, rock is overlain by alluvium, as shown in the geologic map in Figure 4-1, 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. Quaternary flood plain deposits (Qal on Figure 4-1), including indistinct low terrace deposits, consist of gravel, sand, silt, silty clay, and organic matter (UT BEG, 1988). Quaternary terrace deposits (Qt on Figure 4-1) 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 flood plain (Allen and Flanigan, 1986). Thickness of these terrace deposits ranges from 10 to 45 feet.

Away from streams, a layer of residual soil derived from in-situ weathering of the underlying rock consists of brown to black silty clay to clay, 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.

[The final GBR will reference the Reference Information Documents and/or SGDR for additional detail.]

Geotechnical properties of site materials are characterized in Section 9.

4.5.2 OVERBURDEN-ROCK TRANSITION

A zone of highly to completely weathered rock is present between rock and overburden in the DART D2 project area. This material, described as “weathered rock” on DART D2 boring logs in the GDR (GPC6, 2019), corresponds to ISRM weathering grades IV and V and is considered Intermediate Geomaterial (IGM). It is described on logs as fractured, weathered limestone and occasionally as decomposed with clay seams. Thickness of IGM along the DART D2 underground alignment ranges from 1 foot to 10.5 feet, based on boring logs in the GDR (GPC6, 2019). Average thickness encountered in DART D2 borings was 3.7 feet.

The final GBR will reference the Reference Information Documents and/or SGDR for additional detail.]

Geotechnical properties of site materials are characterized in Section 9.

4.5.3 BEDROCK GEOLOGY

AUSTIN CHALK

Excavations for the DART D2 project will be primarily in the 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).

The Austin Chalk (Kau on Figure 4-1) 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).

An unconformity exists at the contact between the Austin Chalk and the underlying Eagle Ford Shale. 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).

EAGLE FORD SHALE

Excavations for the DART D2 project will encounter the Eagle Ford Shale only in the 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.

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 Shale (Kef in Figure 4-1) 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. The plasticity of the moistened shale makes it particularly susceptible to mass-wasting by slumping (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 29 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 formed sulfuric acid which reacted with the calcium carbonate in the shale to produce hydrous calcium sulfate in the form of gypsum (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).

5 SITE CONDITIONS

The DART D2 project is within the commercial core of the Dallas metropolitan area. Land use in the underground alignment area is mixed-use, including commercial and government buildings, arts and cultural centers, recreational facilities, high-density residential developments, and parking facilities.

Specific descriptions in this section are informational and were only considered for developing or confirming baseline statements contained elsewhere in this report. Baselines presented elsewhere in this report take precedence over the information in this report section. Locations, depths, dimensions described in this section are approximate, and information shown on Contract Drawings takes precedence over descriptions and dimensions in this section.

Site environmental conditions related to the presence of potentially hazardous materials are discussed in Section 9.6.

Existing structures and utilities requiring protection, instrumentation, and monitoring are listed in the Specifications.

5.1 Historical Structures

Buried foundations, former basements, and abandoned tunnels are anticipated within private property as well as public right-of-way. Locations of known historical structures potentially impacting construction will be shown in Contract Drawings. *[The final GBR will include additional detail if available or refer to Reference Information Documents.]*

5.2 Existing Structures

The DART D2 alignment is in an urban setting and passes near or beneath numerous existing structures and infrastructure. Several structures of particular concern are identified and described in the following section.

This section is not intended to be a comprehensive list of all structures that could be impacted by the construction of the DART D2 subway. Structure locations potentially requiring protection and/or monitoring will be shown in Contract Drawings, and relevant historical and building information will be provided in the Reference Information Documents.

[This section of the final GBR will describe some of the structures requiring special attention; it is not intended to be a comprehensive list of all structures that could be impacted by the construction of the underground portion of the DART D2 project.]

5.2.1 HISTORIC STRUCTURES

A total of 90 structures and properties listed or eligible for listing in the National Register of Historic Places (NRHP) are within the DART D2 project's Area of Potential Effect (APE). The APE and a complete inventory of these historic properties are provided in the Historic-Age Resource Reconnaissance Survey (GPC6, 2019a).

Historic structures requiring monitoring and protection will be identified or referenced in the final GBR. Locations of these historic structures will be shown on the Contract Drawings.]

5.2.2 BUILDINGS

Where the underground alignment is within the public right-of-way, existing buildings are primarily high-rise commercial buildings or cultural centers. The DART D2 alignment passes with 100 feet of X buildings which are X or more stories in height. *[The final GBR will include building count and height.]*

The following structures are near or adjacent to the planned DART D2 underground alignment and will potentially be affected by construction:

- Dallas World Aquarium, at 1801 North Griffin Street, west of the West Portal, an aquarium and zoo opened in 1992 in a rebuilt warehouse originally constructed in 1924.
- Bank of America Plaza, at 901 Main Street, west of planned Metro Center Station, a 72-story modernist skyscraper completed in 1985.
- Renaissance Tower, 1201 Elm Street, east of Metro Center Station, a 56-story structure completed in 1974 and expanded in 1986.
- One Main Place, at 1201 Main Street, north and east of the DART D2 alignment, a 33-story mixed-use hotel and office tower completed in 1985.
- Magnolia Hotel, at 1401 Commerce Street, a 29-story Beaux-Arts style building constructed in 1922 as a two-part vertical tower clad in Indiana limestone. The

building was listed in the National Register of Historic Places in 1978 and designated a Dallas Landmark in 1978.

- One AT&T Plaza, adjacent to planned Commerce Station on the south side of Commerce Street between Browder and Akard Streets, a 37-story white stone and glass high-rise built adjacent to the Akard Street Mall in 1984.
- Adolphus Hotel, at 1321 Commerce Street, west of Commerce Station, a 22-story Beaux-Arts style building completed in 1912, a designated Dallas Landmark listed in the National Register of Historic Places in 1983.

[Locations of existing buildings within the area of influence of construction or requiring underpinning or protection will be shown on the Contract Drawings and identified or referenced in the final GBR and/or Reference Information Documents.]

5.2.3 UNDERGROUND UTILITIES

Numerous utilities are located within the public right-of-way along the alignment, including water, gas, electrical and communication lines, storm sewers, and sanitary sewers.

Known major utilities potentially affected by construction include a 7-foot inside diameter storm sewer and a 24-inch diameter sanitary sewer beneath Commerce Street between Griffin Street and St. Paul Street. These sewer lines are above the running tunnel and Commerce Station as they are shown on the underground alignment current as of December 20, 2019.

[Known locations, types, and configurations of these and other utilities will be shown on the Contract Drawings. Utilities requiring relocation or monitoring and protection will be identified or referenced in the final GBR and/or Reference Information Documents.]

5.2.4 TRANSPORTATION INFRASTRUCTURE

The DART D2 underground alignment passes beneath the existing DART Light Rail Transit System Blue, Green, Orange, and Red lines at Pacific Avenue. These lines will remain in service during DART D2 project construction. The D2 line will tie into the existing DART System Green Line at grade at Good-Latimer Expressway.

An existing pedestrian tunnel is present above the planned subway alignment at approximately Station 56+50, near Main Street, and an existing parking underground parking garage ramp is present above the planned subway alignment at approximately Station 54+50, near Elm Street. A

[Details of the existing structures and requirements for their monitoring and protection will be included in the Contract Documents and referenced in the final GBR.]

The DART D2 underground alignment current as of December 20, 2019, passes beneath U.S. Route 75/IH 345/North Central Expressway east of CBD East Station. These roadways and their associated viaduct and overpass foundations will potentially be affected by DART D2 construction.

[Structural details and requirements for monitoring and protection will be included in the Contract Documents and referenced in the final GBR.]

6 PREVIOUS CONSTRUCTION EXPERIENCE

This section discusses previous Dallas-area underground construction and is based on publications and reports which will be referenced in the final GBR or included as Reference Information Documents or in the GDR(s). Descriptions of subsurface conditions in this section, including names or descriptive terms for various soil and rock units, are taken from the original referenced publications and do not necessarily conform to the DART D2 project ground classification system which is presented in Section 8. Refer to the original publications for additional details.

6.1 DART North Central Transit Tunnels (Section NC-1B) and Cityplace/Uptown Station

DART's North Central transit tunnels and stations began construction in the early 1990s and were placed into service in December 2000. The tunnels extend 3.5 miles north from the center of Dallas, starting about half a mile north of the DART D2 alignment and running beneath the North Central Expressway (US 75). Construction included open-cut excavations, twin-bore TBM tunnels, and mined excavations for station and escalator structures, ventilation structures, and cross passages. Excavated diameter of each tunnel is 21.3 feet. Maximum depth to invert is about 125 feet below ground surface (DART, 1992a; 1992b).

Tunnel excavation was primarily through the lower portions of the Austin Chalk, with some excavation in weathered rock and terrace sands. The groundwater level was approximately 25 feet below ground surface. Two types of faults were encountered: simple faults with small apertures and less than 5 feet of displacement and major faults with open fractures, reduced rock quality, and more than 20 feet of displacement.

Cityplace/Uptown Station (formerly Cityplace Station) serves DART's Red, Orange, and Blue lines and is currently the only underground station on the DART rail system. The station is beneath the North Central Expressway (US 75) at Haskell Avenue, in the Cityplace district of Dallas, about 1.7 miles north of the DART D2 alignment. Construction was by New Austrian Tunneling Method (NATM), similar to SEM.

The top-down excavation of the station started with installation of slurry walls through the overburden to allow blind-hole drilling of the ventilation shafts and escalator declines (Sauer et al., 1996). Roadheaders completed the excavation in the Austin Chalk. The final station lining is cast-in-place concrete. The station is tri-level in design, with a maximum depth of about 120 feet below ground surface.

Rock dowels were installed as initial support for the TBM-mined tunnels, typically with a pattern of 10-foot long dowels at 5-foot spacing in the crown. In areas with lower rock quality, a pattern of 6.5-foot long dowels at 5-foot spacing was installed. For station enlargements and smaller-diameter ventilation and cross-passage openings, typical pattern dowels were combined with polyfiber-reinforced shotcrete for initial support.

The installed initial support system for shaft sinking through overburden soils included hand-mined liner plates and ring beams, which transitioned to rock dowels combined with shotcrete for shaft excavation through rock.

Specifications required the rock surface to be sealed within 24 hours of excavation. The contractor chose to clean the rock surface with high pressure water and seal it with a clear sodium silica product instead of shotcrete to avoid spraying shotcrete on the TBM equipment. A finishing 50-mm layer of shotcrete was then applied as a second pass operation.

Tunnel mining was delayed by flows of groundwater contaminated with gasoline and solvents issuing from two major, permeable fault zones. The faults were about 50 feet apart and striking northwest-southeast. Construction delays resulted from efforts to investigate and mitigate the contamination source. The fault zones were over-excavated slightly and then sealed with concrete.

Inflows of methane and other natural gases to the heading also caused delays for investigation and upgrading of the mining equipment and ventilation system to comply with OSHA requirements. Methane had not previously been encountered in Dallas tunnel construction. The methane source was attributed to a deep-seated oil or natural gas deposit (Dallas Morning News, 1994; Doyle, 2001).

Section NC-1B and Cityplace/Uptown Station were designed and constructed as a drained system. The tunnels and station reportedly have been experiencing significant calcification during operation, resulting in clogged drains and thick accumulations of hardened scale which require significant regular maintenance to remove. The deposits accumulate over a period of several months and are believed to be the result of changes in groundwater temperature and pH.

Additional project details are provided in Sauer et al., 1996. *[The final GBR will reference additional information provided in the Reference Information Documents.]*

Construction experience on DART Section NC-1B and Cityplace/Uptown Station is relevant for DART D2 construction for TBM mining as well for roadheader excavation of stations and construction of shafts and cross passages. The rock, overburden, and groundwater conditions along DART Section NC-1B are generally similar to those along the DART D2 alignment, and ground behavior will be similar except where localized ground conditions differ. Although no major faults have been encountered in DART D2 explorations to date, the presence of major faults similar to those encountered on Section NC-1B is not precluded.

Potential inflows of methane or other hazardous gases are being assumed for DART D2 construction, and the Specifications require equipment and procedures appropriate for a potentially gassy condition in accordance with OSHA requirements. The potential for inflows of contaminated groundwater is also assumed.

To minimize the potential for drain clogging during system operation, DART D2 is designed as an undrained system with waterproofing. Potentially high rates of accumulation of groundwater precipitates are considered in project design.

6.2 US 75 North Central Expressway Cole Park Detention Vault, Dallas, Texas

The Cole Park Detention Vault project, owned by the City of Dallas Department of Public Works, consists of two access shafts and other ancillary tunnel structures with 13 parallel storm water storage vaults, each 865 long, 41 feet high, and 24 feet wide, with 15-foot wide rock pillars between vaults (Fugro, 2004). The site is located about 2.2 miles north of the DART D2 alignment.

The project was excavated by roadheader entirely in the lower part of the Austin Chalk. During excavation, groundwater inflow was negligible, and no significant deterioration of exposed rock was observed except for thin bands of bentonitic shale.

The excavated Austin Chalk reportedly broke down rapidly with repeated handling and mechanical action, developing into a sticky mass when mixed with water. Consequently, the contractor used non-stick coatings and linings on material handling equipment.

Where exposed near the crown, bentonite layers were removed and replaced with dry-packed concrete. The Bentonite Marker Bed was encountered but did not cause significant problems for construction (Fugro, 2004).

Tunnel crown support consisted of an 8-dowel fan pattern of 10-foot long resin-encapsulated rock dowels at 4-foot centers. Support in the ribs/pillars consisted of three levels of rock dowels, 13.5 feet to 17 feet long, at 6-foot centers. Final lining of the vault excavations, not required for structural support, was 3-inch thick concrete reinforced with welded wire fabric.

The Bentonite Marker Bed was encountered in DART D2 exploratory borings in the vicinity of planned CBD East Station. Ground conditions in the eastern portion of the DART D2 alignment can be expected to be generally similar to those at the Cole Park Detention Vault.

6.3 DART Mockingbird Station, Dallas, Texas

DART's Mockingbird Station is east of US 75 and about 2 miles north-northeast of the DART D2 alignment. Constructed as an open cut excavation to depth approximately 37 feet, the site's subsurface stratigraphy typically consisted of upper 9 feet of clayey fill underlain by 28 feet of Austin Chalk limestone. Final walls for the station were pre-cast fascia panels fixed to tiebacks that had been installed in the rock to control potential rock wedge sliding along rock mass discontinuities. Short-term and long-term soil stabilization was achieved by soil nailing and shotcrete before installation of the fascia panels (Lachel Felice, 2006).

Site residual clays had moderate to high swell potential. However, the design loading envelope in the project Geotechnical Interpretative Report did not include additional wall loading associated with swelling clay.

Ground conditions along the eastern portion of the DART D2 alignment can be expected to be generally similar to those at Mockingbird Station.

6.4 One Main Place, Downtown Dallas, Texas

The 70-foot deep foundation excavation for One Main Place penetrated primarily Austin Chalk limestone, ending in the Fish Bed Conglomerate. Local newspapers reported that over a period of several hours in January 1967, a large section of wall failed as an intact rock block and moved laterally approximately 20 feet into the excavation. A one-block section of the Elm Street pavement later subsided into the cavity that formed behind the translated block. Forensic investigations determined that the cause of the movement was a near-vertical fracture in the Austin Chalk, combined with presence of relatively weaker material at the contact between the Austin Chalk and Eagle Ford Shale, presumably the Fish Bed Conglomerate (Lachel Felice, 2006; Dallas Morning News, 1965; 1967).

The One Main Place site is located within about 400 feet of DART D2 Metro Center Station. Stratigraphy and ground conditions at planned DART D2 Metro Center Station will be generally similar to those at One Main Place.

6.5 Superconducting Super Collider, Waxahachie, Ellis County, Texas

Located approximately 35 miles south of Dallas, the Superconducting Super Collider (SSC) project, managed by the U.S. Department of Energy, was a planned particle accelerator complex authorized by Congress in 1989.

Construction included cut-and-cover excavation and tunneling, vertical excavation of access shafts, TBM tunnel boring, cut-and-cover and caving techniques for excavation of underground interaction halls, and creation of access roads, utility substations, and disposal sites for excavation spoil. By late 1993 when the project was canceled due to budget concerns, 17 shafts had been sunk and 14.6 miles of collider tunnel had been bored. Average depth of the collider tunnel is about 150 feet. After project cancellation, underground openings at the site were flooded for preservation, and the site is now being marketed for use as a data center.

Excavations were in the Taylor Marl of the Ozan Formation, the Austin Chalk, and the Eagle Ford Shale (USDOE, 1990). Initial support included rock bolts combined with 2 to 4 inches of shotcrete, steel mesh, and mine straps, as needed. Support for shaft excavation through soil consisted of reinforced secant pile walls, which transitioned to rock bolts and shotcrete for shaft excavation through rock.

Extensive geologic, geotechnical, hydrologic, and environmental data were collected for the SSC project. These data are relevant for general ranges of engineering properties of DART D2 site materials.

SSC soil and rock stratigraphy and excavation depth are generally similar to those along the DART D2 alignment, but the distance of the SSC project from the DART D2 alignment implies potential differences in site-specific soil, rock, and groundwater conditions. The SSC's rural site conditions also differ from the DART D2 alignment's urban site conditions, with potential associated differences in ground conditions due to historical land use, urban development, grading activities, and utility and infrastructure construction.

6.6 Addison Airport Toll Tunnel, Dallas, Texas

The Addison Airport Toll Tunnel is located about 13 miles north-northwest of the DART D2 alignment and provides an east-west route between the Dallas North Tollway and Interstate 35 E under the Addison Airport runway. Part of the North Texas Tollway Authority system, it is a two-lane vehicular tunnel approximately 1600 feet long. Construction was begun in 1997 and was completed in 1999.

The tunnel was constructed by roadheader excavation entirely in the Austin Chalk (Fugro, 2004). Ground cover above the tunnel crown was 10 feet at the west portal, 28 feet beneath the runway, and 18 feet at the east portal. Portals and difficult ground were driven by multi-drift top method (NATM/SEM), with tensioned rock bolts, steel fiber-reinforced shotcrete, and welded wire fabric as required.

The tunnel approaches were constructed as vertical cuts up to 45 feet deep (Lachel Felice, 2006) through Austin Chalk and weathered Austin Chalk overlain by about 1 to 3 feet of residual soil.

At the approach to the west portal, the excavation encountered a buried channel filled with approximately 20 feet of alluvium. Wall design had closely spaced cantilevered drilled shafts with diameters of 36 to 60 inches to provide substantial horizontal support through this area.

