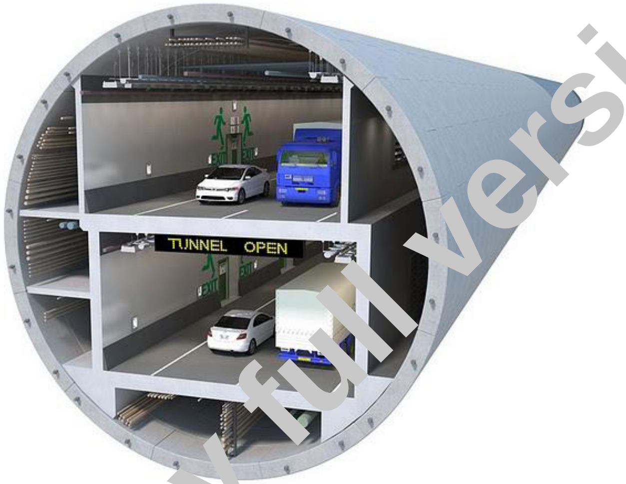
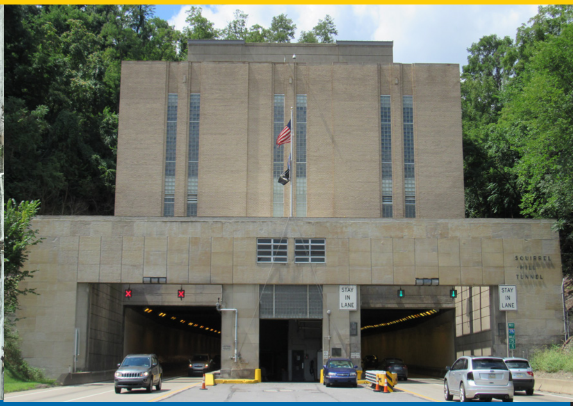


LRFD Road Tunnel Design and Construction Guide Specifications

First Edition, 2017



Publ. Code: LRFDTUN-1
ISBN: 978-1-56051-643-9

American Association
of State Highway and
Transportation Officials
AASHTO

LRFD Road Tunnel Design and Construction Guide Specifications

First Edition, 2017

Publ. Code: LRFDTUN-1
ISBN: 978-1-56051-643-9

American Association
of State Highway and
Transportation Officials
AASHTO

AASHTO

American Association of State Highway and Transportation Officials
444 North Capitol Street, NW, Suite 249
Washington, DC 20001
202-624-5800 phone/202-624-5806 fax
www.transportation.org

Cover photos: 1) top left photo: The Bertha Seattle project. Photo provided by Bijan Khaleghi, Washington State DOT. 2) top right photo: SR 99 Tunnel, courtesy of WSDOT; 3) bottom left photo: East River Mountain tunnel on I-77, Bristol, VA, courtesy of VDOT; 4) bottom middle photo: SR99 Tunnel Construction, courtesy of Prasad Nallapaneni; 5) bottom right photo: the Squirrel Hill Tunnel, Pittsburgh, Pennsylvania, Jonathan McHugh, Gannett Fleming.

ISBN: 978-1-56051-643-9 Pub Code: LRFDTUN-1

AASHTO EXECUTIVE COMMITTEE
2016–2017

Voting Members

OFFICERS:

PRESIDENT: David Bernhardt, Maine*

VICE PRESIDENT: John Schroer, Tennessee*

SECRETARY-TREASURER: Carlos Braceras, Utah

EXECUTIVE DIRECTOR: Bud Wright, Washington, D. C.

REGIONAL REPRESENTATIVES:

REGION I: Leslie Richards, Pennsylvania
Pete Rahn, Maryland

REGION II: Charles Kilpatrick, Virginia
James Bass, Texas

REGION III: Randall S. Blankenhorn, Illinois
Patrick McKenna, Missouri

REGION IV: Carlos Braceras, Utah
Mike Tooley, Montana

IMMEDIATE PAST PRESIDENT: vacant

***Elected at the 2016 Annual Meeting in Boston, Massachusetts**

Nonvoting Members

Executive Director: Bud Wright, Washington, DC

HIGHWAY SUBCOMMITTEE ON BRIDGES AND STRUCTURES, 2016

GREGG FREDRICK, *Chair*
BRUCE V. JOHNSON, *Vice Chair*
JOSEPH L. HARTMANN, Federal Highway Administration, *Secretary*
PATRICIA J. BUSH, *AASHTO Liaison*

