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16. Abstract

This document summarizes the construction and design concepts developed to support the layout and subsurface geotechnical characterization associated with a system of water transport structures planned to provide for drainage of the new I-35 and Ben White Interchange. The drainage system will consist of a set of vertical drop shafts, in soils and bedrock, and a conduit sited in the Austin Chalk (AC) bedrock. It will convey runoff from the interchange south to Williamson Creek.

The main tunnel structure is sited in the AC below the interface between weathered rock and fresh rock. Experience has shown the AC to present relatively good tunneling conditions and, at the depths of the alignment, relatively low rock loading is anticipated on the peripheral rock mass and structural linings. Clay-rich layers, faulting, and deep weathered zones may locally require some special treatment to support the rock mass and to mitigate the impact of any local water inflows.

Because AC has previously proven highly amenable to excavation by mechanical means, both Tunnel Boring Machine (TBM) and roadheader mining methods will be considered in the development of the structural designs under an adequate amount of unweathered rock cover. At the southern end of the alignment, where rock cover is inadequate, cut and cover construction techniques will be used. Auger drilling, which has also been used to good effect in this material, is assumed in the excavation of drop shafts, as envisaged to convey surface runoff water to tunnel level.

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Research Report Number 2949-1F

Research Project 7-2949

Technical Support for Drainage Tunnel on IH-35

conducted for the

TEXAS DEPARTMENT OF TRANSPORTATION

by the

CENTER FOR TRANSPORTATION RESEARCH

Bureau of Engineering Research

THE UNIVERSITY OF TEXAS AT AUSTIN

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IMPLEMENTATION STATEMENT

The rock mass characterization steps and construction methodologies outlined in this report were developed specifically to support the geotechnical site investigation and rock mass characterization undertaken for the layout and design of the IH-35 – Ben White interchange to Williamson Creek tunnel in Austin, Texas.

All argumentation and discussion with regard to design and constructability issues are specific to the investigated site; accordingly, they should not be used in the development of other tunnel projects without a thorough re-evaluation of the specific site layout and rock mass characteristics.

Prepared in cooperation with the Texas Department of Transportation.

DISCLAIMERS

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TABLE OF CONTENTS

SUMMARY

This document summarizes the construction and design concepts developed to support the layout and subsurface geotechnical characterization associated with a system of water transport structures planned to provide for drainage of the new I-35 and Ben White Interchange. The drainage system will consist of a set of vertical drop shafts, in soils and bedrock, and a conduit sited in the Austin Chalk (AC) bedrock. It will convey runoff from the interchange south to Williamson Creek.

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Because AC has previously proven highly amenable to excavation by mechanical means, both Tunnel Boring Machine (TBM) and roadheader mining methods will be considered in the development of the structural designs under an adequate amount of unweathered rock cover. At the southern end of the alignment, where rock cover is inadequate, cut and cover construction techniques will be used. Auger drilling, which has also been used to good effect in this material, is assumed in the excavation of drop shafts, as envisaged to convey surface runoff water to tunnel level.

CHAPTER 1. PROJECT DEFINITION

INTRODUCTION

This document summarizes the construction and design concepts developed to support the layout and subsurface geotechnical characterization associated with a system of water transport structures planned to provide for drainage of the new I-35 and Ben White Interchange. The drainage system will consist of a set of vertical drop shafts (in soils and bedrock) and a conduit sited in Austin Chalk (AC) bedrock. It will convey runoff water from the interchange south to Williamson Creek.

The document also establishes a "working baseline" to be used in the development of the structural design and its associated schedule and cost estimates. The baseline has adopted excavation and support techniques that have already proven to be effective in the typical AC tunneling environment. No technical precedents are proposed, and the mining and lining methods will be familiar to contractors experienced in underground construction techniques in softer rock materials.

Both excavation and lining methodologies are discussed. Unlike most civil engineering design processes involving "manufactured materials" (e.g., concrete and steel), the host rock and excavation and support systems all need to be actively considered during the design of the underground structures. In particular, the shape of the excavated profile and the types of temporary support installed are discussed, as they significantly influence both the layout and design of the final linings. These structures will be designed to be compatible with both the host rock mass conditions and the anticipated construction methods.

The development of the layout and the sizing of structural elements relied primarily upon previous tunneling work undertaken in the same rock formation in Austin and Dallas. Structural and constructability issues will need to be further addressed during final design using site-specific data, with a view to optimizing the structural elements of the project. The use of more cost-effective alternative mining and lining techniques should also be reconsidered during the bid and construction periods, as contractors may offer valid alternatives as a function of equipment owned and of their own accumulated experience or individual preferences.

OBJECTIVES SETTING

Table 1-1 outlines a set of project objectives developed at the outset of the tunnel project to guide the decision-making process with regard to alignment, constructability, and design issues.

Table 1-1: Listing of IH-35 Tunnel Project Objectives

Objectives	Commentary
Structural Integrity	• minor cracking acceptable over design life (> 50 yrs.)
Performance	• capacity to accommodate 100 yr. flood (volume flow rate) • minimal need for inspection/maintenance during operation
Economy in Design and Construction	• application of most appropriate design methods • economic use of construction materials • incorporation of regionally-proven excavation methods
Rock Mass Integrity of Excavated Openings	• maximize location of openings below weathered rock • minimize possibility of intersecting poor quality rock • use of mechanical excavation techniques to minimize disturbance to surrounding rock mass
Construction and Operational Safety	• during construction; compliance with OSHA and other codes • during operation; provision for inspections and clean-up
Siting with Respect to Existing Structures	• minimize disruption to traffic • avoid mining in proximity to existing/proposed structures • stay within IH-35 Right of Way
Constructability	• use established mining technologies in baseline work • lining designed to be compatibility with excavation techniques
Alignment and Tolerances	• maintain a minimum drainage gradient of 0.3% • horizontally align with drop shaft structures • avoid use of unduly strict tolerances
Environment	• monitor pollution levels and treat as required (spoil, dust, noise, traffic, water) before, during, and after construction • allow for appropriate treatment and disposal of spoil • design to reduce outfall water velocities
Rapid Construction Time	• rapid excavation rates possible with mechanized equipment

SCOPE OF WORK

The set of subsurface structures to be constructed as part of the drainage network is described below.