At the approach to the east portal, the weathered Austin Chalk was removed to allow a retaining wall to be founded on sound Austin Chalk. Granular backfill was placed behind the wall. On the south-facing wall, no permanent rock support was installed. On the north-facing wall, the possibility of an additional tunnel tube was incorporated into the design, and the excavation was sloped back and supported with 10-foot long rock bolts on a 7-foot square grid, supplemented with 4-inch thick shotcrete with welded wire fabric. Aesthetic precast fascia panels were anchored to the rock bolts on both sides of the approach.

A rock slide of approximately 500 cubic yards occurred on the south-facing wall during excavation of the eastern approach following heavy rains in January 1998. Major curvilinear fractures had been exposed during excavation. The slide extended approximately 20 feet behind the face over a height of about 30 feet. The slope instability was attributed to the combination of existing curvilinear fractures and flooding of the excavation, with failure triggered by vibration from hoe-ram equipment. Construction proceeded after supplemental rock bolting and remedial treatment of the failed rock surface.

General site stratigraphy and rock fracture patterns at the DART D2 alignment are generally similar to those at the Addison Airport Toll Tunnel, and without preventive measures, similarly unstable conditions can be anticipated.

7 DEFINITION OF ALIGNMENT REACHES AND EXCAVATION HORIZON

7.1 Reach Definition

Underground alignment reaches were defined based on the project alignment and configuration current as of December 20, 2019. *[The final GRB will include revisions to reach definition necessitated by any alignment revisions]*

In areas where the design current as of December 20, 2019, indicates that either cut-and-cover or SEM construction may be used, it is assumed for baseline purposes that construction will 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 is assumed for baseline purposes that mining will be by SEM.

Reach limits apply to both eastbound and westbound alignments.

Ten reaches are defined for the proposed DART D2 project underground alignment. Reach limits are defined based on proposed structures and anticipated construction methods. Reach limits are presented in Table 7-1. Reach stationing in Table 7-1 is for the project reference alignment, which is the eastbound track. General reach descriptions apply to both eastbound and westbound alignments. A legend and a boring and reach location plan are presented in Figures 7-1 and 7-2, respectively. Reach limits are shown on the boring location plan in Figure 7-2.

Reach limits are defined as follows:

- Limits of Reaches 1 and 10 are 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 are 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 are 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 are defined on the basis of limits of proposed SEM station excavation for Commerce Station.
- Limits of Reaches 4 and 6 are 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 are defined on the basis of limits of proposed cut-and-cover tunnel construction adjacent to the west end of CBD East Station.

Reach stationing shown in Table 7-1 is for the project reference alignment, which is the eastbound track.

[The final GBR will have updated reach definitions based on revisions to project design and anticipated construction methods.]

7.2 Excavation Horizon Definition

In this report, excavation horizons are defined based on top of rail elevations shown on the 20% design alignment profile current as of December 20, 2019.

The following upper and lower excavation limits conventions are defined as follows:

- At proposed portals, the excavation horizon extends from invert to ground surface.
- At proposed cut-and-cover tunnels, the excavation horizon extends from invert to ground surface.
- At proposed mined (SEM) tunnels, the excavation horizon extends from invert to tunnel crown, which is 22.2 feet above invert.
- At proposed cut-and-cover stations, the excavation horizon extends from invert to ground surface.
- At mined (SEM) Commerce Station, the excavation horizon extends 44.0 feet upward from invert.

General ground conditions within excavation horizons are included in the reach descriptions shown in Table 7-1.

[The final GBR will define excavation horizons for the final alignment, station configurations, and assumed or required construction methods.]

8 GROUND CLASSIFICATION

8.1 DART D2 Ground Classification System

A ground classification system was developed for the DART D2 underground alignment. The classification considers the project geologic setting, the nature and variability of the rock and soil materials to be encountered, and the probable construction methods to be used.

[The final GBR will incorporate any revisions to the ground classification system that may be required due to new information on soil and rock materials or changes in probable construction methods to be used.]

Weathering grades of the International Society for Rock Mechanics (ISRM), shown in Table 8-1 (from ISRM, 1981), were considered appropriate for ground class distinctions for rock materials of various degrees of weathering ranging from unweathered to residual soil.

DART D2 project ground classes and their distinguishing characteristics are summarized in Table 8-2. The ground classes are based on the following considerations:

- 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, ground classes are linked to ISRM weathering grades shown in Table 8-1 (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. Rock is defined as Ground Classes L-I, L-II, and L-III for limestone and S-I, S-II, and S-III for shale.
- Highly and completely weathered rock are here considered Intermediate Geomaterial (IGM). Their classification is linked to ISRM criteria for weathering grades IV and V (ISRM, 1981), including decomposition and disintegration. The “Weathered Rock” Ground Class Group is defined as highly and completely weathered rock. *[The final GBR will include description of weathered rock based on descriptions of samples from additional borings, to be presented in an SGDR.]*
- For soils, two natural soil groups were defined, along with an additional soil unit for fill. Alluvial soils consist of terrace deposits and Quaternary alluvium. Residual soils consist of completely decomposed limestone. *[It was not possible to distinguish alluvial soils from residual soils corresponding to information on boring logs in the GDR (GPC6, 2019), but the ground class for residual soil was retained for possible future use in the final GBR if supported by additional geotechnical data to be presented in SGDR(s).]*

As shown in Table 8-2, the twelve defined ground classes were grouped into eight Ground Class Groups and three General Ground Class Groups. *[The final GBR will reference the GDR (GPC6, 2019) and SGDR(s) for soil and rock description and classification terminology.]*

Section 9, Geotechnical Properties of Site Materials, provides additional details on ground class characteristics.

8.2 Ground Class Distributions

The distribution of ground classes presented in this preliminary GBR for 20% design was determined based on data available as of August 29, 2019, as presented in the GDR (GPC6, 2019) and the project alignment and configuration current as of December 20, 2019.

Figures 8-1A through 8-1I present a general geologic profile showing distribution of Overburden Ground Class Groups, “Weathered Rock,” and the two prevalent rock types along the DART D2 alignment.

[The final GBR will present an updated profile incorporating data from additional investigations to be presented in SGDR(s) and the final project alignment.]

Levels for top of rock and top of shale were determined from DART D2 project data in the GDR (GPC6, 2019), supplemented by data from logs of historical borings presented in Collier, 2015.

[Top of rock level will be refined for the final GBR, supported by additional data to be presented in SGDR(s).]

For preliminary baseline purposes, top of rock, top of shale, and upper contacts of weathered rock and alluvium are as shown graphically in the general geologic profile in Figures 8-1A through 8-1I. Elevations of contacts, including top of rock, are within +/- 5 feet

of the levels shown. The profile and variability apply to both eastbound and westbound alignments.

[The final GBR will include updated elevations and variability of top of rock, top of shale, and upper contacts of weathered rock and alluvium based on results of additional investigations as reported in SGDR(s).]

Tables 8-3, 8-4, and 8-5 present summaries of percent volumes for Ground Class Groups for excavations for portal U-wall excavation, cut-and-cover excavation, and SEM excavation, respectively. Actual excavation volume percentages will be within 10 percent of the baseline values shown in Tables 8-3, 8-4, and 8-5. The baseline values in Tables 8-3, 8-4, and 8-5 and this baselined variability take precedence over visual interpretations that can be made based on the geologic profile in Figures 8-1A through 8-1I.

[For the final GBR, the precedence of table values over visual interpretations may be reversed, depending on additional supporting data or risk management preferences.]

9 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 data presented in the GDR (GPC6, 2019), supported by the published reports and the investigations by others listed in Section 3.2. Hydraulic properties of site materials are discussed separately in Section 9.4.

[Descriptions in the final GBR will incorporate results of field and laboratory investigations to be presented in SGDR(s).]

The section presents preliminary baseline properties for ground classes. Overburden and “Weathered Rock” materials are characterized by ground class. Rock is characterized by ground class and rock type.

Comparisons to baseline values shall be made by combining all DART D2 existing and new test data for the entire ground class or rock type.

Supporting data from results of investigations and testing presented in the GDR (GPC6, 2019) are provided in the Appendices. The data in the Appendices are for reference and context with regard to the baselines established in this section.

[Appendices in the final GBR will provide additional supporting data from the results of DART D2 investigations and testing programs to be presented in the SGDR(s).]

Ground characterization by reach is addressed in Section 10.

9.1 Overburden Characterization and Properties

Overburden is defined as all non-lithified material above “Weathered Rock” and includes four ground classes for the planned DART D2 project: Fill (F), Cohesive Alluvium (A1),

Granular Alluvium (A2), and Residual Soil (RS). Overburden thickness along the planned DART D2 underground alignment generally increases from west to east.

Preliminary baseline properties for overburden ground classes and bentonite are presented in Table 9-1. The GDR (GPC6, 2019) is the data source for most properties shown in Table 9-1 for Fill, Ground Class A1, and Ground Class A2. Lachel Felice (2006) is the data source for properties of Ground Class RS (Residual Soil) and Bentonite because test data for these materials are not available in the DART D2 GDR (GPC6, 2019). Lachel Felice (2006) is also the data source for unconfined undrained compressive strength properties for Ground Classes Fill, A1, and A2 test results reported in the GDR (GPC6, 2019) are irregular.

For this preliminary GBR, baseline properties are given as ranges instead of single values because the available data set is small and because some test results in the GDR (GPC6, 2019) are irregular, possibly due to sample age.

[The set of DART D2 laboratory test data currently available in the GDR (GPC6, 2019) is not yet sufficiently robust to support refined quantitative analysis for soil properties. Appendices in the final GBR will present graphical plots of geotechnical properties of Overburden ground classes incorporating laboratory test data either from additional investigations, to be presented in SGDR(s) or from applicable published sources.]

9.1.1 FILL (GROUND CLASS F)

Based on boring logs in the GDR (GPC6, 2019), the maximum thickness of Fill along the proposed DART D2 underground alignment is 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 the Fill ground class are shown in Table 9-1 because of the range and variability of its materials. These parameters will require adjustment 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.

[The final GBR will include additional properties for fill in Table 9-1 based on additional data to be presented in SGDR(s). Appendices in the final GBR will include graphical data summary plots for properties of Fill.]

9.1.2 ALLUVIUM GROUP (GROUND CLASSES A1 AND A2)

Alluvium occurs along the length of the alignment and will be encountered in excavations at both portals and all cut-and-cover construction. Alluvium includes alluvial and terrace deposits.

Ground Class A1 is fine-grained, cohesive, and consists of low to high plasticity clay and sandy and silty clays, with some clayey sand.

Soils of Ground Class A1 underlie Fill along the DART D2 alignment and range in thickness from 1 foot to 30.5 feet. Based on boring logs in the GDR (GPC6, 2019), their average thickness is 12.8 feet. They tend to be thickest in the vicinity of proposed CBD East Station.

Soils of Ground Class A1 will be susceptible to consolidation settlement if additional stresses are imposed on them, including increased effective stress from groundwater lowering.

Ground Class A1 soils are highly expansive. To minimize differential settlement for major structures, structural loads will need to be transferred through alluvium to the rock by means of drilled shafts. Alternatively, drilled shafts founded in clay can be belled to anchor them to resist the upward forces of the expansive soils.

Ground Class A2 is granular and consists of mostly cohesionless soils ranging from silty sands to sand and gravel, with some intermixed clay.

Soils of Ground Class A2 underlie and are locally mixed with the fine-grained, cohesive deposits of Ground Class A1. Their maximum thickness along the DART D2 underground alignment is 18 feet, and their average thickness based on DART D2 boring logs in the GDR (GPC6, 2019) is 7.0 feet. They are thickest along the western portion of the alignment.

Granular soils of Ground Class A2 will exhibit running behavior above the water table or in a dewatered excavation and will exhibit flowing behavior below the water table, especially where they consist of clean sand and gravel.

Table 9-1 presents preliminary baseline geotechnical properties for Alluvium ground classes A1 and A2, based on data presented in the GDR (GPC6, 2019). *[Appendices in the final GBR will include graphical data summary plots for properties of Alluvium, incorporating additional data to be presented in SGDR(s).]*

As shown in Table 9-1, there is a high degree of variation in properties of Alluvium ground classes along the alignment. The Contractor's means and methods should be adaptable to the full range of properties to be encountered in soil excavations throughout the DART D2 alignment. *[The final GBR will incorporate results of additional testing to refine selection of baseline soil properties and rule out unreliable test results.]*

9.1.3 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 retains some evidence of the original rock fabric. Huitt and Zollars (1992) report that the stratum is typically about 10 feet thick but can 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 DART D2 boring logs in the GDR (GPC6, 2019).

Residual soils developed from 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).

Residual soils developed from the Austin Chalk are reportedly montmorillonitic and expansive. 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.

Slickensided fractures are common in residual soils in Dallas. Shoring and bracing will be required for excavations in areas with thicker residual soils because these areas will be prone to the sudden sidewall failures along the pre-existing slickensided failure planes that are common in residual soils in Dallas (Allen and Flanigan, 1986).

Table 9-1 shows preliminary baseline geotechnical properties for Residual Soil Ground Class RS, based on data based on data from Lachel Felice, 2006. Additional laboratory test data or further detailed sample examination could allow definition of residual soil as a distinct ground class for the DART D2 project.

[The final GBR will present baseline distribution and properties for Ground Class Residual Soil based on additional DART D2 data to be presented in SGDR(s). Appendices in the final GBR will include graphical data summary plots for properties of Residual Soil.]

9.2 Overburden-Rock Transition Properties (Ground Class IGM)

Below the lower contact of Alluvium or Residual Soil, a transition zone of “Weathered Rock” is defined as highly to completely weathered rock corresponding to ISRM weathering grades IV and V. This material, described as “weathered rock” on DART D2 boring logs in the GDR (GPC6, 2019), is considered Intermediate Geomaterial (IGM).

Ground Class IGM also includes the Fish Bed Conglomerate, which consists of pebbly beds, reworked fossils, and pebble- to cobble-size fragments of limestone. It is classified as IGM because its physical properties are similar to those of “weathered rock.”

“Weathered Rock” 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.

Ground Class IGM occurs along the length of the alignment. As shown in Tables 8-3 and 8-4, IGM will be encountered in excavations at both portals and all cut-and-cover construction. Alluvium includes alluvial and terrace deposits.

Thickness of Ground Class 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.

Ground Class IGM retains some attributes of the parent rock that will influence its behavior, including relict bedding, texture, and fractures. The relict rock mass features will influence behavior of this material in excavation headings by reducing overall strength, causing potential instability due to unfavorably oriented structure and block releases, and introducing a high degree of heterogeneity and variability.

Pre-existing fractures in “Weathered Rock” include both randomly oriented, discontinuous fissures and long, persistent fractures that are part of a regularly oriented joint set. Fractures can be opened or closed by water or air pressure applied during construction.

Table 9-2 presents preliminary geotechnical baseline properties for Ground Class IGM (“Weathered Rock”) based on data presented by Lachel Felice (2006) for weathered Austin Chalk. It is assumed that “Weathered Rock” described on DART D2 boring logs will have

similar properties. For baseline purposes, rock fragments are assumed to constitute less than 50 percent of the volume of Ground Class IGM, with the remaining volume consisting of soil and soil-like material. The baseline maximum dimension for Ground Class IGM rock fragments is 2 feet, and the rock fragments are composed of limestone.

[[The final GBR will present baseline distribution and properties for Ground Class IGM based on additional DART D2 data to be presented in SGDR(s). Appendices in the final GBR will include graphical data summary plots for properties of IGM.]

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

9.3.1 ROCK TYPE DESCRIPTIONS AND INTACT ROCK PROPERTIES

The following sections characterize rock types and their intact rock properties. Intact rock properties are for slightly weathered to unweathered rock.

The distribution of rock types along the DART D2 underground alignment is shown graphically in the general geologic profile in Figures 8-1A through 8-1I. As shown, there are 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 is addressed as a separate rock type in this section because its engineering properties are 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, 4, and 5.

Tables 8-3, 8-4, and 8-5 include the preliminary baseline distribution of rock types by volume of excavation based on data in the GDR (GPC6, 2019). Specific distribution of rock types by reach is discussed in Section 10. *[The final GBR will include refined distributions based on data from additional investigations to be presented in SGDR(s).]*

Table 9-3 presents reference ranges and preliminary baseline intact rock properties for DART D2 rock types based on data in the GDR (GPC6, 2019). The Contractor's means and methods should be adaptable to the full range of properties to be encountered in rock excavations.

Intact rock strength will be highest in a direction perpendicular to bedding, even in rock with no evident penetrative fabric and little or no visible anisotropy. Because DART D2 underground excavations will mostly be advanced in a direction subparallel to mineral alignment and bedding planes, and the loading direction for most laboratory strength tests was perpendicular to mineral alignment and bedding planes, rock strengths encountered in construction will be somewhat lower than laboratory test values shown in Table 9-3.

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 Chalk Group will constitute about 54 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.

The limestone is light to medium gray, medium hard to hard, and unweathered to slightly weathered below the level of start of coring.

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

The limestone includes argillaceous layers and becomes more argillaceous with depth along the DART D2 alignment. The limestone also includes calcareous layers, very hard calcareous stringers and nodules, and occasional shale seams, all less than about 3 inches thick. Frequency and thickness of shale layers increases approaching the underlying shale. Pyrite is present within the limestone.

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

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.

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, including the pyrite described on boring logs, 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 boring logs. *[The final GBR will include a baseline condition for occurrence of the Fish Bed Conglomerate, incorporating information from additional investigations to be presented in SGDR(s).]*

Solution features such as pitting or dissolution cavities are not present in the limestone based on descriptions on DART D2 boring logs in the GDR (GPC6, 2019). *[The final GBR will include a baseline condition for solutioning.]*

Preliminary reference ranges and baseline values for intact rock engineering properties for limestone are presented in Table 9-3, based on data presented in the GDR (GPC6, 2019). According to ISRM criteria (ISRM, 1981), DART D2 limestone is generally weak, soft, non-

abrasive, and not prone to slaking, as shown by the intact rock properties presented in Table 9-3.

Percentile plots of intact rock properties for limestone are presented for reference in Appendix A.

[The final GBR will incorporate information from additional testing to be presented in SGDRD(s).]

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.

The shale is gray to dark gray, fine-grained, soft to medium hard, and unweathered to slightly weathered

The shale includes moderately hard seams of calcareous shale and very hard calcareous nodules and stringers. Two layers of sandy mudstone and fine-grained sandstone 3 to 5 feet thick are present between depth 95 and 120 feet. Scattered 2-inch thick layers of soft clay shale also occur, as well as limestone layers less than 1 inch thick.

Iron staining present on non-bedding fractures dipping 15 to 40 degrees indicates groundwater flow.