ALABAMA, Eric J. Christie, William "Tim" Colquett, Randall B. Mullins
ALASKA, Richard A. Pratt
ARIZONA, David B. Benton, David L. Eberhart, Pe-Shen Yang
ARKANSAS, Charles "Rick" Ellis
CALIFORNIA, Susan Hida, Thomas A. Ostrom, Dolores Valls
COLORADO, Behrooz Far, Stephen Harelson, Jessica Martinez
CONNECTICUT, Timothy D. Fields
DELAWARE, Barry A. Benton, Jason Hastings
DISTRICT OF COLUMBIA, Donald L. Cooney, Konjit C. "Connie" Eskender, Richard Kenney
FLORIDA, Sam Fallaha, Dennis William Potter, Jeff Pouliotte
GEORGIA, Bill DuVall, Steve Gaston
HAWAII, James Fu
IDAHO, Matthew Farrar
ILLINOIS, Tim A. Armbrecht, Carl Puzey
INDIANA, Anne M. Rearick
IOWA, Ahmad Abu-Hawash, Norman L. McDonald
KANSAS, Mark E. Hoppe, John P. Jones
KENTUCKY, Mark Hite, Marvin Wolfe
LOUISIANA, Arthur D'Andrea, Paul Fossier, Zhengzheng "Jenny" Fu
MAINE, Jeffrey S. Folsom, Wayne Frankhauser, Michael Wight
MARYLAND, Earle S. Freedman, Jeffrey L. Robert, Gregory Scott Roby
MASSACHUSETTS, Alexander K. Bardow, Thomas Donald, Joseph Rigney
MICHIGAN, Matthew Jack Chynoweth, David Juntunen
MINNESOTA, Arielle Ehrlich, Kevin Western
MISSISSIPPI, Austin Banks, Justin Walker, Scott Westerfield
MISSOURI, Dennis Heckman, Scott Stotlemeyer
MONTANA, Kent M. Barnes, David F. Johnson
NEBRASKA, Mark Ahlman, Fouad Jaber, Mark J. Traynowicz
NEVADA, Troy Martin, Jessen Mortensen
NEW HAMPSHIRE, David L. Scott, Peter Stamnas
NEW JERSEY, Xiaohua "Hannah" Cheng, Nagnath "Nat" Kasbekar, Eli D. Lambert
NEW MEXICO, Ted L. Barber, Raymond M. Trujillo, Jeff C. Vigil
NEW YORK, Wahid Albert, Richard Marchione
NORTH CAROLINA, Brian Hanks, Scott Hidden, Thomas Koch
NORTH DAKOTA, Terrence R. Udland
OHIO, Alexander B.C. Dettloff, Timothy J. Keller
OKLAHOMA, Steven Jacobi, Walter Peters
OREGON, Bruce V. Johnson, Tanarat Potisuk, Hormoz Seradj
PENNSYLVANIA, James M. Long,Thomas P. Macioce, Lou Ruzzi
PUERTO RICO, (Vacant)
RHODE ISLAND, Georgette Chahine
SOUTH CAROLINA, Barry W. Bowers, Terry B. Koon, Jeff Sizemore
SOUTH DAKOTA, Steve Johnson
TENNESSEE, John S. Hastings, Wayne J. Seger
TEXAS,Bernie Carrasco, Jamie F. Farris, Gregg A. Freeby
U.S. DOT, Joseph L. Hartmann
UTAH, Carmen Swanwick, Cheryl Hersh Simmons, Joshua Sletten
VERMONT, James LaCroix, Wayne B. Symonds
VIRGINIA, Prasad L. Nallapaneni, Kendal R. Walus
WASHINGTON, Tony M. Allen, Thomas E. Baker, Bijan Khaleghi
WEST VIRGINIA, Ahmed Mongi, Billy Varney

WISCONSIN, Scot Becker, William C. Dreher, William Olivia
WYOMING, Paul G. Cortez, Gregg C. Frederick, Michael E. Menghini

GOLDEN GATE BRIDGE, HIGHWAY AND TRANSPORTATION DISTRICT, Kary H. Witt
MDTA, Dan Williams
N.J. TURNPIKE AUTHORITY, Richard J. Raczynski
N.Y. STATE BRIDGE AUTHORITY, Jeffrey Wright
PENN. TURNPIKE COMMISSION, James Stump
U.S. ARMY CORPS OF ENGINEERS—DEPARTMENT OF THE ARMY, Phillip W. Sauser, Christopher H. Westbrook

U.S. COAST GUARD, Kamal Elnahal
U.S. DEPARTMENT OF AGRICULTURE—FOREST SERVICE, John R. Kattell

KOREA, Eui-Joon Lee, Sang-Soon Lee
SASKATCHEWAN, Howard Yea
TRANSPORTATION RESEARCH BOARD, Waseem Dekelbab

This page intentionally left blank.