Inlet Drop-Shafts

A series of drop shafts are planned to convey surface runoff water to the tunnel. Internal pipe diameters of up to approximately 1.83 m are being studied to accommodate the peak flows. Circular excavation and lined structures are adopted for all the drop-shafts. It is anticipated that the shafts will be excavated using drilled-shaft technology. This technology is commonly employed in the excavation of this size of shaft in soft rock formations. At present it is anticipated that the drop shafts will connect directly into the crown of the tunneled structure.

Tunnels

Both horseshoe and circular excavated tunnel cross-sections will be considered within the scope of the design work. The development of two alternative cross-sections will ensure compatibility with two types of mechanical excavation equipment, both of which are commonly used in the excavation of soft rock materials: the roadheader and the Tunnel Boring Machine (TBM). The final choice of equipment will be left to the bidding contractor.

An internal finished tunnel diameter of 4.57 m has been identified for baseline work. A minimum external diameter of approximately 5.49 m has been identified for alignment purposes, assuming that an 0.46-m clearance between internal lining and excavation wall will provide adequate space to accommodate the final lining thickness and satisfy the alignment tolerance specifications of the finished tunnel. The excavated diameter of this tunnel may be adjusted to accommodate the individual contractor's equipment and operational preferences, inasmuch as the functional and structural requirements of the structure are satisfied.

Trenched Structure

In this zone, at the southern end of the alignment, where there is inadequate rock cover above the crown of the tunnel, cut-and-cover construction and provision of a conventional box culvert structure are assumed. The finished size of the structure should be similar to that of the mined tunnel. The adoption of a larger cross-section in this zone may act to reduce the velocity of water flow prior to its outflow into the creek. An energy dissipater may be required within this section to control exit velocity and reduce the scour potential of the exiting tunnel water. A security gate may be required to restrict access into the structure.

Summary of the Set of Subsurface Structures

The basic structural elements of the drainage system are outlined in Table 1-2 below.

Table 1-2: The Set of IH-35 Tunnel Structures

Structures	**Primary Function**	**Descriptor**
Drop Shafts	Water Inlet	vertical pipe connectors between the surface drains and the tunnel
Tunnel	Water Conveyance	low gradient (0.3%) mined tunnel collecting and conveying run-off water to outlet
Culvert	Water Outlet	southern section of the system where cut-and-cover excavation is made and low gradient (0.3%) culvert is constructed

TUNNEL ALIGNMENT ISSUES

Tunnel Alignment Criteria

There was some positional flexibility in the siting of the tunnel and its associated structures in both the horizontal and vertical planes. Provisional selection of a tunnel alignment to support the conceptual studies was primarily made to minimize the length of tunnel excavation sited at shallow depth within the rock mass. At shallow depth, the presence of weathering generally results in a more fractured rock mass and in lower strength fracture surfaces. A brief summary of the basic reasons behind the selection of the chosen alignment is given below in Tables 1-3 and 1-4.

Table 1-3: Principal Criteria Influencing the Vertical Placement of the Tunnel

Criterion	**Reasoning**
Outfall elevation	the tunnel flow line and Williamson Creek flow line intersect
Gradient for Tunnel Flow	a minimum gradient of 0.3% for gravity-driven flow
Gradient for Storage	minimum gradient to maximize storage capacity
Gradient for Outlet Flow	minimum gradient to reduce outflow velocity
Gradient for Geotechnical Siting	minimum gradient is preferred to provide maximum cover of unweathered rock above the tunnel crown

Table 1-4: Principal Criteria Influencing the Horizontal Placement of the Tunnel

Criterion	**Reasoning**
Remain in the Right of Way Corridor	all components of the system are laid-out to remain within the bounds of IH-35 Right of Way
Structure Interference	construction close to either existing or planned surface or sub-surface structures is to be avoided
Geotechnical Siting	rock cover before passing under the I -35 frontage road is to be maximized
Inlet Stations	the tunnel passes vertically below inlet points to facilitate construction of the drop shafts
Tunnel Curvature	to avoid TBM turning complications, a 304 m (1000 ft) minimum horizontal alignment radius is selected

Drop Shaft Drilling Tolerances

Vertical drop shafts are planned to connect directly into the roof of the tunneled structure. Tolerances for the final lining of the drilled shafts should allow for the placement of the final lining at the theoretical intersection points (tunnel and shaft). Anticipated drilling inaccuracies (horizontal deviation of approximately 1 percent of drilled depth may be anticipated) should be accommodated by the use of a larger bored diameter than is strictly required to accommodate the specified minimum lining thickness.

TBM and Roadheader Mining Tolerances

In lined tunnels that have been mined by TBM, boring inaccuracies in the mining of the excavation have a significant impact on the selection of the excavated tunnel diameter. The adoption of a larger diameter than is strictly necessary to meet lining requirements allows the contractor more latitude in the guidance of the TBM. However, the additional latitude in tunnel placement, afforded by the adoption of a larger TBM diameter, requires that additional material be excavated and larger volumes of concrete placed to provide the final internal diameter specified in the contract. The contractor must weigh the guidance advantages of a larger tunnel diameter against the additional costs of excavation and concrete work. Contractor proposals to provide a larger excavated and finished tunnel should be considered where the cover, tolerance and lining adequacies of the proposed structure are re-verified.