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

Other minerals in the shale are quartz (12 percent by volume), as quartz silt and very fine sand, and opaque minerals (4 percent by volume), confirmed by the pyrite recorded in boring logs. The petrographic analysis indicates that despite the high content of soft clay, the shale will be somewhat abrasive, and hydrogen sulfide and acid groundwater are to be expected.

Except for its layers of hard limestone, the Eagle Rock Shale is moderately to highly erodible (Allen and Flanigan, 1986). Cut slopes are 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).

Only limited project-specific test data are available for DART D2 intact shale properties. Preliminary reference ranges and baseline values for selected engineering properties for Shale are summarized in Table 9-3 based on data in the GDR (GPC6, 2019). 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.

Percentile plots of intact rock properties for shale are presented for reference in Appendix A.

[The final GBR will incorporate information from additional testing to be presented in SGDR(s).]

BENTONITE

A regionally persistent bentonite layer, locally known as the Bentonite Marker Bed (Lachel Felice, 2006) is 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, the Bentonite Marker Bed occurs as a 14-inch thick bentonite layer at boring TS-206, located west of planned CBD East Station (see Figure 7-2 for boring location) at depth 36.6 to 37.8 feet below the ground surface (elevation 425.9 to 427.1 feet). It will be encountered in cut-and-cover excavations for CBD East Station and will adversely affect excavation stability if not mitigated.

Additional, thinner bentonite layers are noted in limestone on DART D2 boring logs in the GDR (GPC6, 2019), but data are insufficient to correlate these layers between borings.

Following exposure to moisture after drying, as will occur in excavation operations, clays in bentonite layers will slake and swell to many times their original volume, producing pressures sufficient to induce slabbing and separation along bedding planes in rock.

The bentonite layers are near-horizontal and parallel to bedding and if intercepted by tunnel excavation, will be present for a long distance along the alignment.

Preliminary reference ranges and baseline values for intact rock engineering properties for bentonite are included in Table 9-1, based on data collected for other projects.

[The final GBR will present additional details on depth, thickness, location with respect to planned project structures, and site-specific intact rock properties of bentonite layers based on results of additional investigations to be presented in SGDR(s).]

9.3.2 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 DART D2 boring logs presented in the GDR (GPC6, 2019).

[The final GBR will include descriptions based on results of additional investigations to be presented in SGDR(s).]

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 unweathered to slightly weathered. Fracture spacing is described as very close (less than 2 inches) 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 in the GDR (GPC6, 2019). 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 in the GDR (GPC6, 2019). 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. Bedding in the shale dips 0 to 15 degrees, and many, but not all, fractures occur along bedding.

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 will strongly influence the behavior of the rock mass in response to excavation. Few site-specific rock mass data are currently available in the GDR (GPC6, 2019). *[The final GBR will incorporate project-specific data when they become available.]*

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 8.

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 4.5.3, the Fish Bed Conglomerate or "Transition Zone" 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 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.

[The final GBR will include quantitative information on properties of lithologic contacts based on results of additional investigations to be presented in SGDR(s).]

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 (GPC6, 2019) indicate that dip angles are nearly horizontal, ranging from 0 to 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 north-northeast with a dip of less than 1 degree east (DPG, 1941). For preliminary baseline purposes, bedding is assumed to dip 0 to 20 degrees south-southeast.

Bedding thickness varies. 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.

Faults

No site-specific fault data are currently available, except for observations of slickensided surfaces recorded on boring logs in the GDR (GPC6, 2019).

The boring logs in the GDR (GPC6, 2019) do not indicate any major fault zones crossing the DART D2 underground alignment, with a major fault here defined as a fault with more than 20 feet of displacement and a fault-affected zone measuring more than 20 feet along the alignment. The Geologic Database of Texas of the Texas Natural Resources Information System (TNRIS, 2007) also shows no mapped faults within Dallas County.

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 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 plane 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 in Reach 5 near the central part of 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 but could affect project excavations, depending on their dip directions. Fracture dip directions are not available.

For baseline purposes, it is assumed that the alignment will not intercept any major fault-affected zones greater than 20 feet in length as measured along the alignment.

For baseline purposes, it is assumed that minor faults occur in conjugate sets, striking N65E and dipping 30 to 60 degrees in opposite directions. It is assumed that these minor faults can be intercepted at any location or depth along the alignment. For baseline purposes, it is assumed that the disturbed ground adjacent to each fault measures less than 10 feet in length along the alignment.

[The final GBR will include additional site-specific fault characteristics based on results of additional investigations to be presented in SGDR(s).]

Fractures and Joint Sets

Only limited site-specific data on the nature of fractures and joint sets in rock along the DART D2 are now available. 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 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 member of the Austin Chalk at White Rock Lake

For preliminary baseline purposes, it is assumed that two near-vertical joint sets are present along the DART D2 alignment, one of which strikes 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).

For preliminary baseline purposes, persistence for fractures along bedding planes is 200 feet. Persistence for fractures of other orientations is 50 feet.

[The final GBR will present available site-specific baselines on contacts, bedding, faults, fractures, and joint sets based on results of additional investigations to be presented in SGDR(s).]

9.3.3 IN-SITU STRESS CONDITIONS

Differences among principal in-situ stresses in the rock mass are relatively small. For baseline purposes, vertical in-situ stress in rock along the alignment is assumed to be equivalent to the weight of overlying soil and rock materials. The maximum horizontal in-situ stress, which depends on confinement, erosion and stress history, and rock strength, is assumed to be twice the vertical stress in Austin Chalk limestone and 1.5 times the vertical stress for the Eagle Ford Shale, based on results of hydrofracturing tests at the SSC site (Kim and Schmidt, 1992).

9.4 Groundwater Conditions

9.4.1 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. The final GBR will present ranges and baseline values of hydraulic conductivity for rock and overburden based on data presented in the GDR.

For preliminary baseline purposes, Table 9-4 presents ranges of hydraulic conductivity for individual DART D2 ground classes and preliminary baseline values of hydraulic conductivity for DART D2 Ground Class Groups. Values in Table 9-4 are based on published data and data collected for other projects.

Ranges shown in Table 9-4 for ground classes are applicable for localized assessments of grouting feasibility. Preliminary baseline values shown for Ground Class Groups are applicable for estimates of steady-state inflows, evaluations of groundwater cutoff schemes, estimations of groundwater drawdown around excavations, and sizing of pumps, wells, and other equipment.

Highest groundwater inflows in excavations below the water table will occur from the most hydraulically conductive ground classes shown in Table 9-4, specifically ground classes F, A2, and IGM. High groundwater inflow will also occur along the rock surface and, where present, through the Fish Bed Conglomerate between the Austin Chalk and the Eagle Ford Shale.

[The final GBR will provide baselines developed from site-specific results of additional investigations to be presented in the SGDR(s).]

For preliminary baseline purposes, it is assumed that water-bearing zones within overburden ground classes are interconnected, and that “Weathered Rock” is locally hydraulically linked to overburden. Sustained inflows should be expected in excavations within overburden and “Weathered Rock.”

It is assumed that the Fish Bed Conglomerate is present and is hydraulically connected to the overlying limestone and the underlying shale.

Water-bearing properties of rock in the DART D2 area are defined by fracture flow, with low permeability and porosity in intact rock but localized high permeability and porosity in fractured zones. Groundwater flow in the rock mass will be controlled by the network of fracture openings and related to joint set patterns. For both shale and limestone, hydraulic conductivity is anisotropic, with higher groundwater flow along low-angle bedding planes than vertically. Fast-flow paths along more steeply dipping open fractures which cross bedding planes will have the highest hydraulic conductivity.

Groundwater inflows in rock excavations will largely depend on the spacing, aperture, and connectivity of fractures in the rock. The highest inflows will be from fractured zones. For baseline purposes, it is assumed that inflows in rock excavations will be of limited duration because there is no evident hydraulic connection through rock to a sustained groundwater recharge source.

[The final GBR will include baselines for linear groundwater flow velocities and for groundwater inflows for TBM, SEM, and cut-and-cover excavation, based on results of additional investigations to be presented in the SGDR(s).]

9.4.2 GROUNDWATER LEVELS

Maximum and minimum groundwater levels are shown on the profiles in Figures 8-1A through 8-1I. Tabulated recorded data are presented in the GDR (GPC6, 2019).

Groundwater levels in DART D2 borings and observation wells range 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 at the limestone-shale contact, 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 8-1A through 8-1I, groundwater levels reported in the GDR were generally within the Alluvium Ground Class Group, near the top of "Weathered Rock." Exceptions are seen at the deep well at boring TS-202 in Reach 5, and at boring TS-207 and TS-208, both in Reach 7.

The confining layer or recharge source for the deeper aquifer is not known. Artesian conditions have been locally reported in Dallas (Lachel Felice, 2006), but no site-specific supporting data are available.

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.

For preliminary baseline purposes, maximum and minimum groundwater levels indicated on the baseline profiles in Figures 8-1A through 8-1I are the baseline range of water levels that should be anticipated in construction. These levels include fluctuations due precipitation events and seasonal variation but do not include exceptions where Contract Drawings and/or Specifications or consideration of flood events require different water levels or pressures.

Reach-specific groundwater levels are discussed in Section 10.

[The final GBR will incorporate results of additional monitoring of groundwater levels along the DART D2 alignment to be presented in SGDR(s)].

9.4.3 GROUNDWATER QUALITY

No DART D2 site-specific groundwater quality data were available at time of preparation.

Results of chemical analysis of groundwater and soil for another Dallas-area project are presented in Fugro, 2005. They indicate an alkaline pH, ranging from 7.9 to 9.3.

[The final GBR will include present baseline groundwater chemistry conditions for the DART D2 underground alignment, with reference plots of basic groundwater chemistry parameters]

based on data presented in SGDR(s), a Phase 1 Environmental Assessment, or Reference Information Documents. Parameters will include alkalinity, chloride content, conductivity, hydrogen sulfide content, pH, sulfate content, total dissolved solids, and total sulfide content.]

9.5 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 (See Section 6). The methane source was attributed to 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. Similar subsurface gaseous conditions are assumed possible for underground construction of the DART D2 project.

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.

For preliminary baseline purposes, underground work for the DART D2 project is considered “potentially gassy” in accordance with OSHA regulations. This classification applies to all excavations, including portal retained cut and cut-and-cover sections, tunnels, and stations.

9.6 Potentially Hazardous Materials

The presence of hazardous materials within subsurface soil, rock, and groundwater is expected within the DART D2 corridor. Based on the March 2010 DEIS, organic contaminants common in the Dallas area are pesticides, solvents, degreasers, and petroleum compounds. Inorganic contaminants include nitrates, and heavy metals. Ten High Risk sites and 17 Moderate Risk sites within the DART D2 corridor have potential hazardous materials in soil or groundwater which could be intercepted by subsurface construction (GPC6, 2018). The majority of these sites are associated with former garages, service stations, or dry cleaners.

The Contractor will need to consider the presence of the reported contaminants when assessing potential means and methods, including aspects of the work that will interact with the groundwater, such as grout mixes.

The Contractor will also need to consider potential impacts of the reported contaminants for excavation, handling, testing, transport, and disposal of potentially impacted muck or groundwater, as well as worker and community health and safety requirements. It is assumed that on-site groundwater treatment and verification testing will be required to meet discharge permit requirements and that testing will be required for the Contractor to develop means and methods for handling and disposal of muck from DART D2 excavations.

[The final GBR will reference the completed Phase I Environmental Site Assessment and testing results and refine baseline assumptions for hazardous materials in soil, rock, and groundwater to be encountered in excavations.]

9.7 Obstructions

Obstructions are defined by excavation type in the Specifications and include man-made materials and naturally occurring materials. Measures to limit the likelihood of encountering obstructions within the excavation horizon have been incorporated into 20% design current as of December 20, 2019, but the Contractor should be prepared to encounter the types of known and unknown obstructions described below. This discussion is not inclusive and is not intended to include all types of potential obstructions for excavation.

[The final GBR will have updated baselines for obstructions based on collection of additional data on existing and historical foundations, abandoned utilities, monitoring, injection, and water-supply wells, historical fill and debris disposal, and other potential obstructions.]

For preliminary baseline purposes, it is assumed that buried debris present within Fill will be potential obstructions or impediments for surface-based excavation. No cobbles (particles 3 to 12 inches in size) or boulders (particles greater than 12 inches in size) will be encountered in Alluvium or Residual Soil.

“Weathered rock,” including the Fish Bed Conglomerate where present, will include cobble-size fragments of chalky limestone. Total volume of cobbles will be less than 5 percent of the excavation volume. Intact rock strength of the cobbles is consistent with intact rock strength for limestone shown in Table 9-3.

For preliminary baseline purposes, it is assumed that there are no historical groundwater monitoring wells or groundwater extraction wells within the DART D2 area or historical test boreholes on either public or private property which were not properly abandoned or were incompletely sealed. The Contractor will need to have means and methods available to seal or remove any unreported wells that interfere with construction operations.

It is also assumed for preliminary baseline purposes that historical exploration or construction activities did not leave behind any buried abandoned hardware.

The Contractor should be prepared to perform removal of unreported obstructions, including steel from piles, anchors, well casings, or drilling hardware; rubble from construction debris or historical building or infrastructure foundations; and boulders or rock fragments larger than the sizes given above as preliminary baselines.

[The final GBR will confirm or revise assumption regarding potential obstructions and will include locations and depths as required. The Contractor will need to have means and methods available to seal or remove wells that interfere with construction operations.]

10 GROUND CHARACTERIZATION BY ALIGNMENT REACH

This section describes the reaches along the DART D2 underground alignment current as of December 20, 2019, and the ground characterization within each reach with regard to distribution of ground classes, rock types, excavation conditions, and groundwater conditions.

Reaches are defined in Section 7 and summarized in Table 7-1. As indicated in Section 7, reach descriptions are defined by the reference alignment stationing but also apply to the adjacent non-reference alignment.

Ground classes and excavation face conditions are defined in Section 8. Section 8 also includes preliminary baselines regarding distribution of ground classes. Section 9 provides preliminary baselines for properties of overburden ground classes and intact rock.

Tables 8-3, 8-4, and 8-5 present preliminary baselines for ground class distributions within each reach. The Contractor should be prepared to accommodate excavation conditions in each reach consisting of a combination of the overburden ground classes and a combination of rock ground classes within that reach.

All structure descriptions and locations given in the following sections are based on the alignment current as of December 20, 2019, and geotechnical data available as of August 29, 2019, as presented in the GDR (GPC6, 2019).

Actual excavation volume percentages of ground classes and rock types will be within 10 percent of the given preliminary baseline volume percentages. Actual top of rock levels and groundwater levels will be within +/- 5 feet of the preliminary baseline levels shown on Figures 8-1A through 8-1I.

Additional baselines are indicated for each reach in the following sections where applicable.

10.1 Reach 1 (West Portal)

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 8-1C.

Preliminary baseline ground class distributions are shown in Table 8-3, which is based on information in the GDR (GPC6, 2019) and the alignment current as of December 20, 2019. As shown, about 77 percent of the volume to be excavated in Reach 1 will be Alluvium. The remaining portion will be excavated in Fill (21 percent) and small amounts (1 percent each) of Ground Class IGM ("Weathered Rock,") and Ground Class L-I limestone near the excavation invert.

Geotechnical properties of Overburden, "Weathered Rock," and Rock ground classes are discussed in Section 9.

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 8-1C, 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. Preliminary baseline groundwater level for Reach 1 is elevation 410.5 feet.

10.2 Reach 2 (Cut-and-Cover Tunnel)

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 is 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 8-1C and 8-1D.

Preliminary baseline ground class distributions are shown in Table 8-4, which is based on information in the GDR (GPC6, 2019) and the alignment current as of December 20, 2019. As shown, 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 8-1C and 8-1D, 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 Section 9.

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 8-1C and 8-1D, 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. Preliminary baseline groundwater level for Reach 2 is elevation 410.0 feet.

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

The planned 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 baselines, 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 8-1D.

Preliminary baseline ground class distributions are shown in Table 8-4, which is based on information in the GDR (GPC6, 2019) and the 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, 10 percent), Alluvium (32 percent), and Fill and "Weathered Rock" (together, 8 percent).

As shown in Figure 8-1D, 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 8-1D, 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 (GPC6, 2019), the shale is the 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 9.3.2. If present, these faults could adversely affect excavation stability. The orientation and continuity of the reported features are not known. Faults in Reach 3 will be zones of increased hydraulic conductivity and will potentially act as fast-flow paths.

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

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 8-1D, 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 8-1D, 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.

Preliminary baseline groundwater level for Reach 2 is elevation 408.0 feet.

10.4 Reach 4 (SEM Tunnel)

The planned 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 preliminary baseline purposes, excavated height of the SEM tunnel is assumed to be 22.2 feet

Preliminary baseline ground class distributions are shown in Table 8-5, which is based on information in the GDR (GPC6, 2019) and the 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 (19 percent) and Ground Class S-II shale.

As shown in Figures 8-1D and 8-1E, 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 8-1D and 8-1E, 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 the reduced quality Ground Class S-II shale.

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

The Sump/Pump Room planned 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 8-1E.

Geotechnical properties of Rock ground classes are discussed in Section 9.

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 8-1E, 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. Preliminary baseline groundwater level for Reach 4 is elevation 407.1 feet.

10.5 Reach 5 (SEM Station - Commerce Station)

The planned structures to be constructed within Reach 5 is Commerce Station. 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 station entrance and egress shafts and an adit, were still 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 8-1E and 8-1F.

Preliminary baseline ground class distributions are shown in Table 8-5, which is based on information in the GDR (GPC6, 2019) and the alignment current as of December 20, 2019. As shown, SEM excavation for Reach 5, Commerce Station, will be entirely in rock.

Almost all the rock to be excavated (96 percent) will be Ground Class L-I limestone. The remainder will be Ground Class L-II limestone and up to 4 feet of shale above invert level for the westernmost part of the reach.

As shown in Figures 8-1E and 8-1F, 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. 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 9.3.2, including slickensided fractures, faults, and shears which are recorded on boring logs in the GDR (GPC6, 2019). Information on fracture dip direction is not available. Until additional data are available, it is assumed for preliminary baseline purposes that these fractures correspond to the regional northeast- and northwest-striking fault sets dipping in opposite directions and that they are configured to form a daylighting rock wedge just above the station crown. Stability of the cavern crown will be adversely affected, and additional support will be required. Faults in Reach 5 will be zones of increased hydraulic conductivity and will potentially act as fast-flow paths.

Geotechnical properties of intact rock and the rock mass are discussed in Section 9.

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 8-1F, 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 8-1F, 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.

Because a recharge source for the deeper aquifer and the continuity of a potential confining layer are not known, the preliminary baseline groundwater level for Reach 5 is elevation 417.6 feet.