AASHTO LRFD Road Tunnel Design and Construction Guide Specifications

ABBREVIATED TABLE OF CONTENTS

This page intentionally left blank.

SECTION 1 – INTRODUCTION

TABLE OF CONTENTS

This page intentionally left blank.

1.1—PURPOSE AND SCOPE

The provisions of these Specifications are intended for the design, evaluation, and rehabilitation of highway tunnels. These Specifications are intended for the design of tunnels constructed using cut-and-cover, bored, mined, and immersed tunnel construction methodologies.

Provisions are not included in these Specifications for water conveyance, utility, transit, or rail tunnels or for shafts. For tunnel elements not explicitly covered herein, the provisions of these Specifications may be applied, as augmented by the Engineer with additional design criteria where required.

Construction specifications consistent with these design Specifications are not included. There is a listing of suggested construction specification sections included in Appendix B.

Structures internal to tunnels that support roadways over ventilation plenums, roadways, or other openings in the tunnel shall be designed in accordance with the *AASHTO LRFD Bridge Design Specifications* (hereafter referred to as the *LRFD Specifications*) including all applicable interim changes and as modified or supplemented herein. The load effects of these internal structures shall be applied to the tunnel lining, walls, or other supporting members in accordance with these Specifications.

Retaining walls for retained cut approaches to tunnels shall be designed in accordance with the *LRFD Specifications*.

Support and ancillary structures such as ventilation, control, and administrative buildings are not covered by these Specifications. These structures shall be designed in accordance with local building codes.

These Specifications are not intended to supplant proper training and experience or the exercise of judgment by the Engineer, and provide only the minimum requirements necessary for public safety. The Owner or the Engineer may require the sophistication of design or the quality of materials and construction to be higher than the minimum requirements. The design of tunnels is strongly dependent upon the geologic setting, site conditions, and construction methodology, and this fact is considered in the Specifications. The concept of ground/structure interaction is emphasized for mined and bored tunnels; however, it is also applicable to cut-and-cover and immersed tunnels.

The concept of safety through redundancy and ductility is emphasized for tunnel elements subject to repeated loads and load reversals.

The design provisions of these Specifications employ the Load and Resistance Factor Design (LRFD) methodology. The load factors have been calibrated using structural analysis modeling for a limited number of loading conditions that take into account ground/structure interaction.

C1.1

These Specifications are modeled after the *LRFD Specifications* and the AASHTO *Guide Specifications for LRFD Seismic Bridge Design*. The philosophy and guidance provided in those documents are carried forward and implemented in this document.

Whenever the *LRFD Specifications* are referenced in this document, the reference is to the latest edition including all applicable interim changes.

The term “notional” is often used in these Specifications to indicate an idealization of a physical phenomenon, as in “notional load” or “notional resistance.” Use of this term strengthens the separation of an engineer’s “notion” or perception of the physical world in the context of design from physical reality itself.

The term “shall” denotes a requirement for compliance with these Specifications.

The term “should” indicates a strong preference for a given criterion.

The term “may” indicates a criterion that is usable, but other local and suitably documented, verified, and approved criteria may also be used in a manner consistent with the LRFD approach to tunnel design.

The load factors specified in Section 3 have been calibrated to provide designs with member proportions consistent with the current practice in tunnel design.

The calibration is based upon analyses performed for a circular bored tunnel. Additional calibration for different tunnel cross-sectional geometry and loadings from a variety of ground conditions would be useful in further validating and refining the load factors.

The primary loads on structural components of tunnels are groundwater and earth loads. For immersed tunnels, loads imposed by transporting immersed elements from the fabrication site to the tunnel location can also govern the design of these tunnels. For pre-fabricated linings used in bored tunnels, construction-imposed loading can govern the design. The determination of groundwater, earth, transportation, and other construction loads varies based on the in-situ conditions, level of testing during subsurface investigations, and ground conditions may have great variation. There are little data available to establish a statistically significant sampling in order to calibrate these Specifications based upon structural reliability theory. As such, judgment and past experience were also used to select the load factors.

