Table C5.5.5-2—Estimation of Disturbance Factor, *D* (AASHTO, 2010)

Description of Rock Mass	Suggested Value
Excellent quality controlled blasting or excavation by TBM results in minimal disturbance to the confined rock mass surrounding a tunnel.	$D = 0$
Mechanical or hand excavation in poor quality rock masses (no blasting) results in minimal disturbance to the surrounding rock mass. Where squeezing problems result in significant floor heave, disturbance can be severe unless a temporary invert is placed.	$D = 0$ $D = 0.5$ No invert
Very poor quality blasting in a hard rock tunnel results in severe local damage, extending 6 to 9 ft, in the surrounding rock mass.	$D = 0.8$
Small scale blasting in civil engineering slopes results in modest rock mass damage, particularly if controlled blasting is used. However, stress relief results in some disturbance.	$D = 0.7$ Good blasting $D = 1.0$ Poor blasting
Very large open pit mine slopes suffer significant disturbance due to heavy production blasting and also due to stress relief from overburden removal. In some softer rocks, excavation can be carried out by ripping and dozing, and the degree of damage to the slope is less.	$D = 1.0$ Production blasting $D = 0.7$ Mechanical excavation

Table C5.5.5-3—Estimation of E_m based on RQD (AASHTO, 2014; modified after O'Neill and Reese, 1999)

RQD (percent)	E_m/E_i	
	Closed Joints	Open Joints
100	1.00	0.60
70	0.70	0.10
50	0.15	0.10
20	0.05	0.05

Table C5.5.5-4—Summary of Elastic Moduli for Intact Rock (AASHTO, 2014; modified after Kulhawy, 1978)

Rock Type	No. of Values	No. of Rock Types	Elastic Modulus, E_i (ksi $\times 10^3$)			Standard Deviation (ksi $\times 10^3$)
			Maximum	Minimum	Mean	
Granite	26	26	14.5	0.93	7.64	3.55
Diorite	3	3	16.2	2.48	7.45	6.19
Gabbro	3	3	12.2	9.8	11.0	0.97
Diabase	7	7	15.1	10.0	12.8	1.78
Basalt	12	12	12.2	4.20	8.14	2.60
Quartzite	7	7	12.8	5.29	9.59	2.32
Marble	14	13	10.7	0.58	6.18	2.49
Gneiss	13	13	11.9	4.13	8.86	2.31
Slate	11	2	3.79	0.35	1.39	0.96
Schist	13	12	10.0	0.86	4.97	3.18
Phyllite	3	3	2.51	1.25	1.71	0.57
Sandstone	27	19	5.68	0.09	2.13	1.19
Siltstone	5	5	4.76	0.38	2.39	1.65
Shale	30	14	5.60	0.001	1.42	1.45
Limestone	30	30	13.0	0.65	5.7	3.73
Dolostone	17	16	11.4	0.83	4.22	3.44

5.5.6—Poisson's Ratio

Poisson's ratio for rock shall be determined from tests on intact rock core.

C5.5.6

For representative values of Poisson's ratio for rock, see Table C5.5.6-1.

Table C5.5.6-1—Summary of Poisson's Ratio for Intact Rock (AASHTO, 2014; modified after Kulhawy, 1978)

Rock Type	No. of Values	No. of Rock Types	Poisson's Ratio, ν			Standard Deviation
			Maximum	Minimum	Mean	
Granite	22	22	0.39	0.09	0.20	0.08
Gabbro	3	3	0.20	0.16	0.18	0.02
Diabase	6	6	0.38	0.20	0.29	0.06
Basalt	11	11	0.32	0.16	0.23	0.05
Quartzite	6	6	0.22	0.08	0.14	0.05
Marble	5	5	0.40	0.17	0.28	0.08
Gneiss	11	11	0.40	0.09	0.22	0.09
Schist	12	11	0.31	0.02	0.12	0.08
Sandstone	12	9	0.46	0.08	0.20	0.11
Siltstone	3	3	0.23	0.09	0.18	0.06
Shale	3	3	0.18	0.03	0.09	0.06
Limestone	19	19	0.33	0.12	0.23	0.06
Dolostone	5	5	0.35	0.14	0.29	0.08

5.6—ENVIRONMENTAL ISSUES

The aggressive subsurface environment due to groundwater chemistry/corrosive soils, handling of hazardous minerals within the excavated zone (e.g., asbestiform minerals), and hazardous and explosive gases within the subsurface (e.g., hydrogen sulfide, H_2S, and methane, CH_4) shall be considered when developing subsurface investigations. If present, necessary measures shall be included in the design of the structures.

The spoils, tunnel muck, and dredged material shall be treated, reused, or disposed of in accordance with applicable local and national regulations.

All necessary precautions and instrumentation shall be implemented to mitigate the impact of construction of highway tunnels on air quality, noise, vibration, traffic, nearby aboveground and underground structures/utilities, groundwater, surface water, etc.