10.6 Reach 6 (SEM Tunnel)

The planned structures to be constructed within Reach 6 consist 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 preliminary baseline purposes, excavated height of the SEM tunnel is assumed to be 22.2 feet.

Preliminary baseline ground class distributions are shown in Table 8-5, which is based on information in the GDR (GPC6, 2019) and the 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.

Proposed Cross Passage 2 is located between the two DART D2 borings in Reach 6, and based on information from these borings, 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 9.

A groundwater level measurement taken during drilling from one boring (T-204) is available for Reach 6. As shown in Figure 8-1F, 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 near the top of "Weathered Rock" at about elevation 440 feet. Preliminary baseline groundwater level for Reach 6 is elevation 440.0 feet.

10.7 Reach 7 (Cut-and-Cover Tunnel)

The planned 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 8-1G.

Preliminary baseline ground class distributions are shown in Table 8-4, which is based on information in the GDR (GPC6, 2019) and the alignment current as of December 20, 2019. As shown, 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 8-1G, 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 Section 9.

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 8-1G, 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 (GPC6, 2019), 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 8-1G, 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.

Because a recharge source for the deeper aquifer and the continuity of a potential confining layer are not known, the preliminary baseline groundwater level for Reach 7 is elevation 442.5 feet.

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

The planned structure to be constructed within Reach 8 consists of 8 is CBD East Station, from Station 93+13 to 98+05, based on the 20% alignment current as of December 20, 2019. For preliminary baseline purposes, 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 8-1G and 8-1H.

Preliminary baseline ground class distributions are shown in Table 8-4, which is based on information in the GDR (GPC6, 2019) and the alignment current as of December 20, 2019. As shown, most of the material to be excavated in Reach 8 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 8-1G and 8-1H, 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 Section 9.

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 8-1H, 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 8-1H, 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. Preliminary baseline groundwater elevation for Reach 8 is 448.0 feet.

10.9 Reach 9 (Cut-and-Cover Tunnel)

The planned 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 8-1H.

Preliminary baseline ground class distributions are shown in Table 8-4, which is based on information in the GDR (GPC6, 2019) and the alignment current as of December 20, 2019. As shown, more than half (52 percent) of the excavation in Reach 9 will be in Alluvium, with additional 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. 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 Section 9.

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 8-1H, the water level measured during drilling of boring T-112, as reported in the GDR (GPC6, 2019), 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. Preliminary baseline groundwater level for Reach 9 is elevation 448.5 feet.

10.10 Reach 10 (East Portal)

The planned 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.

Preliminary baseline ground class distributions are shown in Table 8-3, which is based on information in the GDR (GPC6, 2019) and the alignment current as of December 20, 2019. As shown, about 69 percent of the volume to be excavated in Reach 10 will be Alluvium. The remaining portion will be excavated in Fill (29 percent) with small amounts of “Weathered Rock” and Ground Class L-I limestone 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 Section 9.

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 (GPC6, 2019), 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. Preliminary baseline groundwater level for Reach 10 is elevation 455.6 feet.

11 DESIGN CONSIDERATIONS

Ground behavior will be governed by:

- Orientation, condition, and spacing of rock mass discontinuities
- Groundwater conditions
- In-situ and construction-induced stresses in the rock mass
- Swelling and slaking properties of soil and of layers of bentonite and shale, and the thickness and location of these layers with respect to the excavation
- Methods of excavation and construction

For vertical cuts in the Austin Chalk, such as those at shafts, portals, and stations, stability of excavated rock faces will be affected by the orientation and condition of fractures and faults in the rock mass. Length, spacing, and orientation of rock bolts, prestressed anchors, or other measures to support potentially unstable rock wedges will need to consider orientation of rock mass discontinuities.

Minor faults, with less than 5 feet of displacement and small apertures, are known to be present. Major faults, those with displacements greater than 20 feet and fault-affected rock zones greater than 20 feet along the alignment, were not recorded in DART D2 boring logs. However, their presence cannot be precluded. In such fault zones, rock will be closely fractured, weaker, and more weathered than adjacent unaffected rock. Standup times will be reduced, groundwater inflows will increase, additional support will be required, and widths of unsupported spans will need to be reduced.

Selection of initial support for excavations in rock will require an observational approach, with support design adjusted or confirmed based on ground conditions and behavior encountered during excavation. The Contract Documents will provide design details for various classes of ground support, selection of which will depend on conditions encountered during construction.

For design of support of excavations for shafts, earth loads should consider potential swell pressures, hydrostatic pressures, any surcharge loads, and the sequence of construction. Similar considerations will apply for design loading for construction of station walls.

The final design of the waterproofing and drainage system will depend on averaged steady state groundwater inflows as well as locally higher inflows. Groundwater chemistry and potential calcification of tunnel and station equipment will require consideration for drainage system design and for maintenance and operations planning. Groundwater chemistry is also a consideration for evaluation of corrosion potential. The presence of pyrite in the rock along the DART D2 alignment indicates a potential long-term condition of acidic groundwater.

[The final GBR will describe rationale for the selected mining methods for tunnels and stations, consistent with other final contract documents. Excavation of portal approaches and headwall structures will consider overbuild constraints and requirements for sufficient stable cover.]

[The final GBR will describe support requirements developed based on anticipated ground conditions, planned underground structures, and compatibility with selected excavation methods. The final GBR will also provide justification for selection of support system. The final design support system will be designed to carry all initial ground and water loads during excavation that included initial support.]

12 CONSTRUCTION CONSIDERATIONS

[The final GBR will include potential sources of delay or construction problems for each type of construction (SEM, cut-and-cover) and structure-specific considerations for each type of cross section and station.]

12.1.1 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, will 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.

12.1.2 CONSTRUCTION IN ROCK

It is assumed that orientations of vertical joint sets, bedding planes joints, and small-displacement faults forming graben structures will allow formation of potentially unstable rock wedges, either as a single plane or as a line of intersection of two or more planes daylighting 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 are assumed to be capable of forming 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 unless protected.

The regionally identified joint set striking N65E is assumed to be present along the proposed DART D2 alignment, and it is oblique to the long axis of Commerce Station, potentially affecting 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 assumed to be present near the eastern end of the alignment just below invert level of planned CBD East Station. 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 will reduce this risk.

Swelling of clay minerals, especially in shale but also in limestone, will lead to volumetric expansion and potential slabbing and invert uplift for all type of excavations in rock.

Solutioning has not been reported in draft boring logs, but its presence should be considered possible.

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, the SEM tunnels to be constructed in Reach 4, and Commerce Station to be constructed by SEM in Reach 5 will have their invert 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 invert 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 will create unexpected zones of resistance in the otherwise soft shale matrix.
- The shale is slightly abrasive and will produce greater equipment wear than the limestone.

12.1.3 ROCK COVER

As shown in Figures 8-1E and 8-1F, 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.

12.1.4 GROUNDWATER CONDITIONS

Groundwater inflows at retained excavations in fill, alluvium, “weathered rock”, and along the top of rock surface will consist of stable equilibrium inflows as well as less predictable locally high flush groundwater inflows at sandy layers, faults, or other relatively permeable zones.

Permeable sand and gravel of Ground Class A2 will 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 or station construction could affect stability of the excavation face or cut-and-cover construction.

Measures to control groundwater inflow in surface excavations will 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 are anticipated to be of only limited duration. Groundwater control measures may need to be modified from designed measures to accommodate actual site conditions.

[The final GBR will include quantitative baselines and construction considerations related to groundwater conditions based on in-situ hydraulic conductivity test results to be presented in SGDR(s).]

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.

[The final GBR will include quantitative baselines and construction considerations related to potentially hazardous contaminants in groundwater or soil based on results of additional investigations to be presented in SGDR(s) or in Reference Information Documents.]

12.1.5 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 and OSHA 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.

12.1.6 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 can be one consequence of this rock-water interaction if not properly controlled. 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.

12.1.7 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 and foundations located near planned East Portal construction.

12.1.8 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.

12.1.9 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

12.1.10 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.

13 INSTRUMENTATION, MONITORING, AND PROTECTION OF EXISTING STRUCTURES

13.1 General

Construction-related movements of adjacent and overlying structures, including buildings, utilities, storm drains, roadways, and sidewalks, can be expected to occur along the DART

D2 underground alignment unless mitigated. Construction along the DART D2 underground alignment involves both mined tunnel excavations and cut-and-cover excavations. Construction-related movements are expected to occur from:

- SEM mining in rock
- Cut-and-cover excavation, including movements that occur during excavation as well as movements that occur during removal of struts and construction of permanent slabs
- Groundwater control operations for cut-and-cover excavations
- Utility relocations around station and portal structures
- Ground improvement and underpinning operations, if required

[The final GBR will describe the protection measures and the instrumentation and monitoring program that will have been developed based on evaluation of construction operations and assessment of existing structures with respect to construction-induced movements. The final GBR will reference requirements in the Contract Drawings and Specifications for mitigating risks associated with construction-induced movements and verifying performance of the work in accordance with the Specifications.]

13.2 Protection of Existing Structures

Some structures along the DART D2 underground alignment will require mandatory protection measures, as provided in the Specifications. The Contractor is responsible for the final design of the mandatory protection measures. Proper implementation of mandatory protection measures will reduce or mitigate settlement impacts to within allowable thresholds.

[The final GBR will reference the maximum volume losses for TBM- and SEM-mined tunnels indicated in the Specifications. The Contractor may include additional protection or settlement mitigation measures based on performance of the work in the event that he is unable to meet specified criteria using his selected means and methods. The Specifications will include requirements for assessments and submittals to be made by the Contractor with regard to the performance of the work.]

13.3 Instrumentation and Monitoring

[The final GBR will reference the instrumentation and monitoring program developed to verify that construction-related movements meet specified criteria and to provide an early indication if adjustments or additional protection measures are needed during the work. The instrumentation data will also provide an indication of the performance of the tunneling or cut-and-cover excavation work, as well as the effectiveness of adjustments or corrective actions that are implemented. The minimum instrumentation and monitoring requirements will be indicated on the Contract Drawings and in the Specifications.]

13.3.1 TYPES OF INSTRUMENTATION

Instrumentation is included in order to measure:

- Vertical and horizontal ground movements due to tunnel excavations
- Vertical and horizontal ground movements due to cut-and-cover excavations
- Vertical, horizontal, and tilt movements of existing structures, including pavements, buildings, utilities, storm drains, and other structures
- Movements inside existing structures, including vertical and horizontal movements
- Changes to groundwater levels
- Movements of subsurface gases or vapors
- Movements of excavation support systems
- Strains within excavation support systems or other structures
- Movements within SEM mined excavations
- Changes in cracks on existing structures
- Construction-related vibrations and noise

[The final GBR will reference information in Contract Drawings and Specifications regarding specific types of instrumentation and that plan requirements are not intended to cover Health and Safety requirements. Additional instrumentation and monitoring devices and provisions may be needed to satisfy health and safety requirements.]

13.3.2 INSTRUMENTATION AND MONITORING REPORTING PROGRAM

The instrumentation and monitoring program will be designed to provide indication of the performance of the work as it progresses as well as to alert the Contractor and Engineer when the performance of the work could potentially adversely impact existing structures.

[The final GBR will reference the Specifications for threshold levels that will have been established for existing structures.]

In addition to the threshold levels, minimum monitoring requirements and frequency will be included in the monitoring program. The frequency of the monitoring will vary based on proximity to the work, the type of work, the sensitivity of adjacent structures, and the measured performance of the work. More frequent readings will be taken as the work is closer to a particular structure and if the measured movement exceeds the threshold values.

For cut-and-cover excavations, monitoring data will be used to assess the timeliness of installation of support elements, the level and effectiveness of prestressing, if any, and effectiveness of ground improvement.

For SEM excavations, the monitoring will provide an indication of the performance of the ground support measures and whether adjustments or additional support measures are needed.

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15 GLOSSARY

Usage of terms in this preliminary GBR is consistent with the following definitions. Usage of geologic terms generally conforms to the American Geosciences Institute (AGI) *Glossary of Geology, Fifth Edition, Revised*, (AGI, 2011) and ASTM Standard D 4879-02 (ASTM, 2002). *[Terminology for project soil and rock descriptions not included in the final GBR text will be provided in a SGDR or Reference Information Documents.]* This glossary is not intended to be exhaustive.

alluvium	A general term for detrital recent time deposits made by streams on river beds, flood plains, and alluvial fans.
aperture	perpendicular distance between adjacent rock walls of a discontinuity in which the intervening space contains air, water, or uncemented infilling materials.
arenaceous	Consisting wholly or partly of sand-size fragments.
argillaceous	Containing an appreciable amount of clay.
artesian	Pertaining to groundwater under sufficient hydrostatic pressure to rise above the aquifer containing it.
aquifer	A body of rock or sediment that is sufficiently permeable to conduct groundwater and to yield economically significant quantities of water to wells and springs.
Atterberg limits	The basic measure of the nature of fine-grained soils that is dependent on the water content; the water contents of a soil mass corresponding to the transition between a solid, semi-solid, plastic solid or liquid. Laboratory test used to distinguish the plasticity of clay and silt particles.
bedding plane	A planar or nearly planar bedding surface that visibly separates each successive layer of stratified rock of the same or different lithology from the preceding or following layer; a plane of deposition marking a change in circumstances of deposition.
block release	Sliding, or other movement toward an excavation, of a block of rock or cohesive soil bounded by discontinuities.
boulder	A detached rock mass with minimum dimension greater than 12 inches in size, somewhat rounded or otherwise shaped by abrasion in the course of transport.
Cerchar Abrasivity Index	Calculated mean value of results of two to five individual scratch tests performed on rock samples with a steel needle of defined

geometry and hardness, developed by the Centre d'Etudes at Recherches des Charbonnages de France.

chalk	A fine-textured, limestone of marine origin consisting almost wholly of calcite, formed mainly by calcareous tests of floating microorganisms and comminuted remains of calcareous algae in a structureless matrix of very finely crystalline calcite.
cobble	A naturally occurring piece of soil or rock with dimension greater than 3 inches and less than 12 inches in size, rounded or otherwise shaped by abrasion during transport.
cohesive soils	Soil containing clay minerals and possessing plasticity.
Cretaceous Period	The time period spanning between about 145 and 65 million years ago.
crown	The curved roof of a tunnel.
debris	Concrete, brick, asphalt, sawdust, logs, piles, ship ballast, sawmill byproducts, trees, man-made debris and other waste within the fill deposits.
density	The mass or quantity of a soil or rock per unit volume.
dewatering	The removal of groundwater by pumping to lower the water level and reduce the flow rate or diminish pressure.
dip	The angle that a planar feature makes with the horizontal, measured in the vertical plane.
discontinuity	A boundary or break in the rock mass that marks a change in rock properties.
discontinuity spacing	

Fracture Spacing

Description	Spacing
Extremely close	< 0.75 in
Very close	0.75 in – 2.5 in
Close	2.5 in – 8 in
Moderate	8 in – 2 ft
Wide	2 ft – 6 ft
Very wide	6 ft – 20 ft

Note: Fractures refer to natural breakages, including joints and faults.

fault	A fracture or fracture zone along which there has been displacement of the sides relative to one another parallel to the fracture.
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fault zone	A zone of numerous faults or of fault breccia or gouge. A fault zone may be tens or hundreds of feet wide.
fill	Man-made deposits of rock, soil, and other materials used to raise the level of a low area or to make an embankment.
flowing ground	A mixture of earth materials and water flowing into an excavation like a viscous fluid.
fracture	A surface along which material has lost cohesion, forming a crack, joint, fault, or other break in the rock.
groundwater	That part of the subsurface water that is in the saturated zone; subsurface water as distinct from surface water.
invert	The floor of a tunnel or other underground opening.
Holocene	Geologic epoch extending from about 11,000 years ago to the present.
hydraulic conductivity	The volume of water at the existing kinematic viscosity that will move in a porous medium in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow.
interbed	A bed, typically thin, of one kind of rock material occurring between or alternative with beds of another kind.
joint	A planar fracture, crack, or parting in rock or soil without shear displacement which occurs as one in a series of parallel to subparallel fractures.
joint set	A group of subparallel joints.
marl	An impure, argillaceous limestone consisting chiefly of clay and calcium carbonate.
muck	The soil or rock materials generated in excavating a tunnel. Included with these materials are byproducts of the tunneling operation such as soil conditioners, waste cement, grout, and other construction-related residue.
natural water content	The ratio between the mass of water and the mass of soil solids. $w = (\text{wet weight} - \text{dry weight}) / \text{dry weight}$.
parting	A thin sedimentary layer within a bed
perched groundwater	Unconfined groundwater separated from an underlying main body of groundwater by a zone of unsaturated rock or soil.
permeability	The capacity of a rock or soil to transmit fluid. See hydraulic conductivity.
persistence	The maximum dimension measured in any direction along a fracture surface.

Pleistocene	Geologic epoch extending from 2.5 million years ago to 11,000 years ago.
portal	The tunnel portal is the transition from surface to subsurface. For this preliminary GBR, the portals consist of the works for the retained cuts and the cut-and-cover tunnel sections included within the scope.
Quaternary	The most recent geologic period from approximately 2.6 million years ago to present; it includes the Pleistocene and Holocene epochs.
raveling ground	Ground that begins to drop out of the roof or sides of a tunnel, or steep natural and cut slopes, after being exposed. In fast raveling ground, the process starts within a few minutes; otherwise, the ground is considered slow raveling.
running ground	Soil or rock materials that will not stand, especially when wet, and that tend to flow freely into an excavated area on removal of roof or side support; granular materials without cohesion which are unstable at a slope greater than their angle of repose
seam	A thin layer or stratum separating two distinct layers of different composition.
shotcrete	Concrete sprayed through a hose and projected at high velocity to cover a surface.
slabbing	Outward expulsion of pre-existing slabs of rock parallel to the surface of an excavated opening.
slaking	The crumbling and disintegration of earth materials upon exposure to air or moisture.
slickenside	A polished fault surface formed by frictional wear during sliding, commonly with groove lineations indicating the direction of slip on the fault.
stickiness	The capacity for a soil, primarily clay, to adhere to other objects.
strike	The direction of the line of intersection of a plane with the horizontal plane.
swell	The increase in volume exhibited by soil or rock in response to removal of stress or the absorption of water; increase in soil volume; volumetric expansion of a soil due to changes in water content.
swell potential	The relative change in volume of a soil to be expected with stress relief and an increase in water content.
USCS	Unified Soil Classification System. A system of soil classification based on grain size, liquid limit and plasticity of soils.



water table

The level of groundwater beneath which the ground is completely saturated with water.