These Specifications are an initial attempt to codify and standardize highway tunnel design. As such, as future data that are produced in a systematic fashion in accordance with these Specifications become available, recalibration may be implemented based on statistical evaluation of these data.

The commentary is not intended to provide a complete historical background concerning the development of these Specifications, nor is it intended to provide a detailed summary of the studies and research data reviewed in formulating the provisions of the Specifications. However, references to some of the research data are provided for those who wish to study the background material in more depth.

The commentary directs attention to other documents that provide suggestions for carrying out the requirements and intent of these Specifications. However, those documents and this commentary are not intended to be a part of these Specifications.

The Specifications direct the Engineer to utilize other documents in the development of designs. When this occurs, the most current edition of those documents should be utilized. Those documents referenced in the Specifications are intended to be part of these Specifications by reference.

Unless otherwise specified, the Materials Specifications referenced herein are the *AASHTO Standard Specifications for Transportation Materials and Methods of Sampling and Testing*.

1.2—DEFINITIONS

For definitions not shown, see the *LRFD Specifications.*

Bored Tunnel—A tunnel constructed utilizing a tunnel boring machine.

Calibration—The selection of load and resistance factors to achieve a specified goal such as uniform reliability, as is the case with the bridge design specifications, or member proportions consistent with past practice, as is the case with these Specifications.

Collapse—A major change in the geometry of the tunnel lining or other structural component rendering it unfit for use.

Component—Either a discrete element of the tunnel or a combination of elements requiring individual design consideration.

Contract Documents—Drawings, specifications, reports, and memoranda that provide direction and/or guidance for the construction of a tunnel and that form a contractual basis for the work to be performed.

Contractor—Entity responsible for the construction of the tunnel and associated construction engineering.

Cut-and-cover—Sequence of construction in which a trench is excavated and the tunnel or conduit section is constructed and then covered with backfill. (AASHTO, 2010)

Design—Proportioning and detailing the components and connections of a tunnel.

Design Life—Period of time on which the statistical derivation of transient loads is based: 150 years for these Specifications.

Engineer—Agency, design firm, or person responsible for the design of the tunnel and/or review of design related to field submittals.

Evaluation—Determination of the load carrying capacity of one or more components of an existing tunnel.

Extreme Event Limit States—Limit states relating to events such as earthquakes, flooding, vehicle fire, or vehicle and vessel collision, with return periods in excess of the design life of the tunnel.

Force Effect—A deformation, stress, or stress resultant (i.e., axial force, shear force, torsional or flexural moment) caused by applied loads, imposed deformations, temperature changes, or volumetric changes.

Immersed Tunnel—A tunnel constructed from prefabricated elements constructed off the tunnel alignment, floated into place over the tunnel alignment, and placed into a prepared trench. Placement is facilitated by the addition of ballast to the elements to cause them to be immersed to the pre-determined depth and then joined to the adjacent element(s) already in place.

Limit State—A condition beyond which the tunnel or component ceases to satisfy the provisions for which it was designed.

Load Modifier—A factor accounting for ductility, redundancy, and the operational classification of the tunnel.

Mined—Any tunnel construction methodology that involves excavation of the tunnel without opening the excavation to the surface and without the use of a tunnel boring machine, including mechanical excavation, blasting, and hand excavation.

Model—An idealization of a structure or structure–ground system for the purpose of analysis.

Owner—Person or agency having jurisdiction over the tunnel.

Regular Service—Condition excluding the presence of special permit vehicles and extreme events.

Rehabilitation—A process in which the resistance or functionality of a tunnel component or connection is either restored or increased.

Resistance Factor—A statistically or experience-based multiplier applied to nominal resistance accounting primarily for variability of material properties, structural dimensions, and workmanship, an uncertainty in the prediction of resistance, but also related to the statistics of the loads through the calibration process.

Service Life—The period of time that the tunnel is expected to be in operation.

Tunnel—Road tunnels as defined by the American Association of State Highway and Transportation Officials (AASHTO) Technical Committee for Tunnels (T-20) are enclosed roadways with vehicle access that is restricted to portals regardless of type of the structure or method of construction. The committee further defines road tunnels not to include enclosed roadway created by highway bridges, railroad bridges, or other bridges. This definition applies to all types of tunnel structures and tunneling methods such as cut-and-cover tunnels, mined and bored tunnels in rock and soft ground, and immersed tunnels.