The tunnel excavation specifications should be flexible enough to allow the contractor a reasonable amount of latitude during excavation, while respecting the final drainage and maintenance needs of the tunnel. Specific tolerances should be called-out to ensure that items, such as those listed below, are respected in the placement of the final lining:

- a tighter conformance to theoretical position may be required to accommodate specific structural requirements and steel placement, such as adjacent to drop shaft intersections;
- a minimal downward gradient should be maintained towards the tunnel outlet to avoid significant pooling of water in the tunnel;
- the designed minimum "concrete sleeve" thickness should be maintained around the full periphery of the bored tunnel;
- requirements for lining circularity and longitudinal "straightness" should be specified to ensure a minimal level of attention is paid to the condition maintenance of the form work.

The use of a relatively "generous" basic set of horizontal alignment criteria during excavation, allowing a significant amount of horizontal displacement from the theoretical alignment (say +/- 6 ins) may provide enough latitude to allow an experienced contractor to locate concrete form work with respect to the excavated profile, thus simplifying the lining process and ensuring that the TBM mining and lining processes can progress rapidly without excessive time being lost to keep within "over-precise" excavation tolerances that may not be justified given the final function of the structure.

Cut and Cover Section and Outfall Tolerances

Conventional cast-in-place concrete tolerances should be applied to the cut and cover and outfall structures.

CHAPTER 2. DESCRIPTION OF THE ROCK MASS

OVERVIEW

Geological and geotechnical data are being gathered to support the general subsurface characterization and final design of the subsurface structures. The main aims of the site investigation work are to improve the designer's and contractors' knowledge of the geologic structure and materials, to support the decisions on alignment and design of the structural support elements, and to provide adequate information to support the selection of appropriate mining techniques. The site investigation performed should identify, and place in perspective, the set of intact and rock mass parameters likely to have an impact on the design and construction elements of the project. To this end, data from a variety of sources are of use, including reference to similar case histories, outcrop observation, borehole core observation, and down-hole and laboratory testing.

The data should be used to provide for the development of a clear interpretation of the geologic framework, and for a definition of the geotechnical parameters of use in the development of the tunneled project. During design and contracting, the data should be used to support the selection of suitable tunneling methods, and to provide for the design of the structures, as based on a set of interpreted conditions. During the bid period, all the source data and interpretative reporting should be made available to the bidding contractors to provide a basis for an independent re-evaluation of construction methodologies within the context of the contract design and schedule framework, and to support the estimation of a bid price and evaluation of value engineering proposals that may be developed.

Given that a summary of the site investigation activities will be provided by Trinity Engineering and Testing Company (TETC), this study concentrates on comparing data sets from other jobs, and provides a wider perspective as to the typical range of AC rock mass conditions, based on the use of established rock mass classification systems.

ROCK MASS CHARACTERIZATION

General

Two rock parameters commonly available from site investigation data are Uniaxial Compressive Strength (UCS) and Rock Quality Designation (1) (RQD). UCS and RQD data sets were obtained from the Superconducting Super Collider (SSCL) geotechnical library and TETC. Borehole cores are the primary means of providing a quantitative basis for rock mass-to-rock mass comparison. The primary objective here was to collect and compare the AC data with that obtained from other tunnel drives made in the AC to verify the applicability of SSCL and Austin Area (e.g., the Govalle tunnel from the Canterbury Lift Station to the South Austin Regional Plant), tunneling techniques (TBM) to the IH-35 rock mass.

Intact Rock Strength

The basic statistical parameters of the UCS data sets from the SSCL and Govalle sites are provided in Table 2-1. Data in this table, which includes the IH-35 project, indicate that IH-35 and Govalle average UCS values are comparable, but that the cores tested for the IH-35 tunnel show a higher standard deviation. The SSCL average UCS values are higher than those obtained on either of the AC data sets derived from Austin sites.

Table 2-1: UCS Range and Average AC Values from Govalle IH-35 and SSCL Sites

Tunnel Project	No. of Observations	Min, psi	Max, psi	Mean, psi	Standard Deviation, psi
IH-35	67	159	3647	1525	918
Govalle	59	493	3102	1490	622
SSCL	316	306	3984	2072	760

The AC at all three sites is categorized, using strength descriptors defined by Bell (2), as a weak or "very soft" rock, with UCS values comparable to those of a very low strength concrete.

Rock Quality Designation (RQD)

The AC RQDs returned from the IH-35 and Govalle sites are shown in Table 2-2. The data for these two projects are comparable, but are somewhat lower than those observed on the SSCL site cores, which included a greater amount of deep coring below any weathered zone. At the SSCL, over 85 percent of the RQD values returned were in excess of 90 percent, corresponding to a classification of "excellent" under the RQD rock mass classification system.

For the two sets of site investigation data sampled in Austin, less than 40 percent of the rock core achieved an "excellent" ranking. However, only a small percentage, less than 5 percent of the rock core, at the Austin sites returned RQDs of less than 50 percent, and no core run returned an RQD value below 25 percent. The minimal presence of "poor rock" (25 percent < RQD < 50 percent) and absence of "very poor rock" (RQD < 25 percent) may be considered to provide a qualitative indication of the typical and lower range of fractured rock mass conditions to be encountered along the tunnel drive. All RQD values are reported for a 3-m core run; where

RQD evaluations were made for 1.5-m runs, adjoining RQD values were combined and averaged to produce an equivalent 3-m run RQD.