TABLES

Table 2-1. DART D2 Project Major Underground Elements

Structure ⁽¹⁾	Anticipated construction ⁽²⁾	Approximate stationing ⁽¹⁾⁽³⁾⁽⁴⁾		Approximate length along alignment, ft ⁽¹⁾⁽³⁾⁽⁴⁾
		from	to	
West Portal	U-wall retained cut	35+30	41+50	620
Running Tunnel	Cut-and-cover (SEM option for east portion)	41+50	49+27	777
Metro Center Station	Cut-and-cover	49+27	54+22	495
Running Tunnel	SEM-mined (TBM option)	54+22	68+05	1,383
Commerce Station	SEM-mined	68+05	75+26	721
Running Tunnel	SEM-mined (TBM option)	75+26	86+30	1,104
Running Tunnel	Cut-and-cover (SEM option)	86+30	93+13	683
CBD East Station	Cut-and-cover	93+13	98+05	492
Running Tunnel	Cut-and-cover	98+05	101+65	360
East Portal	U-wall retained cut	101+65	107+60	595
Cross Passage 1	SEM-mined	61+00		18
Cross Passage 2	SEM-mined	80+00		18
Cross Passage 3 (for SEM tunnel option only)	SEM-mined	87+00		18
Pump/Sump Room	SEM-mined	66+25		18
Shafts (?)				

NOTES:

(1) Structures, alignment, and stationing are current as of December 20, 2019.

(2) Anticipated construction methods shown are assumed for baseline purposes.

(3) Stationing limits and dimensions are approximate. See Plans for actual dimensions.

(4) Estimated cross passage and pump/sump room stationing is at structure centerline; length is perpendicular to twin running tunnels.

Table 7-1. DART D2 Project Underground Alignment Reach Descriptions

Reach ⁽¹⁾	Proposed Structures ⁽²⁾	General Ground Conditions within Planned 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 8-1. 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 8-2. DART D2 Ground Classification System

	Ground Class Group	Ground Class	Distinguishing Characteristics ⁽¹⁾
Overburden	Fill	F	<ul style="list-style-type: none">• 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	<ul style="list-style-type: none">• Cohesive alluvium; low to high plastic clays and sandy and silty clays, and sandy clay
		A2	<ul style="list-style-type: none">• Granular alluvium; mostly cohesionless material ranging from silty sands to sand and gravel and clayey sand
	Residual Soil	RS	<ul style="list-style-type: none">• “Residual Soil” overlying Austin Chalk; completely decomposed limestone that exhibits a rock-like fabric (as described by Huitt-Zollars, 1992). Note: <i>Not truly residual soil, which has no relict rock structure.</i>• 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	<ul style="list-style-type: none">• 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	<ul style="list-style-type: none">• 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	<ul style="list-style-type: none">• 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	<ul style="list-style-type: none">• 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	<ul style="list-style-type: none">• 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 8-3. Preliminary Baseline Ground Class Distribution for Portal U-Wall Excavation

Ground Class Group	Rock Type	Percent Volume for Reach	
		1	10
		(West Portal)	(East Portal)
Fill	N/A	21%	29%
Alluvium	N/A	77%	69%
“Weathered Rock”	N/A	1%	1%
I	Limestone	1%	1%

NOTES:

1. Based on available information and alignment current as of December 20, 2019.
2. Preliminary baseline volume is +/- 10 percent of volume shown.

Table 8-4. Preliminary Baseline Ground Class Distribution for 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%	52%
“Weathered Rock”	N/A	7%	5%	11%	1%	17%
I	Limestone	35%	48%	41%	4%	0%
II	Limestone	1%	2%	8%	7%	5%
I	Shale	0%	7%	0%	0%	0%
II	Shale	0%	3%	0%	0%	0%
Bentonite		0%	0%	0%	1%	0%

NOTES:

1. Based on available information and alignment current as of December 20, 2019.
2. Preliminary baseline volume is +/- 10 percent of volume shown.

Table 8-5. Preliminary Baseline Ground Class Distribution for SEM Excavation

Ground Class Group	Rock Type	Percent Volume for Reach		
		4	5	6
		(Tunnel)	(Commerce Station)	(Tunnel)
I	Limestone	62%	96%	75%
II	Limestone	19%	2%	25%
I	Shale	0%	2%	0%
II	Shale	19%	0%	0%

NOTES:

1. Based on available information and alignment current as of December 20, 2019.
2. Preliminary baseline volume is +/- 10 percent of volume shown.

Table 9-1. Preliminary Baseline 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	-	-
		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
		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	-	-
		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
		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	-	-
		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	-	-
		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
		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
		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
		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
		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	-	-
		Preliminary baseline value or range (25th-75th percentile)	bpf	-	6-9	7-11	-	-
	Unconfined Compressive Strength	Min	psf	-	2,160	-	2,448	-
		Max	psf	-	6,163	-	3,108	-
		Preliminary baseline value or range (25th-75th percentile)	psf	-	2,902-5,740	-	2,736	-
	UU Compressive Strength	Min	psf	-	3,150	-	-	-
		Max	psf	-	7,352	-	-	-
		Preliminary baseline value or range (25th-75th percentile)	psf	-	5,733	-	-	-
	Triaxial Strength, Effective Stress (peak)	ϕ '	Min	deg	-	24	-	18
			Max	deg	-	24	-	35
			Preliminary baseline value or range (25th-75th percentile)	deg	-	24	-	-
		c'	Min	psf	-	466	-	500
			Max	psf	-	466	-	2,500
			Preliminary baseline value or range (25th-75th percentile)	psf	-	466	-	1,467
		ϕ '	Min	deg	-	-	-	35
			Max	deg	-	-	-	48
			Preliminary baseline value or range (25th-75th percentile)	deg	-	-	-	42
	Direct Shear Strength, Effective Stress (peak)	c'	Min	psf	-	-	-	1.1
			Max	psf	-	-	-	1.8
			Preliminary baseline value or range (25th-75th percentile)	psf	-	-	-	1.5

Table 9-1. Summary of Properties for Overburden Ground Classes and Bentonite (continued)

Ground Class				Fill	A1	A2	RS	Bentonite
Consolidation Properties	Compression Ratio	Min	-	-	0.16	-	-	-
		Max	-	-	0.27	-	-	-
	Recompression Ratio	Min	-	-	0.04	-	-	-
		Max	-	-	0.08	-	-	-
	Overconsolidation Ratio	Min	-	-	17.0	-	-	-
		Max	-	-	45.0	-	-	-
		Preliminary baseline value or range (25th-75th percentile)	-	-	See Note (8)	-	-	-
Swell Properties	Simple Swell (% of H _o)	Min	%	-	0.2	-	-	-
		Max	%	-	6.7	-	-	-
		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	-	-	-
		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
		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	-	-
		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	-	-	-
		Preliminary baseline value or range (25th-75th percentile)	ohm-cm	850	800-1,451	-	-	-
	Chloride Content	Min	mg/kg	262.0	0.0	484.0	-	-
		Max	mg/kg	262.0	1,800.0	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	-	-
		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	-	-
		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 from test results 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.
- (11) UCS test results greater than 20,000 psf were excluded. High strengths possibly related to samples drying out before testing.

Table 9-2. Preliminary Baseline Properties for Ground Class IGM ("Weathered Rock")

Ground Class				IGM ("Weathered Rock")
USCS Classification of disaggregated rock				Limestone
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 Strength, Diametral	Min	psi	377
		Max	psi	377
		Mean (preliminary design)	psi	377

NOTES:

- (1) Source: Lachel Felice & Associates, 2006 data for Weathered Austin Chalk. No site-specific DART D2 data are available.
- (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 9-3. Preliminary Baseline Intact Rock Properties

L-I,L-II / 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, ν ⁽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 (Type I)
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)

S-I, S-II / 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, ν ⁽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 (Type II)

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 9-4. Preliminary Baseline Hydraulic Conductivity for DART D2 Ground Classes

Ground Class	Hydraulic Conductivity Range (cm/sec)		Ground Class Group	Preliminary Baseline Hydraulic Conductivity for Ground Class Group (cm/sec)
	Low	High		
F	1.00E-04	1.00E-02	Fill	1.00E-03
A1	1.00E-06	1.50E-03	Alluvium	5.00E-02
A2	1.00E-05	1.00E-01		
RS	1.00E-04	1.00E-03	Residual Soil	5.00E-03
IGM	1.00E-06	1.00E-02	"Weathered Rock"	5.00E-03
L-III	1.00E-07	1.00E-03	III	1.00E-04
S-III	1.00E-07	1.00E-03		
L-II	1.00E-07	1.00E-04	II	5.00E-05
S-II	1.00E-07	1.00E-04		
L-1	1.00E-07	1.00E-05	I	5.00E-05
S-I	1.00E-07	1.00E-05		

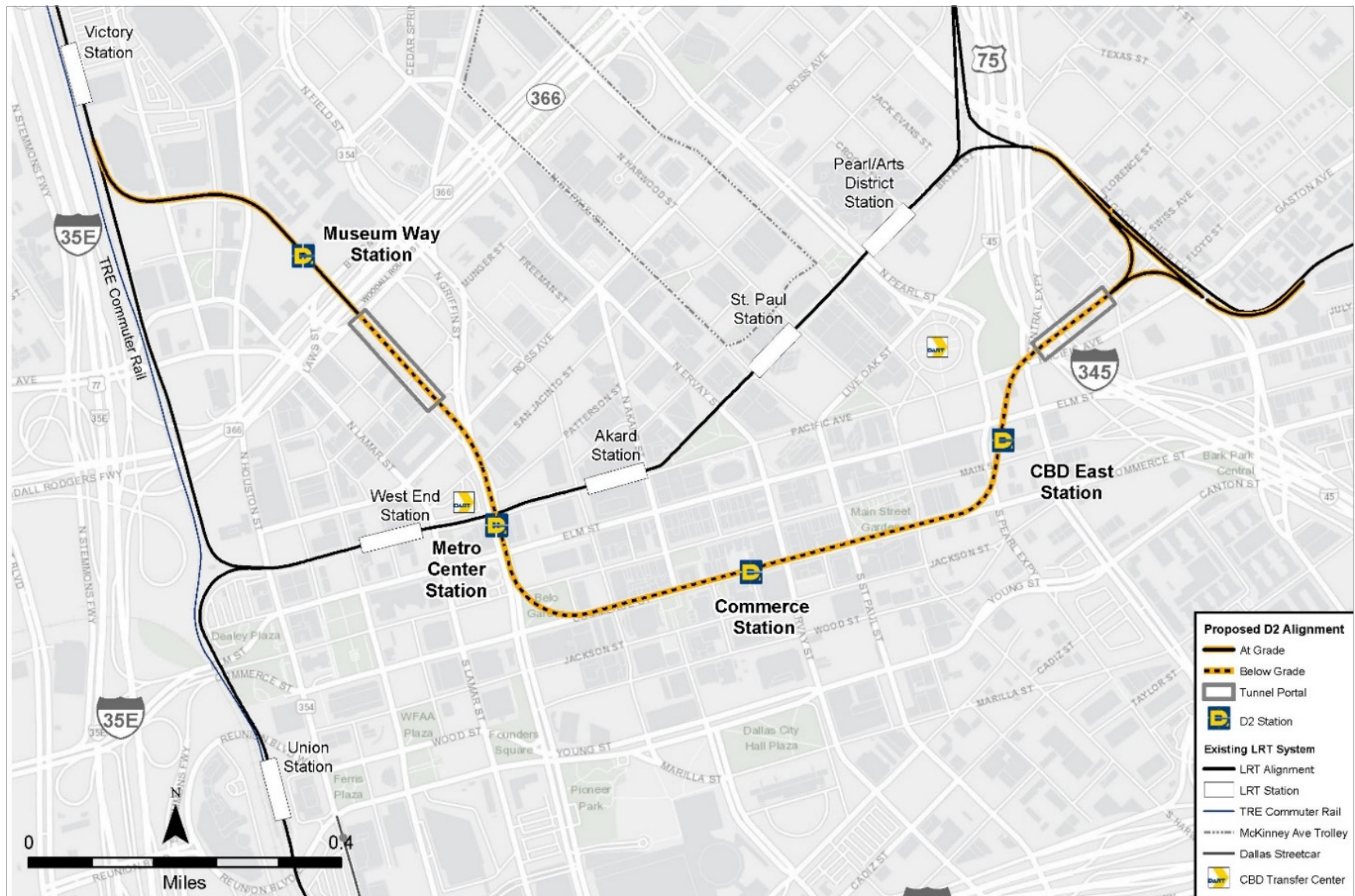
NOTE:

Based on information in Terzaghi and Peck, 1967 and Lachel Felice, 2006.



FIGURES

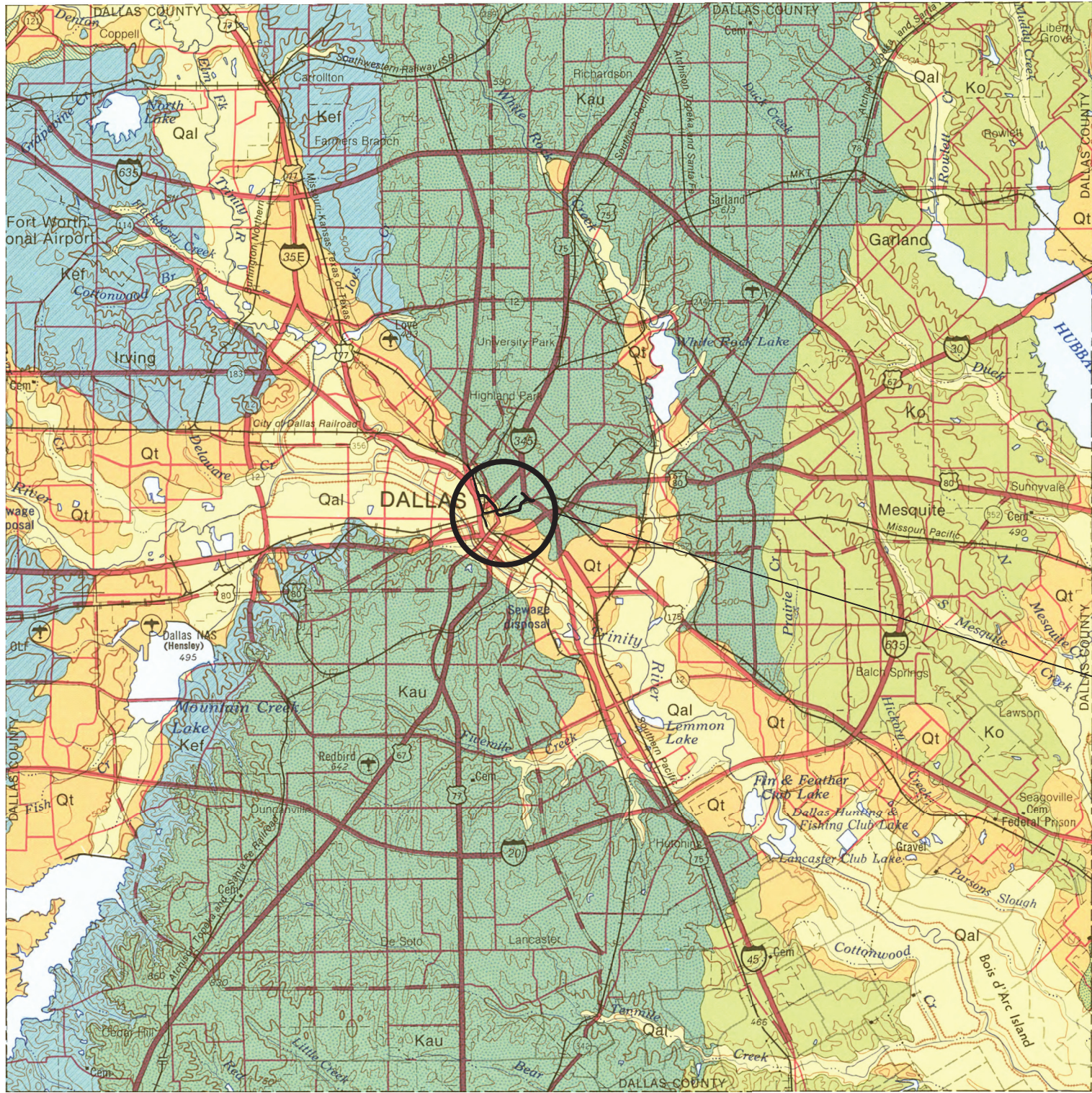
FIGURE 2-1. DART D2 PROJECT LOCATION PLAN



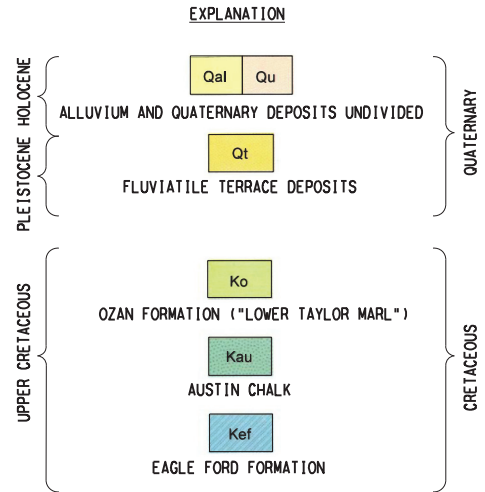
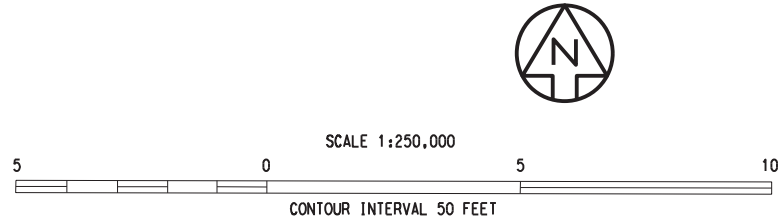
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GC4-0080

DWG No.



DART D2 LPA



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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PRELIMINARY 20% DESIGN

CONTRACT SHEET No. _____ OF _____

LIGHT RAIL TRANSIT SYSTEM
LINE SECTION CBD-2

FIGURE 4-1
GEOLOGIC MAP OF DALLAS COUNTY

IN-PROGRESS

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DART PROJECT



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



CONTRACT	DWG No.	GC4-0080	REV
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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).