5.7—INSTRUMENTATION AND MONITORING

An instrumentation and monitoring program shall be in place for all tunneling projects to:

- Prevent and minimize damage to existing structures/utilities and the structure under construction by providing data to evaluate the source and magnitude of ground movements and changes to groundwater levels;
- Assess the safety of works by comparison of the observed response of ground and structures with the predicted response and allowable deformations of disturbance levels;

Additional information on geotechnical instrumentation and monitoring is provided by J. Dunnicliff (FHWA, 1998).

- Develop protective and preventive measures for existing and new structures;
- Select appropriate remedial measures, when required;
- Evaluate critical design assumptions where significant uncertainty exists;
- Determine adequacy of Contractor's methods, procedures, and equipment;
- Monitor effectiveness of protective, remedial, and mitigative measures;
- Assess Contractor's performance, Contractor-initiated design changes, change orders, changed conditions, and disputes;
- Provide feedback to Contractor on its performance; and
- Provide documentation for assessing damages sustained to adjacent structures allegedly resulting from construction related activities.

Threshold and limiting values regarding vibrations, horizontal and vertical deformations, groundwater drawdown, loads in structural elements, and minimum standards for instrumentation shall be defined. Included with the monitoring plan shall be proposed mitigation measures to be taken in the event threshold and limiting deformations are exceeded.

Pre- and post-construction condition surveys of all critical structures and utilities shall be performed and documented.

5.8—GEOTECHNICAL REPORTS

5.8.1—Geotechnical Data Report

The GDR shall present the factual subsurface data for the project without including an interpretation of these data. All factual geological, geotechnical, groundwater, and other data obtained from subsurface investigations shall be included.

Data reduction shall be limited to determination of the properties obtained from individual test samples, while avoiding any recommendations for the geotechnical properties for the soil or rock unit from which the sample was obtained.

The GDR shall contain the following information, at a minimum:

- Description of the geologic setting;
- Descriptions of the site exploration program(s);
- Logs of all borings, trenches, and other site investigations;
- Groundwater measurements;
- Descriptions/discussions of all field and laboratory test programs; and
- Results of all field and laboratory testing.

C5.8.1

The GDR avoids making any interpretation of the data since these interpretations may conflict with the data assessment subsequently presented in the Geotechnical Design Memoranda (GDM) or other geotechnical interpretive or design reports, and the baseline conditions defined in the Geotechnical Baseline Report (GBR). Any such discrepancies may be a source of confusion to contractors and open opportunities for claims of differing site conditions.

For more information on GDR, refer to the *Technical Manual for Design and Construction of Road Tunnels—Civil Elements* (AASHTO, 2010).

5.8.2—Geotechnical Baseline Report

The GBR shall establish the site specific subsurface conditions to be considered as baseline conditions to

C5.8.2

The GBR translates facts, interpretations, and opinions regarding subsurface conditions into clear, develop bids and select means and methods. The GBR shall not be interpreted as a prediction or warranty of the actual site conditions, but rather seen as a contractual instrument for allocating risks and a basis for determining the merits of claims of differing site conditions during construction. The GBR shall be based on factual information presented in the GDR engineering evaluations made in GDM, as well as input from the Owner. The baseline presented in the GBR shall be clear and concise and be such that it can be measured during construction.

unambiguous statements for contractual purposes. Items typically addressed in GBR include:

- Amounts and distribution of different materials along the selected alignment;
- Description, strength, compressibility, grain size, and permeability of the existing materials;
- Description, strength, and permeability of the ground mass as a whole;
- Groundwater levels and expected groundwater conditions, including baseline estimates of inflows and pumping rates;
- Anticipated ground behavior and the influence of groundwater, with regard to methods of excavation and installation of ground support;
- Construction impacts on adjacent facilities; and
- Potential geotechnical and man-made sources of potential difficulty or hazard that could impact construction, including the presence of faults, gas, boulders, solution cavities, existing foundation piles, and the like.

Items to be baselined should be limited to those that have significant influence on construction operations, cost, and schedule.

For further information, refer to the *Technical Manual for Design and Construction of Road Tunnels—Civil Elements* (AASHTO, 2010) and *Geotechnical Baseline Reports for Construction: Suggested Guidelines* (ASCE, 2007).

5.9—GEOTECHNICAL DESIGN MEMORANDA

One or more GDM shall be prepared for the project, based on the project complexity. The number, format, and content of the GDM shall be determined by the Project Geotechnical Engineer and the Project Structural Engineer, subject to review and approval by the Project Manager in accordance with Owner requirements.

Separate GDM may be prepared for design of Temporary (Initial) Support and for the design of the final structures of the different tunnel types. Alternatively, a GDM may contain information required for the design of both Temporary (Initial) Support and the final structure.

Each GDM shall contain unfactored ground loads and water loads and ground deformation parameters in the format required by the Project Structural Engineer.

Each GDM shall address construction stages as well as final equilibrium states.

Water loads shall reflect time-dependent variation, including water table elevation lowering during excavation as applicable, post-completion groundwater level recovery, and lining details, i.e., drained or undrained. Water loads for drained linings shall also include a partial clogging condition.