Table 2-2: RQD Range and Average Values from the two Austin Tunnel Sites

Tunnel Project	No. of Observations	Minimum	Maximum	Arithmetic Mean
IH-35, BHs 1-9	52	27.5	100.0	78.0
Govalle BHs 1-8	92	40.5	98.5	81.5

Both the RQD and UCS lower ranges at the IH-35 site are lower than observed at the Govalle site, and significantly lower than those observed at the SSCL. This fact may, in part, be attributed to the closer proximity of the IH-35 tested rock to the weathered rock interface, and the tunnel may well encounter more weathered or permeable fracture zones than were observed in the other tunnels. However, in general, tunneling conditions should be similar to those experienced at the SSCL and Govalle projects.

Block Size

RQD is the most common quantitative value used in the U.S. tunneling industry to describe the fractured state of a rock mass. It forms an integral part of most geotechnical data sets collected and reported during the tunnel site investigation process. RQD is easy to compute, although the basis of computation is not always consistent from job to job, and it has been used as an empirical aid in the design and excavation planning of most underground excavations. However, the reporting of RQD alone provides an incomplete and, from a geotechnical perspective, highly unsatisfactory description of a rock mass. RQD should always be supplemented by additional observations made on borehole core, outcrop, and tunnel-logged fractures to obtain a clearer understanding of the rock mass structure, along with its impact on the overall stability of a tunneled opening.

Field work was carried out to supplement core data and to provide an estimate of typical discontinuity spacing, geometry, and conditions. A set of typical block descriptors is identified in Table 2-3 below. For rock mass classification purposes, the rock mass is considered to contain two primary joint sets. The presence and nature of joint sets were difficult to identify at the IH-35 site, given that the limited amount of rock exposed had a weathered nature. However, an estimate of block size (Ib), as defined by the International Society of Rock Mechanics (ISRM) (3), has been projected based on a limited amount of observed structures present along the Williamson Creek rock outcrops, adjacent to the proposed tunnel outfall.

Table 2-3: Estimated Block Size Index, lb, based on ISRM procedures

Rock Mass Block Descriptors	**Average Discontinuity Set Spacing**			**Block Size Index, lb**
Discontinuity Sets	Set 1	Set 2	Set 3	lb
Discontinuity Type	Bedding	Joint 1	Joint 2	(cubic block)
Outcrop-Based Average Spacing for IH-35, meters	0.5	1.5	1.5	1.2
SSCL Reported	0.5	1.6	1.6	1.5

The stability of individual blocks within the rock mass around the tunneled opening is governed by the scale, geometry, and contact characteristics of the discontinuity-bounded rock surfaces. The various factors that influence an opening's stability are discussed below based on the TETC findings (4).

Discontinuity Roughness

The large-scale planarity (first order) of the discontinuity surfaces, as estimated from the borehole core, is primarily identified as undulating and planar. At the smaller scale of description, which is perhaps more easily discernible at a borehole scale of observation, approximately half the discontinuities are classed as slickensided. The presence of planar and slickensided discontinuity surfaces is indicative of rock blocks and wedges bounded by relatively low shear strength surfaces. However, these slickensided features are of relatively high relief and, hence, directional in nature, and are only likely to result in rock fall-out when the geometry of the tunnel alignment and discontinuity planes are found in "unfavorable combination." Such combinations of tunnel and geologic structure are expected to be only locally present along the length of the tunnel.

The borehole discontinuity surfaces are, in general, slightly rougher than that logged on the Govalle tunnel by TETC, where the majority of discontinuity surfaces were second-order slickensided, and first-order rough or undulating. First-order roughness is typically identified on the scale of outcrop observation. Second-order roughness is more typically associated with roughness as observed from retrieved core, with a consequent smaller scale of reference for assessing surface roughness than for first-order measures. The discontinuities were generally characterized as "tight," implying intimate surface-to-surface contact, as shown in Table 2-4.

Table 2-4: Observation of Discontinuity Surface Roughness or Presence of Soft Fill, Percent Observations

	1st Order Roughness			
2nd Order Roughness	Rough/Healed	Undulating	Planar	Soft Fill
Rough	0	46	0	0
Smooth	0	3	0	0
Slicken sided	0	22	27	0
Shear Through Fill/Seam	0	0	2	0

Borehole-Observed Discontinuity Degree of Weathering

Weathering rank was recorded on the preliminary logs for all discontinuities below the weathered zone. A higher degree of weathering would be indicative of a weakened intact rock zone bordering the discontinuity. Such weakening or the presence of soft fill can be expected to contribute to a reduction in shear strength. Relative degrees of weathering, expressed as degree of weathering percentage of the total logged discontinuities, are indicated in Table 2-5 by reference to TETC standard descriptive terms provided in the aforementioned report.

Table 2-5: Observation of Degree of Weathering Around the Discontinuity Surfaces

Degree of Weathering Descriptor	**Percent of Observations**
Unweathered	76
Slightly Weathered	16
Weathered	5
Severely Weathered or Clay Filled	3

In general, the degree of weathering associated with the IH-35 core was greater than that observed for the Govalle tunnel. The Govalle core discontinuities were almost exclusively unweathered. However, less than 10 percent of the IH-35 discontinuities were more than slightly weathered. The more weathered fracture conditions were generally logged for high-angle discontinuities encountered at shallow depth below the weathered rock zone.

Borehole-Observed Discontinuity Inclination

The bedding is subhorizontal and the borehole-observed jointing tends to be low to intermediate in dip. Relatively few high-angle joints were logged in the IH-35 core. This is consistent with Govalle core log findings. However, it should be noted that, given the relatively small angle between high-angle discontinuities and vertical boreholes, high-angle discontinuities are systematically under-sampled by vertical boreholes and are better observed from outcrop or inclined boreholes. The relative occurrence of ranked dip angles, for discontinuities intersected in the core, are given in Table 2-6 using TETC standardized descriptors.