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

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



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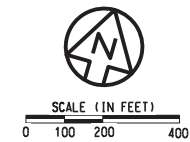
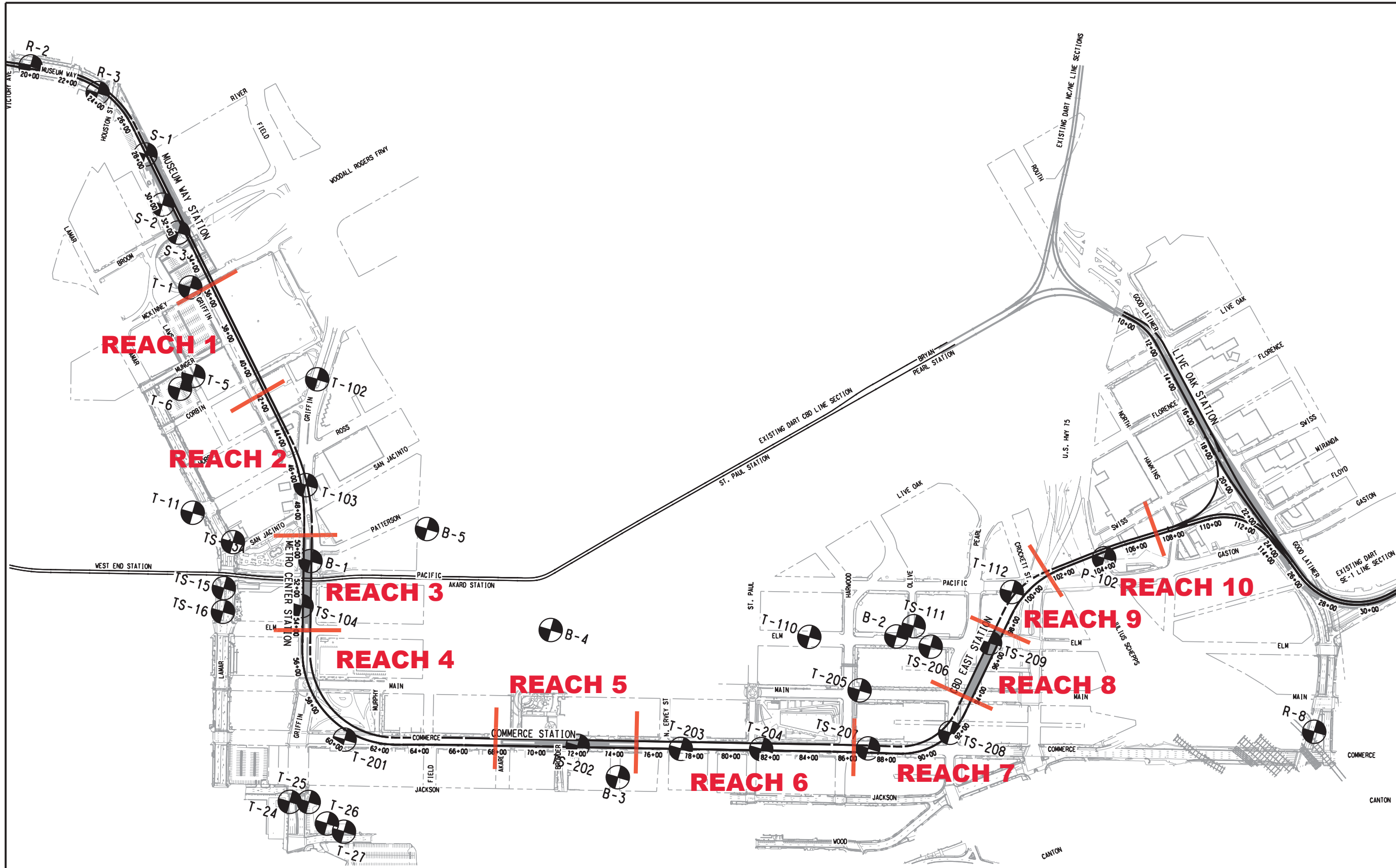


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DRAWN	K. SHEFF
DESIGNED	M. CIANC
CHECKED	C. STON
IN CHARGE	C. STON
DATE	03/06/202



LIGHT RAIL TRANSIT SYSTEM
LINE SECTION CBD-2
FIGURE 7-1
LEGEND AND NOTES
BORING LOCATION PLAN
AND GEOLOGIC PROFILE

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NOTE:
SEE FIGURE 7-1 FOR LEGEND AND NOTES

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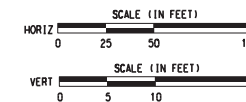
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LIGHT RAIL TRANSIT SYSTEM
LINE SECTION CBD-2
FIGURE 7-2
BORING AND REACH
LOCATION PLAN
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LIGHT RAIL TRANSIT SYSTEM
LINE SECTION CBD-2

FIGURE 8-1B
GENERAL GEOLOGIC PROFILE
STA 22+00 TO STA 34+00

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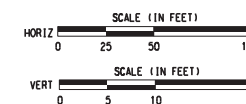
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LIGHT RAIL TRANSIT SYSTEM
LINE SECTION CBD-2

FIGURE 8-1C
GENERAL GEOLOGIC PROFILE
STA 34+00 TO STA 46+00

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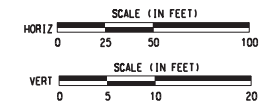
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LIGHT RAIL TRANSIT SYSTEM
LINE SECTION CBD-2

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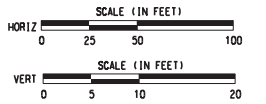
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LIGHT RAIL TRANSIT SYSTEM
LINE SECTION CBD-2

FIGURE 8-1G
GENERAL GEOLOGIC PROFILE
STA 82+00 TO STA 94+00

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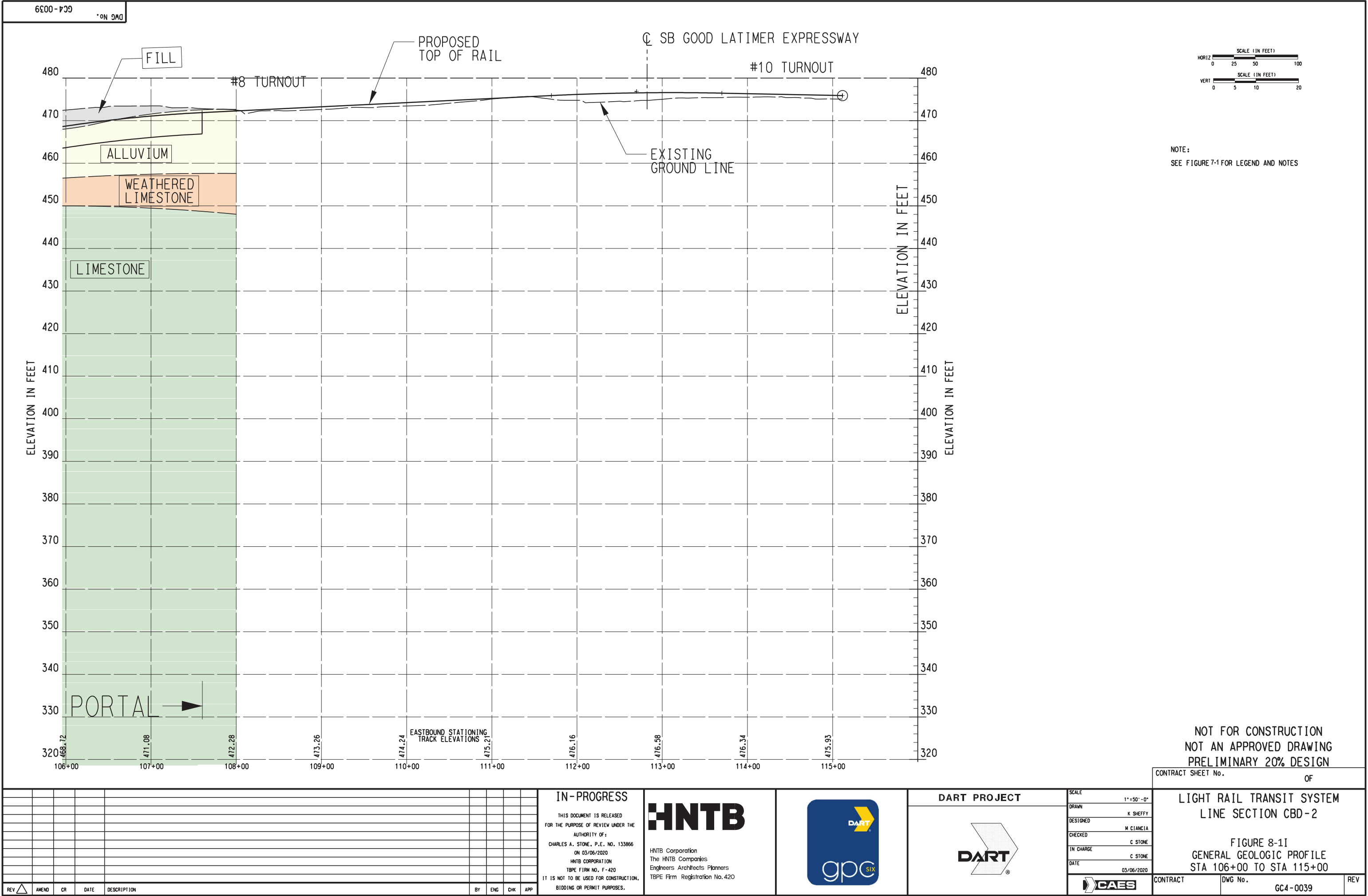
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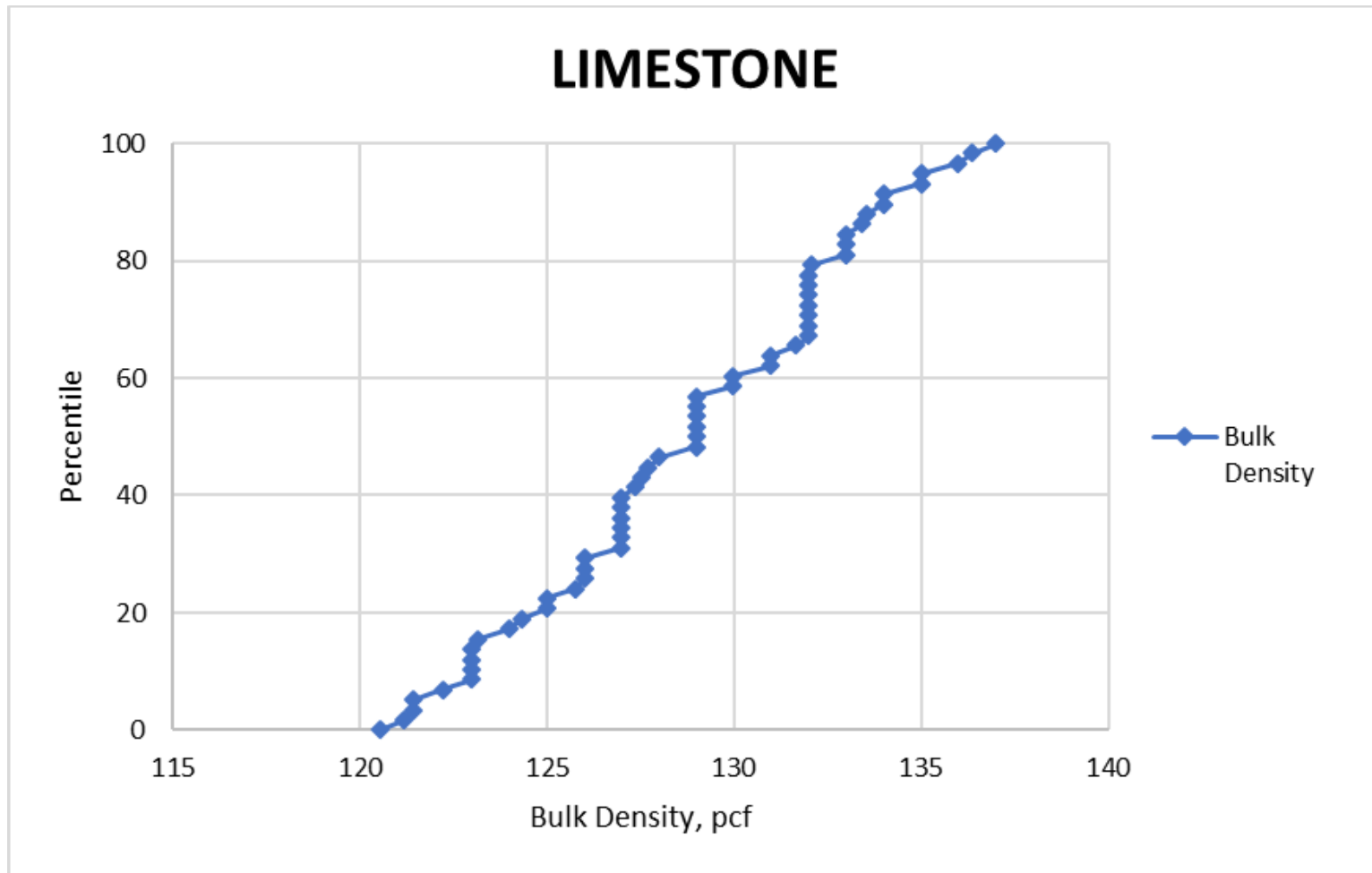
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		FIGURE 8-1I GENERAL GEOLOGIC PROFILE STA 106+00 TO STA 115+00	
CONTRACT	DWG No.	GC4-0039	REV



Appendix A

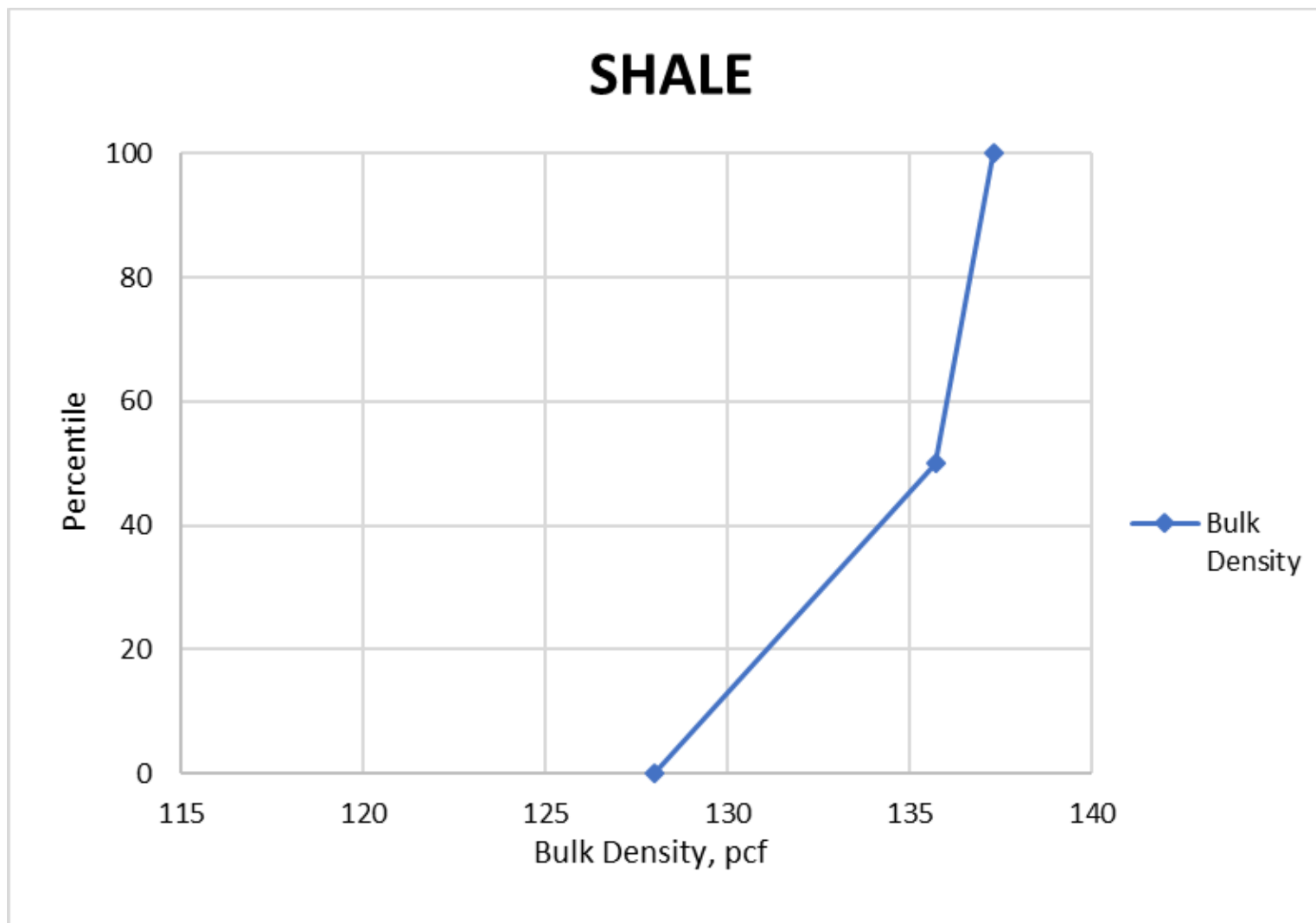
Intact Rock Property Plots

Figure A-1. Bulk density, limestone



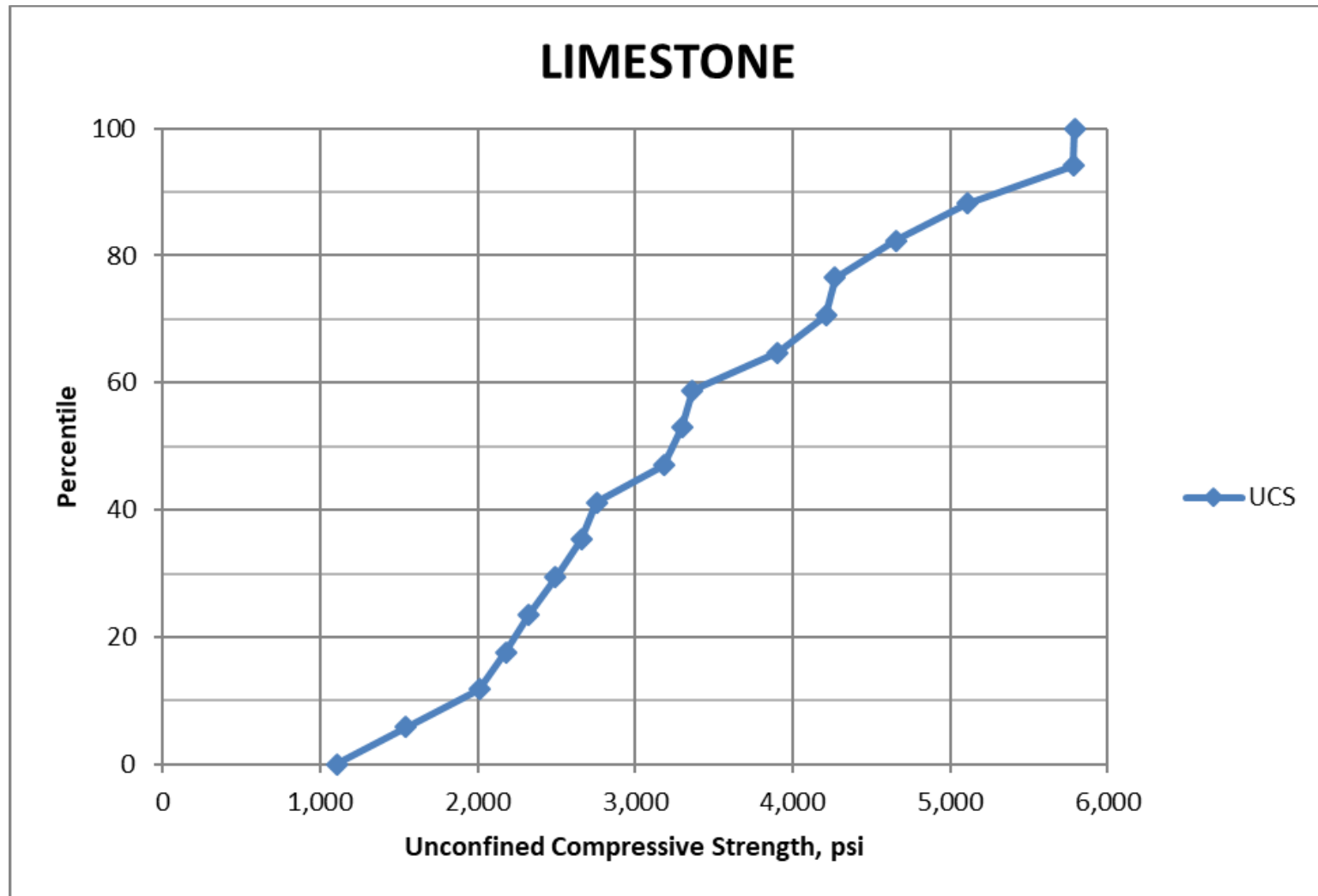
NOTE: Plot shows bulk density at as-received moisture content.