5.10—REFERENCES

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SECTION 6 – CUT-AND-COVER TUNNEL STRUCTURES

TABLE OF CONTENTS

6.1—SCOPE

The provisions of this Section shall apply to the planning, design, evaluation, and rehabilitation of cut-and-cover highway tunnels, and the permanent support of excavation (SOE) systems that are incorporated into the final tunnel structure. The tunnels may be constructed in place or formed of precast sections. Temporary SOE and temporary slopes for open excavations are not included in this Section.

Cut-and-cover tunnels and their components shall be designed to sustain the most severe combination of loads to which they may be subjected both during construction and after the final stage when the construction is complete and the tunnel is in service.

Effects of erection, bracing, excavation sequence, and other temporary loads during the construction shall be considered in the design of cut-and-cover tunnels and their components. A structural system study shall be prepared to determine the most suitable structural alternatives for construction of the cut-and-cover tunnel. This study shall include a determination of the proposed tunnel section, the excavation support system, the tunnel structural system, the construction method (top-down or bottom-up), and the waterproofing system.

When an open cut with stable sloped sides for the earth being excavated is not practical, an SOE system (shoring system) shall be used to stabilize the ground. Permanent SOE systems may be used as part of the final structure if they are designed and detailed accordingly.

Refer to Section 3 for load factors and load combinations that shall be considered during the design of cut-and-cover tunnels.

Refer to Section 4 for material properties and resistance factors that shall be considered during the design of cut-and-cover tunnels.

Refer to Section 10 for seismic considerations during the design of cut and cover tunnels.

Cut-and-cover tunnel structures shall be designed in accordance with AASHTO *LRFD Bridge Design Specifications* (hereinafter referred to as the *LFRD Specifications*) including all applicable interim changes, except as modified or supplemented here.

C6.1

Cut-and-cover tunnels are tunnels constructed in an open excavation or trench, then backfilled with fill material. Shallow depth vehicular tunnels are usually designed as cut-and-cover tunnels. For invert depths up to 60 feet below grade, this method is often less expensive and more practical than tunneling. Cut-and-cover vehicular tunnels are also used at the approaches to mined, bored, and immersed tunnels.

The ground surrounding a tunnel can act as a supporting mechanism, loading mechanism, or both, depending on the nature of the ground, the tunnel size, and the method and sequence of constructing the tunnel. Thus, the rock or soil surrounding a tunnel is a construction material.

6.2—DEFINITIONS

Reinforced Concrete Diaphragm Wall—Slurry wall designed to span vertically with no structural continuity between panels. Typically reinforced with conventional deformed reinforcing steel bars.

Soldier Pile and Tremie Concrete (SPTC) Wall—Slurry wall reinforced with vertical wide-flange steel sections placed at the ends of the panels.

Secant Pile Wall—Wall constructed of drilled shafts that intersect the perimeter of adjacent shafts.

Slurry Panel—Smallest unit of length of slurry wall constructed at one time. Panels are constructed in an alternate pattern; primary panels are constructed first, followed by secondary panels.

Tangent Pile Wall—Wall constructed of drilled shafts that touch each other, but do not overlap.

6.3—NOTATION

6.3.1—General

ft^2	=	square feet (C6.10.2)
gals	=	gallons (C6.10.2)
H	=	The height of vertical wall of a cut-and-cover tunnel from the bottom of the invert slab to top of the roof slab (6.7.3.2)

6.3.2—Abbreviations

ASTM:	ASTM International (formerly known as the American Society for Testing and Materials)
AREMA:	American Railway Engineering and Maintenance-of-Way Association
EPDM:	Ethylene propylene diene monomer
FE:	Finite element analysis
PTI:	Post-Tensioning Institute
PVC:	Polyvinyl chloride
RCDW:	Reinforced concrete diaphragm wall
SOE:	Support of excavation
SPTC:	Soldier pile and tremie concrete

6.4—GROUND AND MATERIAL PROPERTIES

6.4.1—Determination of Ground Properties

C6.4.1

Soil and rock parameters to be used in design should consider possible changes in properties during construction, such as changes in shear strength, unit weight, and/or permeability due to ground improvement methods.

6.4.1.1—General

A subsurface investigation shall be performed to obtain information on the ground conditions:

- Defining the subsurface profile
- Determining soil and rock material properties and mass characteristics
- Identifying geotechnical anomalies, fault zones, and other hazards
- Defining hydrogeological conditions
- Identifying potential construction risks

Design parameters to be used for excavation support and to define an appropriate and cost-effective route and location for cut-and-cover tunnels shall be obtained through subsurface investigations such as borings, sampling, in-situ testing, geophysical investigation, and laboratory material testing. Refer to Section 5 for geotechnical considerations for cut-and-cover tunnels and requirements for subsurface investigations.

C6.4.1.1

Ground conditions including geological, geotechnical, and hydrological conditions have a major impact on the planning, design, construction, and cost of a road tunnel.

Surrounding ground acts as a supporting system for cut-and-cover tunnels, ground properties, and groundwater table level and their variations are important parameters to establish for use during the design process.

6.4.1.2—Invert Condition

The embedment of both permanent and temporary supports for excavation shall be analyzed with respect to stability of the base and ground water cut off or dewatering

C6.2.1.2

The Engineer is responsible for investigating the stability of the excavation prior to the construction and backfilling of the permanent structure. Studies should