Table 2-6: Discontinuity Orientation Relative to Horizontal, % Occurrence

Dip Description	Range of Dips	% of Observations
Low Angle	0 - 20	53
Intermediate Angle	20 - 50	33
High Angle	50 - 90	14

Based on outcrop observation, there are a significant number of higher angle joints within the rock mass. The presence of such features should be considered within the framework of the design procedure.

Mining Difficulties

The main feature that may be expected to give rise to mining difficulties in this tunnel is the presence of faulting. However, in previously mined tunnels such faults have not caused significant construction problems. In the AC material, the disturbed zone thickness bordering a fault is generally of limited extent. The maximum thickness observed from surface mapping of the SSCL site was approximately 2.4 m, though it typically was much less. It is notable that "prolonged" mining stoppages (> 1 week) were recorded on both the SSCL and the Dallas Area Rapid Transit (DART) tunnel drives to seal-off water and gas inflows, respectively. In neither instance, however, were these stoppages strictly necessary to maintain a suitable mining environment. Stoppages were effected primarily at the request of the client. Such stoppages cannot be ruled out in the mining of the IH-35 tunnel. As the alignment is mainly below the water table, there is a possibility that grouting may be required to avoid the inflow of fluids, particularly if pollutants are encountered in the surrounding rock mass. Based on SSCL and DART experience, any significant fluid inflow will most likely be encountered at the intersection of faulting or fracture zones

Stress Levels and Time-Dependent Phenomena

Stress levels at the tunnel depths are not anticipated to provoke any significant over-stress-related failure of the rock mass material. Some swell- or shrinkage-related phenomena with resulting local loading of the lining may occur over time, particularly if the clay-rich elements exposed within the tunnel cross-section are not protected or removed prior to placement of the final lining. Clay-rich layers along the tunnel should be over-mined and local shotcrete or concrete applied to avoid the onset of swell or slake action before the placement of a final lining.

ROCK MASS CLASSIFICATION

Overview

To aid in the interpretation of site investigation data, several semi-quantitative systems have been developed to provide an estimate of the required level of rock mass support. These systems have been developed using case history data from a wide range of rock openings to predict the relative stability and support requirements of openings in similar rock masses.

We advise against the indiscriminate application of these systems to the IH-35 tunnel, since the majority of the case history openings used were excavated using explosives as the primary means of excavation. The support recommendations from any given system should not be applied directly to a mechanically excavated tunnel without a significant re-calibration of the support measures. A recent study by Løset (5) indicated a marked deterioration in the quality of an exposed rock mass that was blasted rather than bored. For a bored tunnel section that was subsequently blasted, Løset indicated a typical reduction in the estimated RQD value from 75 to 50.

Despite this need for re-calibration before use in evaluating the support requirements of a bored tunnel, the classification systems do provide some guidance as to the relative stability of a given rock mass based on a limited set of commonly available rock mass parameters. The parameters used in four of the more well-established rock mass classification systems are discussed below, and a set of representative values for the AC are identified. Both the average and worst-case conditions are considered within the context of developing an understanding of the excavation support requirements of the tunnel. Worst case conditions are considered to be representative of low cover mining and areas of fault zone traversal.

Rock Mass Rating

The Rock Mass Rating (RMR) system (6), which has been in use since the 1970s, is deemed appropriate for use in classifying Austin Chalk, from a discontinuity perspective, as it assumes that three discontinuity sets are present within the rock mass.

Table 2-7: RMR for Average and Worst Case Austin Chalk Conditions

RMR	Average Conditions	Average Rating	Estimated Worst Case Combination
UCS, ksi	1.5	2	1
Rock Quality Designation, RQD, %	78 %	16	8
Disc. Spacing, m	1.3	15	13
Discontinuity Surface Conditions	slightly rough/weathered	25	15
Ground Water	damp	10	7
Discontinuity Orientation	fair	- 5	-10
Total		63	34
Class		Good	Poor

The AC classification using the RMR is "good rock." Worst-case conditions result in the classification of the rock mass as "poor rock." The rating for this rock is somewhat conservative owing to the very low contribution of the intact rock strength to the overall rating value in this method. Given the low stress (shallow depth) environment, intact rock strength is not likely to play a significant role in influencing the stability of the tunneled opening. The RMR rating elements are shown in Table 2-7.

Q-System

The Q system (7) was primarily developed by reference to case histories for stronger igneous and metamorphic rocks. However, it is commonly used in assessing rock masses in sedimentary units and is therefore included here for completeness. The components of the Q-System are shown in Table 2-8.

Table 2-8: Q-System Rating for Average and Worst Case Austin Chalk Conditions

Q-System	Average Conditions	Factor	Estimated Worst Combination
Rock Quality Designation, RQD, %	78	x 78	x 40
Number of Joint Sets	three joint sets	÷ 9	÷ 15
Joint Roughness	planar - smooth	x 1	x 0.5
Joint Alteration	wall contact	÷ 1	÷ 4.0
Joint Water Reduction	damp	x 0.66	x 0.5
Stress Reduction	no problem	1	÷ 1.0
Total		5.7	0.66
NATM Support Prediction		bolts and shotcrete	

Mining Rock Mass Rating

The Mining Rock Mass Rating (MRMR) system (8), used to determine the information in Table 2-9, was also developed for blocky rock conditions. It is based on the RMR system, but has a refined set of rating definitions for rock masses having fewer than the three discontinuity sets that are assumed for the RMR classification.