Figure A-2. Bulk density, shale



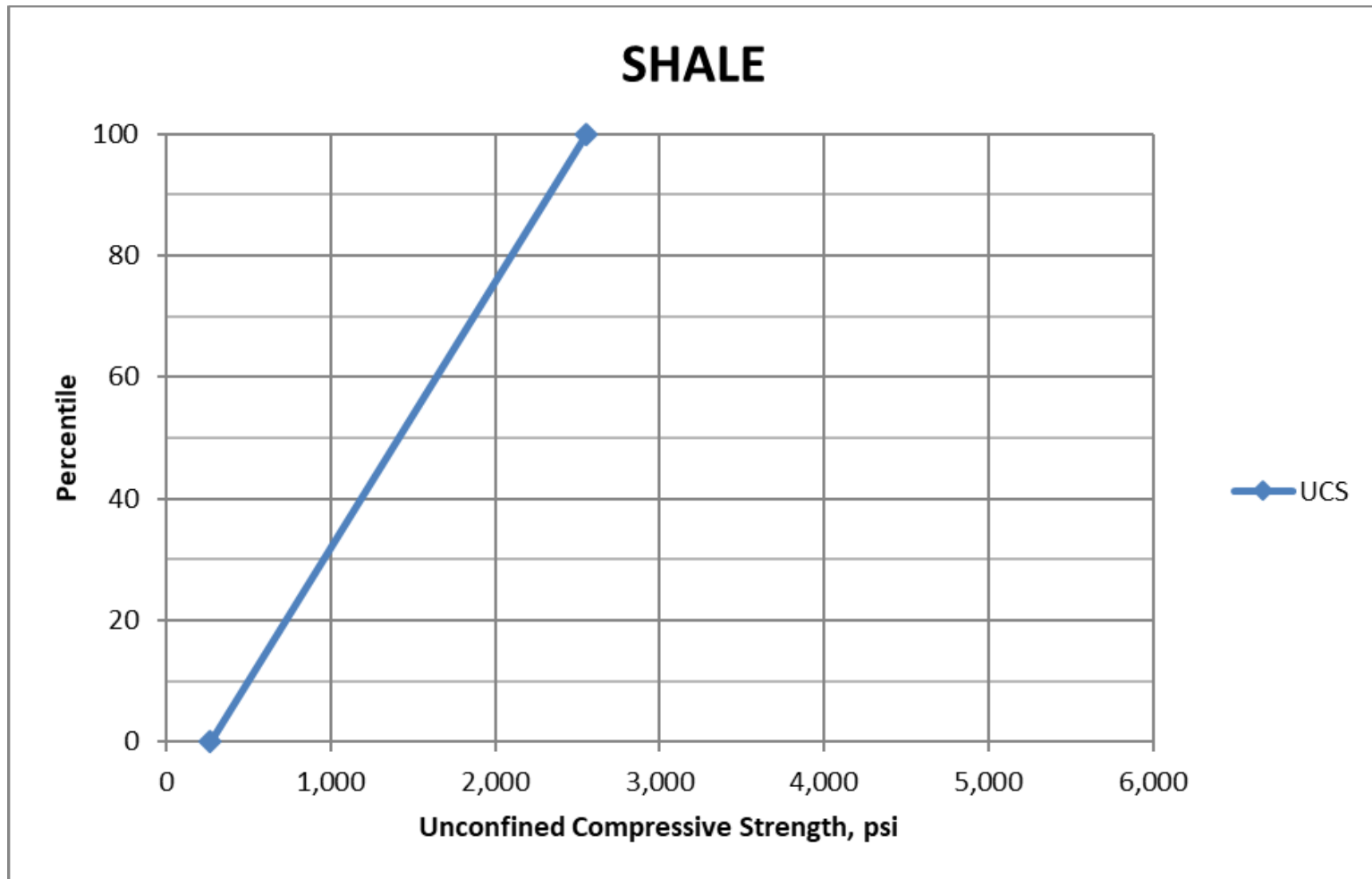
NOTE: Plot shows bulk density at as-received moisture content.

Figure A-3. Unconfined compressive strength, limestone



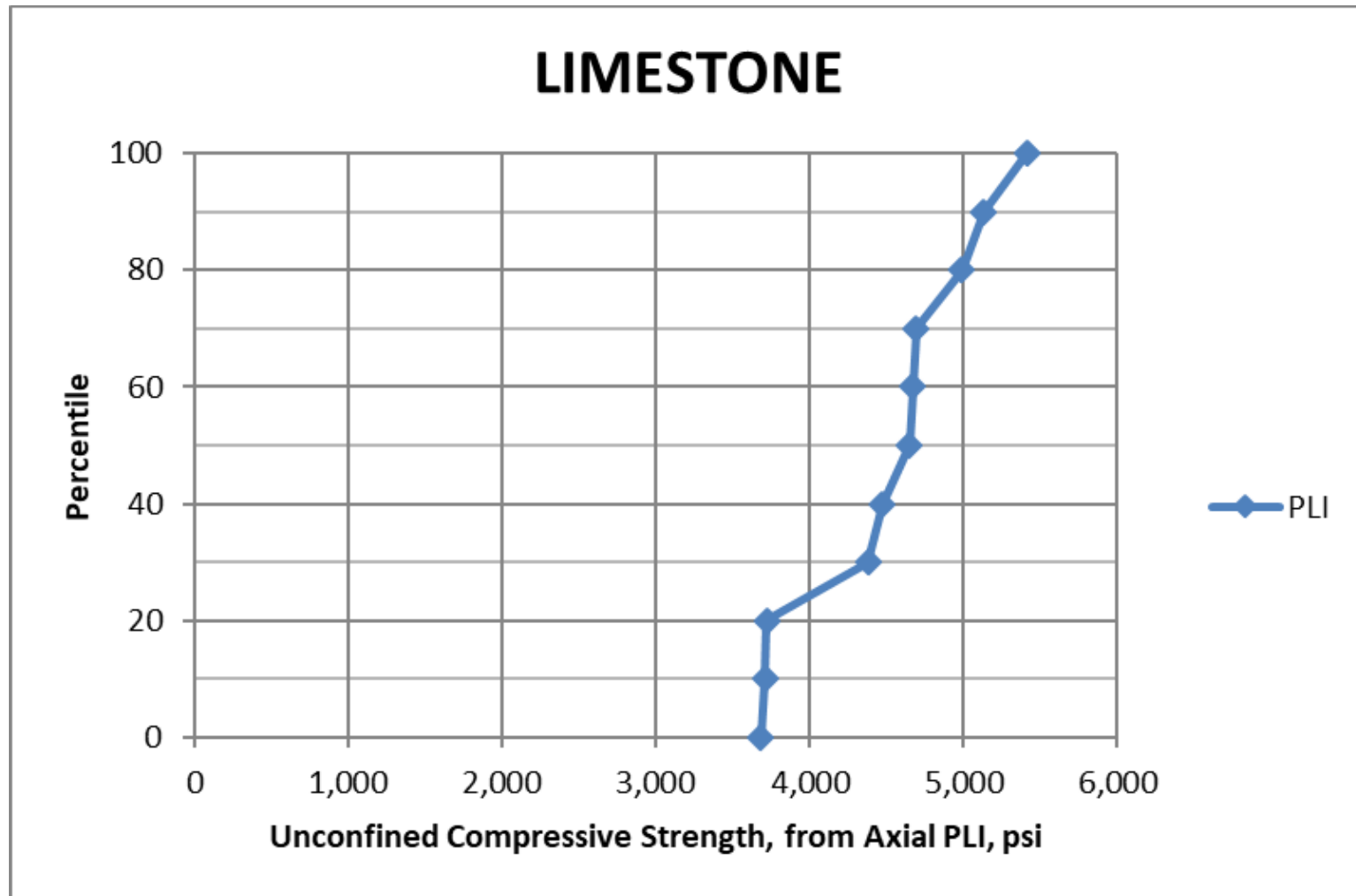
NOTE: Specimens were tested at as-received moisture content by ASTM D7012-C and D-7012-D.

Figure A-4. Unconfined compressive strength, shale



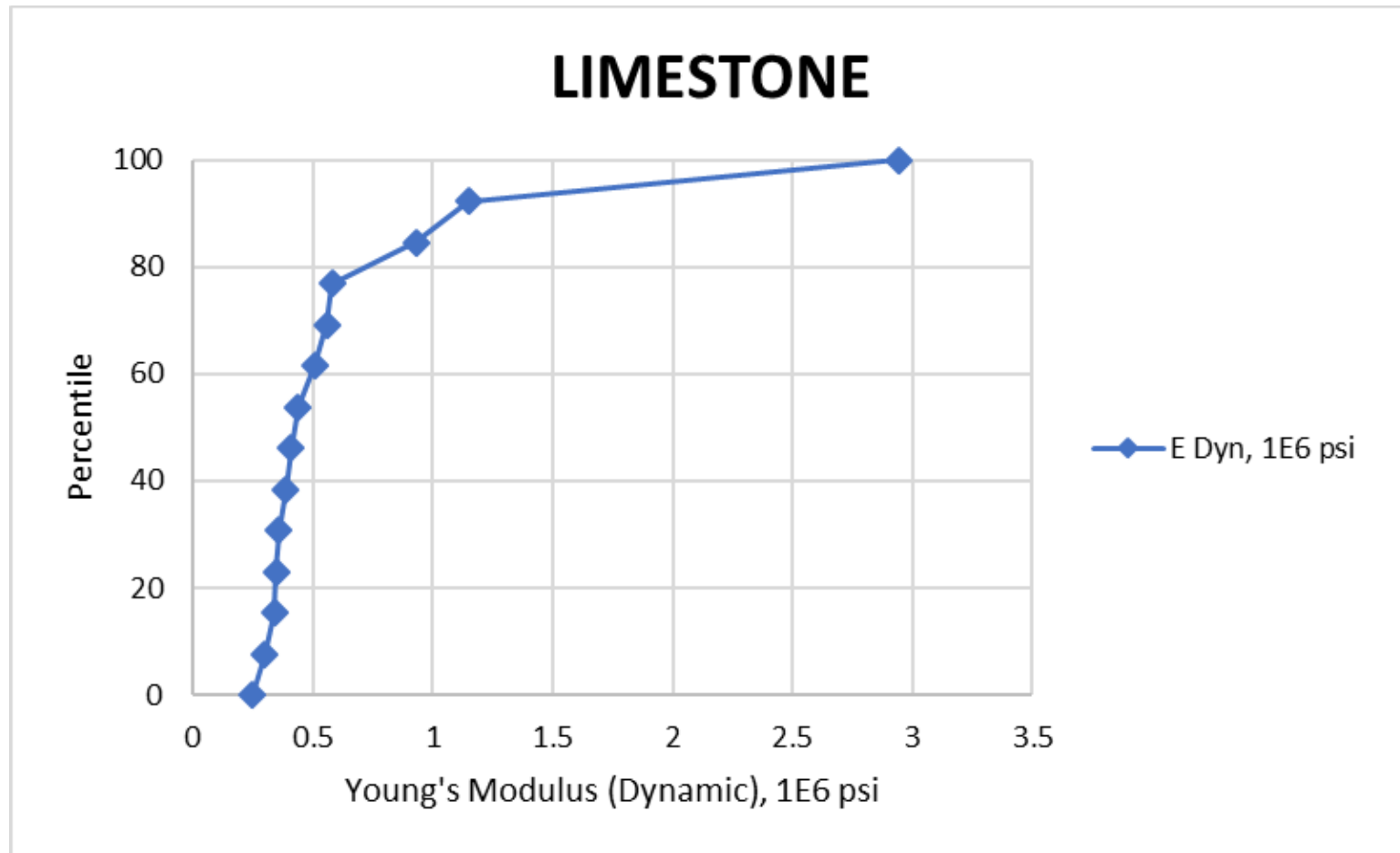
NOTE: Specimens were tested at as-received moisture content by ASTM D7012-C and D-7012-D.

Figure A-5. Unconfined compressive strength estimated from axial point load index tests, limestone



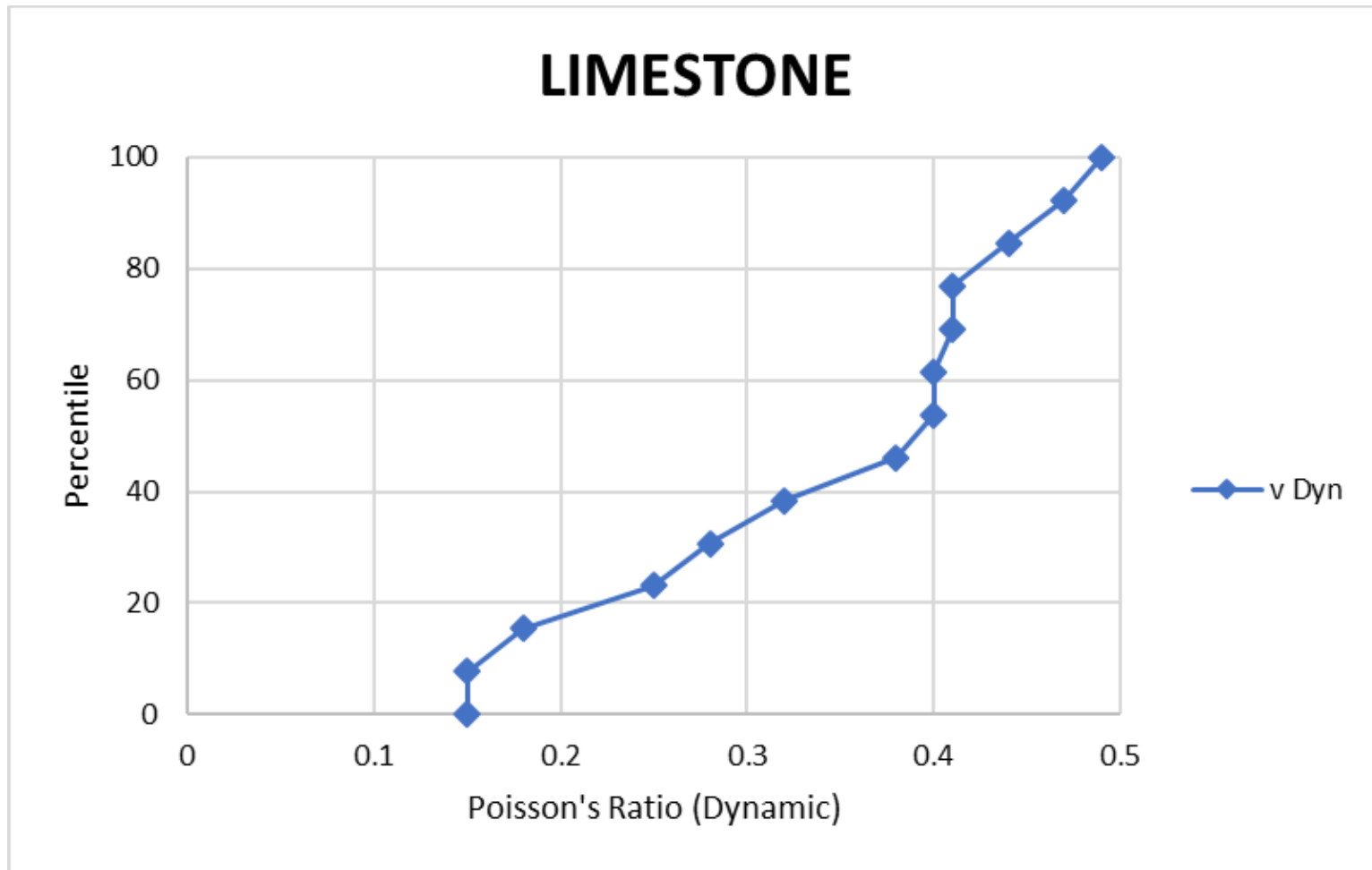
NOTE: Specimens were tested in saturated condition by ASTM D5731.