Tunnel Boring Machine (TBM)—Machine that excavates a tunnel by drilling out the heading to full size in one operation. Sometimes called a mole, the TBM is typically propelled forward by jacking off the excavation supports emplaced behind it or by gripping the side of the excavation (AASHTO, 2010).

1.3—DESIGN PHILOSOPHY

1.3.1—General

Tunnels shall be designed for specified limit states to achieve the objectives of constructability, safety, and serviceability, with due regard to issues of inspectability, maintenance and economy. Additional information regarding tunnel systems, planning, ancillary facilities, and appurtenances can be found in Section 2. Regardless of the type of analysis used, Equation 1.3.2.1-1 shall be satisfied for all specified force effects and combinations thereof.

C1.3.1

The limit states specified herein are intended to provide for a buildable, serviceable tunnel capable of safely operating for a specified design life. As defined in Article 1.2, the design life relates to the return period of the transient loads of the strength limit states and hence their nominal magnitude. The design life should not be confused with the service life. As defined in Article 1.2, the service life relates to the eventual demonstrated durability of the tunnel. The service life of

The specified 150-year design life is appropriate for the design of tunnel geotechnical features and soil–structure-interaction-systems given the high capital costs of rehabilitation and replacement and the likely importance to the transportation network. Internal structures such as roadway slabs and suspended ceilings as well as system components, such as signs, piping, and their supports; communication and signal devices; and ventilation equipment that are more easily replaced, may have design lives assigned to them by the Owner. The service life of a tunnel is not specified in these Specifications, just as the service life of a bridge is not specified in the *LRFD Specifications*, as the durability of tunnels or bridges is not well quantified.

The resistance of components and connections is determined, in many cases, on the basis of inelastic behavior. In other words, the capacity of tunnel components used to define their nominal resistance at the strength limit states is based upon behavior past first yield of the material. On the other hand, the force effects on the load side of the LRFD equation, Equation 1.3.2.1-1, are determined using elastic analysis but amplified by the specified load factors. This apparent inconsistency is consistent with most modern structural-design codes including the *LRFD Specifications*. The application of this comparison of loads and resistances for design is a result of incomplete knowledge of inelastic structural action combined with the behavior of the earth surrounding the tunnel that acts in concert with the tunnel structure.

1.3.2—Limit States

1.3.2.1—General

Each component and connection shall satisfy Equation 1.3.2.1-1, for each limit state unless otherwise specified. For service and extreme limit states, resistance factors shall be taken as 1.0 except for bolts. For bolts, the provisions of Article 6.5.5 of the *LRFD Specifications* shall apply.

$$\Sigma \eta_i \gamma_i Q_i \leq \phi R_n = R_r \qquad (1.3.2.1\text{-}1)$$

in which:

For loads for which a maximum value of γ_i is appropriate:

$$\eta_i = \eta_D \eta_R \eta_I \geq 1.0 \qquad (1.3.2.1\text{-}2)$$

For loads for which a minimum value of γ_i is appropriate:

$$\eta_i = \frac{1}{\eta_D \eta_R \eta_I} \leq 1.0 \qquad (1.3.2.1\text{-}3)$$

where:

γ_I = load factor: a multiplier applied to force effects

ϕ = resistance factor: a multiplier applied to nominal resistance, as specified herein

η_i = load modifier: a factor relating to ductility, redundancy, and operational classification

C1.3.2.1

Equation 1.3.2.1-1 is the basis of the LRFD methodology.

Ductility, redundancy, and operational classification are considered in the load modifier η. Whereas the ductility and redundancy directly relate to physical strength, operational classification concerns the consequences of the tunnel being out of service. The grouping of these aspects of the load side of Equation 1.3.2.1-1 is therefore, arbitrary. However, it constitutes a first effort at codification. In the absence of more precise information, each effect is estimated as ±5 percent, accumulated geometrically, a clearly subjective approach.

Groundwater is an example of a loading that would be appropriate to apply as a maximum and a minimum. Variation in groundwater elevations are common due to seasonal changes and tidal influences. Tunnel linings are designed as compression members; therefore, maximum groundwater pressures would produce maximum axial loads and vice versa. As such, both maximum and minimum groundwater loads should be checked.