Table 2-9: MRMR System or Average and Worst Case AC Conditions

MRMR	Average Conditions	Rating	Estimated Worst Combination
UCS, ksi	1.5	0	0
RQD, %	78	13	7
Disc. Set Spacing, m	0.5, 1.5, 1.5	9	5
Disc. Surfaces	smooth/moist	58	40
Total		70	52
Class		Good	Fair

Rock Structure Rating

The Rock Structure Rating (RSR) system, developed for predicting rib support requirements for tunnels, is not highly appropriate for a tunnel in the AC at shallow depth, where bolt and canopy-type (wire mesh or steel straps) support systems have been most commonly used for rock support. However, the RSR (9) approach does provide a simple check on support levels developed using other systems, and provides a reference for load levels to be taken by the support system, as shown in Table 2-10.

Table 2-10: RSR for Average and Worst Case Austin Chalk Conditions

RSR	Average	Rating	Estimated Worst Combination
Rock Type and Geo-Structure	soft sedimentary and uniform geology	19	15
Disc Pattern and Drive Direction	cross dipping and moderately blocky	28	19
Sub-Total		47	34
Water Inflow / Joint Condition	slight water & good joint conditions	19	11
Total		66	45
Estimated Roof Load, psf		~ 1000	~ 2000

Summary

In summary, the AC rock mass is typically classified as a good quality rock, with the locally more fractured zones being of poorer quality. Recent mining experience tends to confirm the generally favorable tunneling conditions afforded by this rock material.

CHAPTER 3. CONSTRUCTION BASELINE

MECHANICAL EXCAVATION IN THE CHALK

Host Rock for the Underground Structures

The subsurface drainage structures will be constructed in AC excavations (tunnel, lower shafts and lower cut and cover) and in overlying soils (upper section of shafts and cut-and-cover sections). The AC is relatively soft, non-abrasive, and has proven highly amenable to excavation by mechanical equipment. Mechanical excavation techniques have achieved high production rates and have provided for the creation of relatively stable rock mass openings. As such, the AC rock mass is a suitable candidate for mechanical excavation, which is proposed as the baseline methodology for all excavation work.

Shaft Drilling for Inlets or Drop Shafts

Vertical drop shafts, with an estimated maximum internal diameter of 1.83 m, will convey surface runoff to the tunnel level. It is anticipated that these shafts will be excavated using auger drilling technology. Based on discussions with a local shaft drilling contractor, it will be possible to drill and support vertical shafts in this diameter range with only limited deviation.

Portal Access and Mining Direction

It is intended that construction activities associated with the mining and lining of the subsurface structures will be confined to the IH-35 right-of-way corridor. To this end, it is envisaged that a portal will be provided for tunneling work at the southern end of the alignment on the eastern side of the IH-35 frontage road. The fact that the associated work platform is relatively small should be emphasized to the contractors within the contract documents. Tunneling is assumed to take place from this portal towards the northern terminus. Where a TBM is used, provisions should be made to allow for its withdrawal through the mined tunnel, taking into account that passage will be required through sections of reduced diameter, where internal rock support elements (ribs) may have been installed. Alternatively, a shaft could be constructed at the northern end of the alignment to facilitate TBM removal. Such a shaft would need to be at least 6 m in diameter, or larger, to facilitate cutterhead passage; it may be planned to allow for early access to treat and mine through a potential poor rock mass zone (under investigation at the time this report was written).

Tunneling under Adequate Cover

Where adequate unweathered rock cover is established above the excavated crown of the tunnel, a TBM is identified as the baseline method for excavation of the main tunnel. TBMs have been used successfully on a number of recent tunnel projects of similar diameter driven in the Austin Chalk, notably SSCL (10-12), Dallas Area Rapid Transit (DART) (13), and the Dallas Central Expressway drainage tunnel. TBM mining provides for a rapid, cost-effective means of excavation while maintaining a relatively stable tunnel profile and minimizing the environmental impact of the construction work. In addition to these larger tunnels constructed in the Dallas area, several smaller tunnels have also been completed in the local Austin Chalk formation in recent years, in particular at Govalle, Onion Creek and Slaughter Creek (14-17). Figure 3-1 shows a TBM and back-up or support equipment assembly underground. A roadheader option for tunneling may be considered if other contract specifications and requirements are met.