Figure A-6. Dynamic Young's modulus, limestone



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

Figure A-7. Dynamic Poisson's ratio, limestone



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

Figure A-8. Splitting tensile strength, limestone

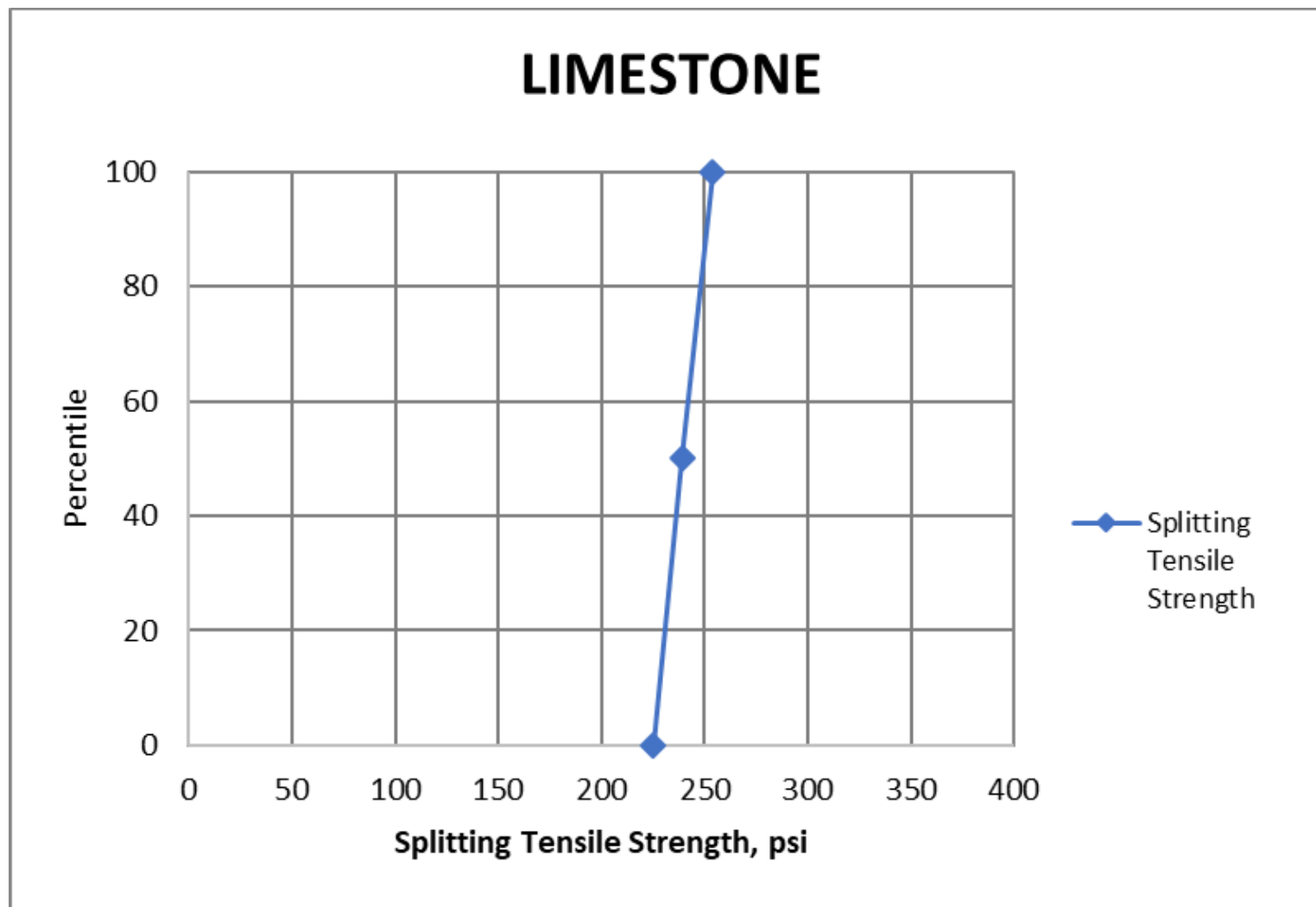


Figure A-9. CERCHAR Abrasiveness Index, limestone

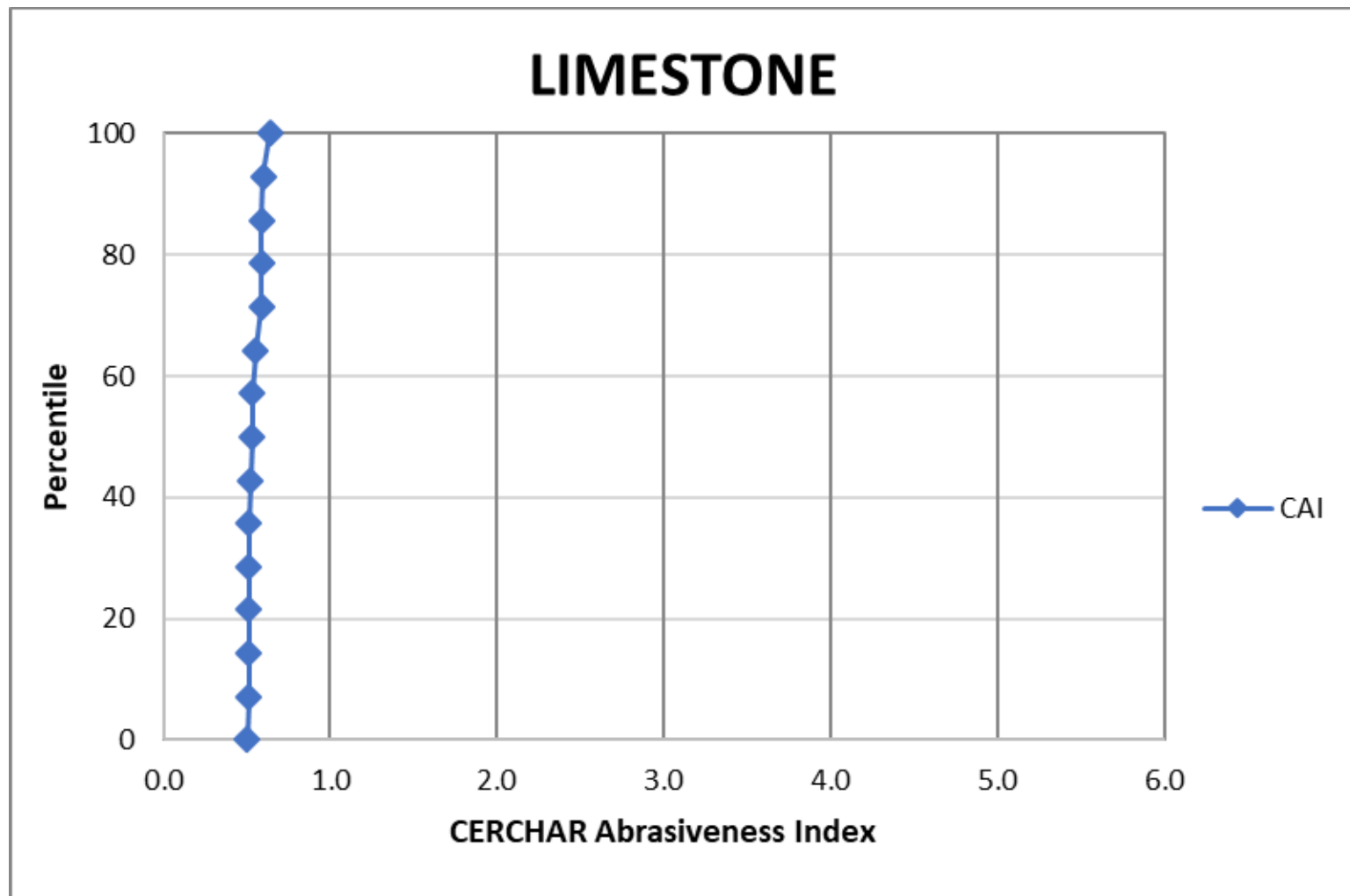
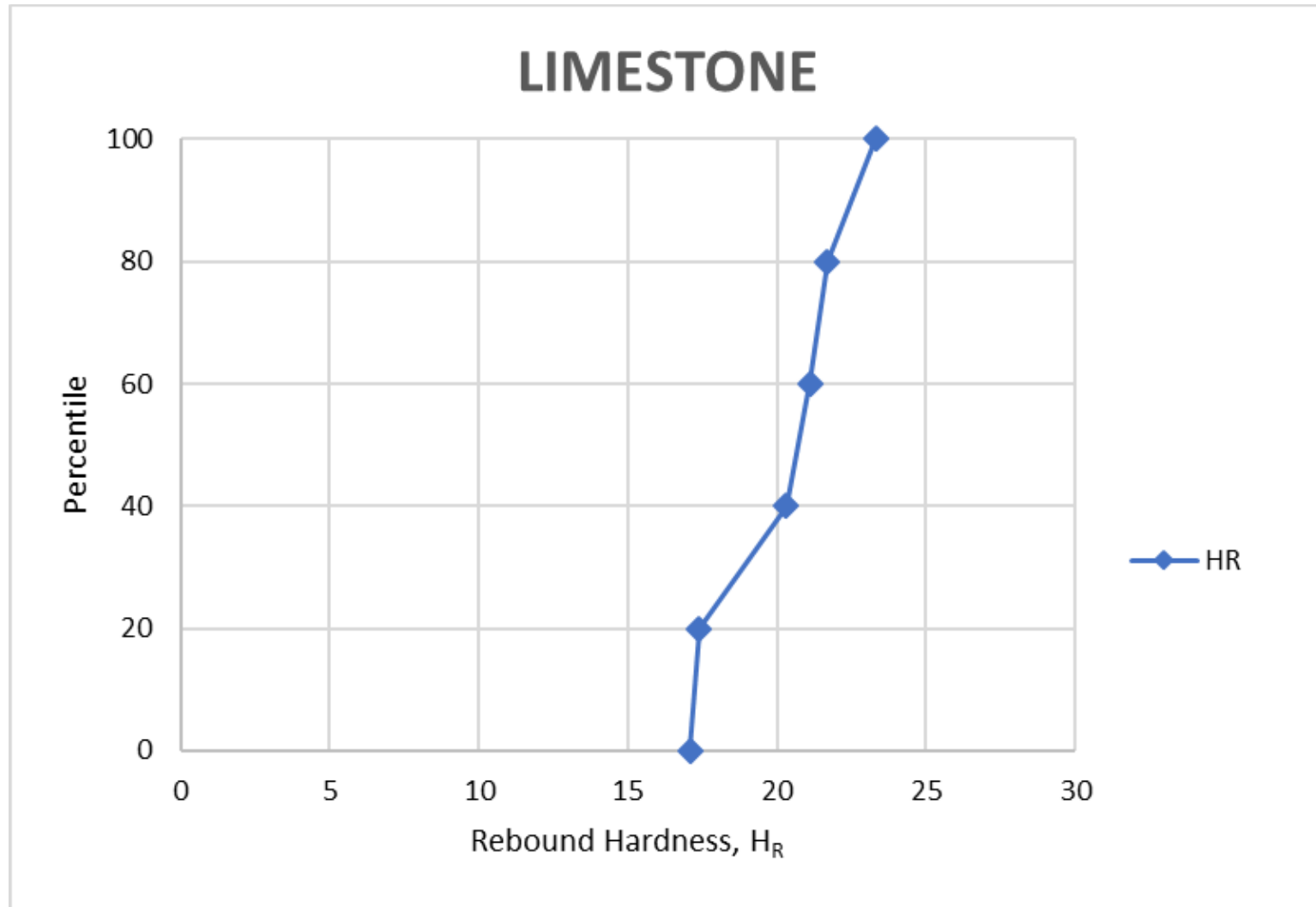


Figure A-10. Rebound hardness, limestone



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

Figure A-11. Slake durability, limestone

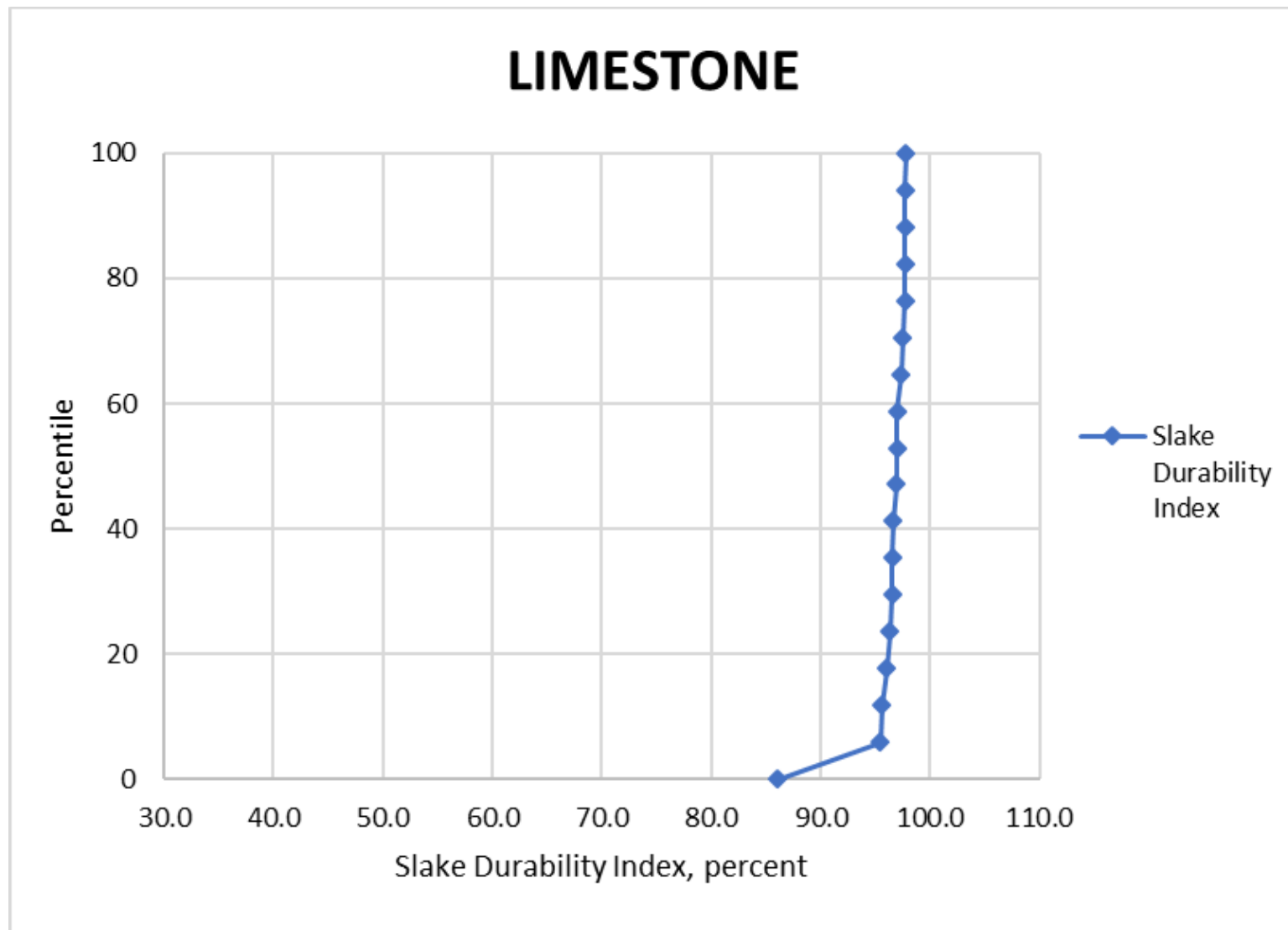


Figure A-12. Slake durability, shale

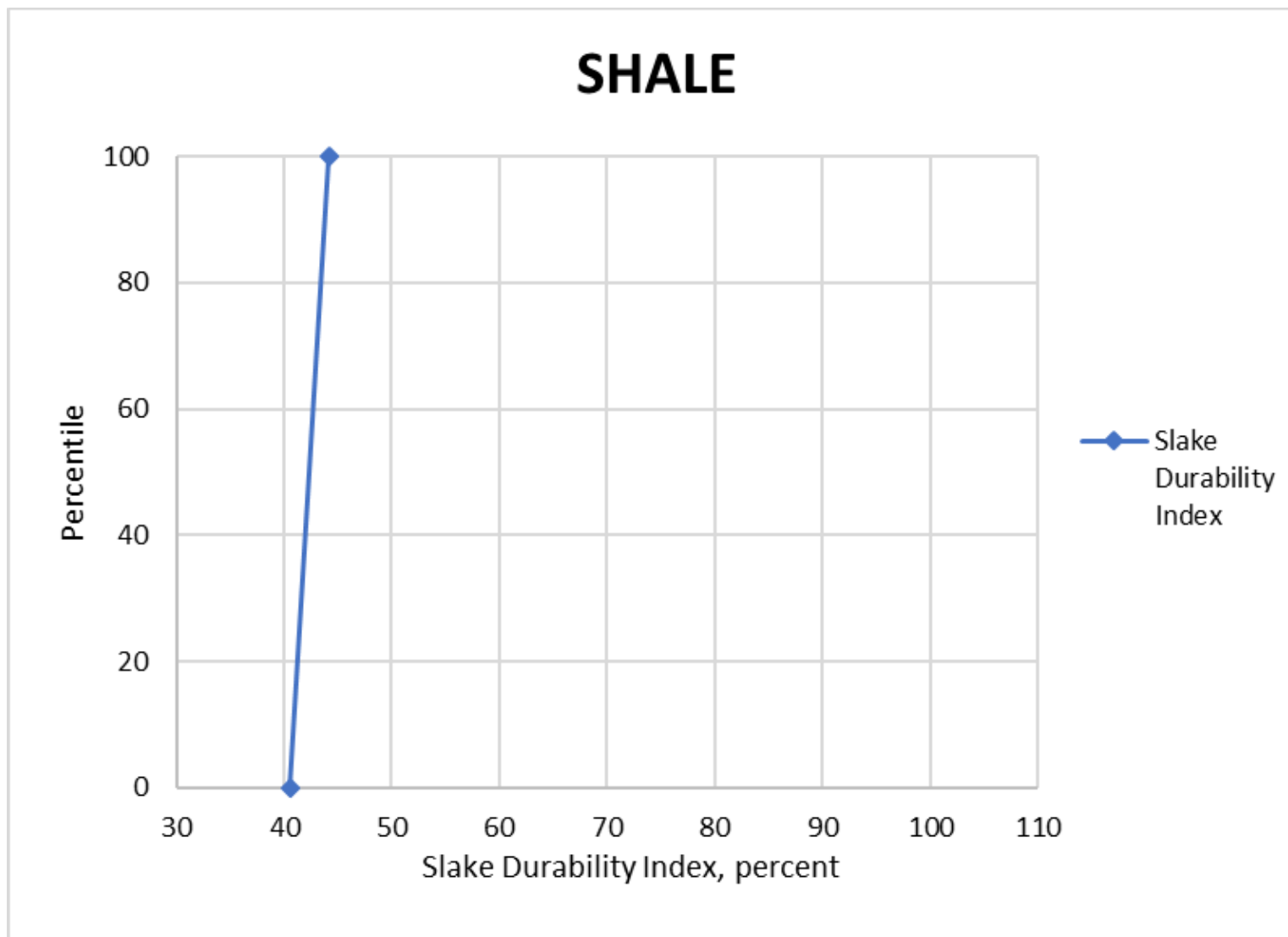


Figure A-13. Drillability indices, limestone