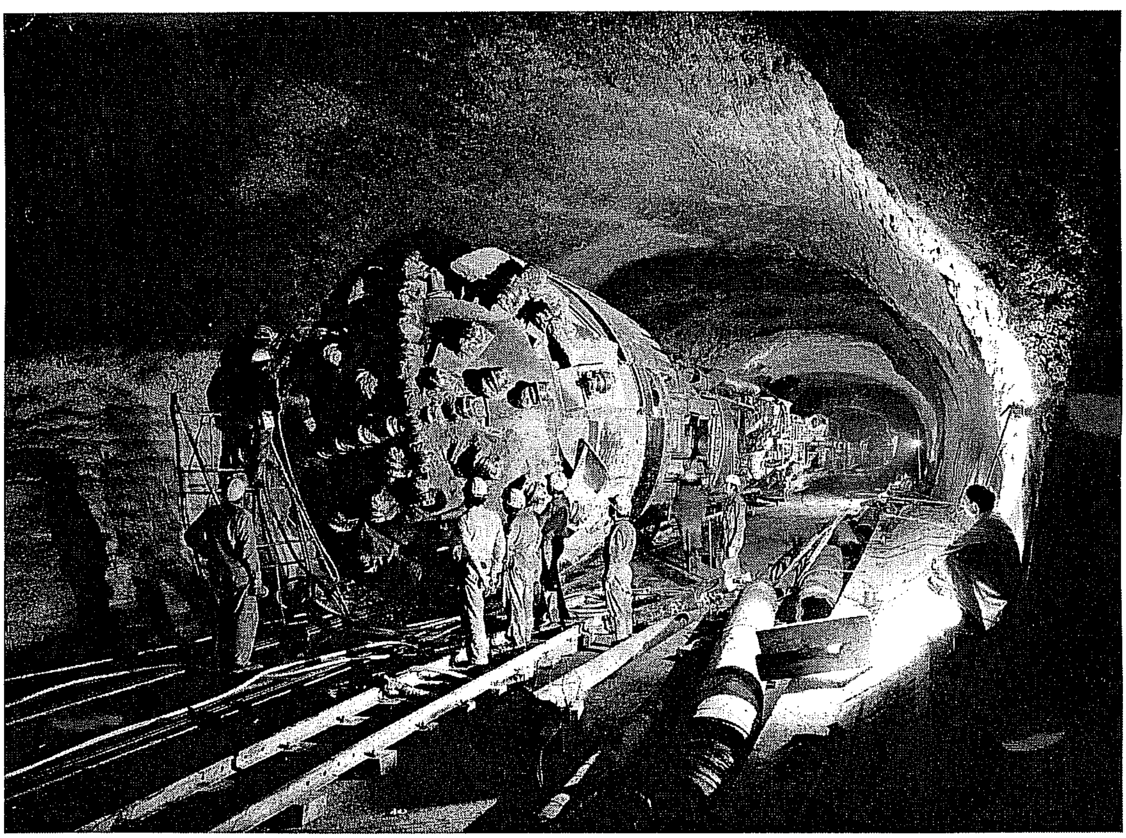

Figure 3-1: Tunnel Boring Machine and Back-up Equipment Assembly

Tunneling under Low Cover

Roadheader work is expected at the transition from cut-and-cover to tunnel at the southern end of the alignment under low cover conditions. The use of a roadheader in this low cover zone will facilitate the rapid support of the excavated tunnel profile and will minimize the risk of peripheral instability and profile deformation. It is anticipated that the roadheader section of the tunnel will serve as a starter section for the TBM equipment, providing a tunnel profile from within which TBM gripper reaction on the tunnel sidewalls can be achieved.

Cut-and-Cover Excavation Where Shallow

Based on initial site investigation and survey work, there appears to be an inadequate thickness of unweathered rock cover at the southern end of the alignment to provide for formation of a tunnel arch. Therefore, conventional cut and cover techniques are provisionally identified.

TEMPORARY SUPPORT INSTALLED ON EXCAVATION

General Temporary Support Functions

Failure of the rock mass surrounding the tunnel during construction represents an obvious safety hazard. Such failure would interfere with the efficient running of the construction site and would compromise the stability of the remaining rock structure. In rock materials like AC, rock reinforcement and protective measures should be aimed primarily at preventing:

- loosening and fall-out of discontinuity-bounded (primarily joints and bedding) wedge or block elements in the roof and sidewalls; and
- onset of deterioration in slake- or swell-susceptible clay-rich materials.

If degraded or loosened materials are left behind a final lining, they may give rise to relatively uneven loading being transmitted to the final lining over time. It is therefore important to maintain a "tight structure," within the peripheral rock mass, from excavation up to placement of the final lining. Any loose and/or degraded rock materials should be removed prior to placement of the final linings.

Ultimately, selection of temporary support measures will be made by the contractor. However, a set of criteria for temporary rock support selection is cited below to support development of the "baseline concept."

Tunneling under Adequate Cover

Support provision should be made to anchor potential fall-out of blocks or wedges upon excavation by the use of rock bolts. In this relatively large tunnel diameter range, a minimum level of support of pattern bolting should be anticipated along the full length of the tunnel. Locally, in more fractured zones encountered along the tunnel, provision should be made for "all-round" internal support of the excavated profile by the use of steel canopy or ribs, supplemented in zones of small block size by fiber-reinforced shotcrete.

Within the TBM tunnel, provision should be made to protect slake-susceptible rock material exposed around the tunnel periphery. The proposed mechanism to achieve this end is fiber-reinforced shotcrete typically applied within less than 24 hours of excavation. The shotcrete should be applied as necessary where slake-susceptible materials are exposed, before the onset of the slaking process. The provision of a time specification for the application of the protectant will support improved quality of shotcrete/rock bonding and help maintain the integrity of the peripheral rock mass material. Shotcrete may be applied to all or only part of the tunnel periphery as required.

Drainage measures should be provided to prevent water ponding in the tunnel. The presence of standing water in the tunnel invert can lead to rock deterioration and rail instability; it could also cause significant interruption in the mining process.

Where the time of surface exposure to air and moisture is relatively limited, and where slake durability of the exposed rock mass is high, the AC may, in many cases, be left uncovered with minimal degradation of the exposed rock mass.

Tunneling under Low Cover

The combined use of bolts, steel ribs, and fiber-reinforced shotcrete, installed on a cyclic basis at the face, is expected to provide sufficient support in the low cover section(s) excavated by roadheader. Such mechanisms should provide all-round internal support to the excavated profile.

Cut-and-Cover

At the southern end of the alignment, the soil cover may be either removed or supported at the sides of the excavation. Support of rock sidewalls will be required to provide both safety and an adequate guarantee of stability for the adjacent frontage road. Within the scope of this open-cut support work, provisions may be made to allow for the interception and drainage of the excavation sidewalls and floor.

Drop Shafts

The use of temporary casing is anticipated during the drilling process to facilitate the excavation through overburden materials. It is anticipated that the AC will, in most cases, be self-supporting up to the placement of the final lining.

Ground Water Treatment

As previously stated, it is anticipated that all mining will be conducted in an uphill direction working northward from the Williamson Creek shaft. Some local treatment of ground water along the tunnel may be required in fault areas to prevent water table draw-down and to limit outflow rates at the southern exit.

Given the potential for relatively high water inflow into the cut-and-cover section under storm conditions, and to accommodate water outflow from the tunnel itself, specific provisions may be required for the collection, sedimentation, and evacuation of water during the excavation period. Contingency plans may be prepared within the context of the contract in the event that contaminated water/spoil is encountered along the tunnel alignment. Such plans may include the need for on-site storage of quantities of contaminated water and spoils prior to treatment and off-site evacuation.

FINAL CAST-IN-PLACE LININGS

General Requirements

In general terms, the lining will provide "all-round" contact and resistance to any long-term local "gravity-loosening" or swelling pressures generated by the rock structure.

The final linings will provide a smooth internal surface. The smoothness of the surface is not an advantage in this instance, as it is anticipated that there will be a requirement to maximize the tunnel's storage capacity and minimize the flow velocity of tunnel water at the Williamson Creek outlet.

Lining Placement

A circular concrete sleeve of cast-in-place (CIP) concrete is envisaged in the mined tunnel sections. A grouted-in pipe is anticipated for the final support of the drop shafts. Contact grouting will be practiced in both cases to ensure that "all-round" contact is established between the lining and the rock mass to minimize the possibility of the lining being subjected to local loading and deformation over time. Local reinforcement is anticipated at the shaft-tunnel intersections. Cast-in-place culvert structures are envisaged for all the open-cut sections located at the tunnel outlet.

Summary of Support and Lining Baseline Strategies

Table 3-1 summarizes the baseline rock support and final lining mechanisms envisioned for the I-35 Tunnel Project.

Table 3-1: Baseline Support and Lining Methods for the IH-35 Tunnel Structures

Construction Measures	**Equipment**	**Mining Support**			**Lining**
Structure	Excavation Means	blocky ground	fractured ground	clay-rich layers	concrete shell
Running Tunnel	TBM	bolts	ribs	shotcrete	CIP
Starter Tunnel	Roadheader	bolts	ribs	shotcrete	CIP
Cut & Cover	Back hoe	bolts		shotcrete	CIP
Shafts	Auger Drill	casing as required			grouted pipe

Sizing of these support elements will be made using construction and rock load estimates provided by the geotechnical engineer.

REFERENCES

1. Deere, D. U., "Technical Description of Rock Cores for Engineering Purposes." *Rock Mechanics and Engineering Geology,* Vol. 1, No. 1, 1964, pp. 17-22.
2. Bell, F., *Fundamentals of Engineering Geology.* Butterworth, London, 1983, p. 534.
3. "International Society of Rock Mechanics Recommended Procedures," *International Journal of Rock Mechanics and Geomechanics Abstracts, 1978,* Vol. 15, pp. 319-368.
4. Young, C. J., and L. B. Yates, "Geotechnical Investigation IH-35 Tunnel Ben White Boulevard to Williamson Creek, Austin, Texas," prepared for Texas Department of Transportation, Austin District, Austin, Texas, Project No. Au-3454, June 1995.
5. Løset, F., "Support Needs Compared at the Svartisen Road Tunnel," *Tunnels and Tunneling,* June 1992, pp. 53-55.
6. Bienawski, Z. T., "Rock Mass Classifications in Rock Engineering," Proceedings of the Symposium on Exploration for Rock Tunneling, Johannesburg, South Africa, November 1976, pp. 97-106.
7. Barton, N., "Rock Mass Classification and Tunnel Reinforcement Selection Using the Q-System," Rock for Engineering Purposes, ASTM STP 984, Louis Kirkaldie (ed.), American Society for Testing Materials, Philadelphia, 1988, pp. 59-88.
8. Laubscher, D. H., and H. W. Taylor, "The Importance of Geomechanics Classification of Jointed Rock Masses in Mining Operations," Proceedings of the Symposium on Exploration for Rock Tunneling, Johannesburg, South Africa, November 1976, pp. 119-128.
9. Wickham, G. E., H. R. Tiedemann, and E. H. Skinner, "Ground Support Prediction Model RSR Concept," Rapid Excavation and Tunneling Conference, San Francisco, June 1972, Vol. 1, pp. 691-707.
10. Prince, R., J. Bhore, T. Martin, and R. Richards, "Superconducting Super Collider Construction of Tunnels and Shafts," Rapid Excavation and Tunneling Conference Boston, June 1993, pp. 681-690.
11. Corry, T. B., "Construction of the 1122/1130 Tunnels on the Superconducting Super Collider Project," Rapid Excavation and Tunneling Conference, San Francisco, June 1995, pp. 425-443.
12. Whitchurch, J. A., "Construction of the N20 to N25 Tunnel (basic) Segment of the Super Conducting Super Collier Project," Rapid Excavation and Tunneling Conference, San Francisco, June 1995, pp. 445-464.
13. Rogstad, D., "The Dallas Area Rapid Transit Subway Tunnel Project," Rapid Excavation and Tunneling Conference, San Francisco, June 1995, pp. 425-443.
14. Martin, D., "Triple TBM Drive Puts Austin Interceptor into Top Gear," *Tunnels and Tunneling,* October 1987, pp. 24-26.
15. Nelson, P. P., "Case Histories in Tunneling: The Austin Cross-town Wastewater Interceptor Tunnel Contracts 5029-1 and 5029-3," Geotechnical Engineering Report GR. 86-10, Civil Engineering Department, The University of Texas at Austin, September 1986.

16. Nelson, P. P., "Soft Rock Tunneling: Equipment Selection Concepts and Performance Case Histories," Rapid Excavation and Tunneling Conference, June 1987, pp. 583-600.

17. Nelson, P. P., "Performance Comparisons for Tunneling Projects in Weak Rock," *Rock Mechanics: Proceedings of the 28th U.S. Symposium,* University of Arizona, June 1987, pp. 329-336.