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NCHRP PRACTICE-READY SOLUTIONS FOR

Roadway Tunnels

NCHRP NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

RESEARCH TOPIC HIGHLIGHTS

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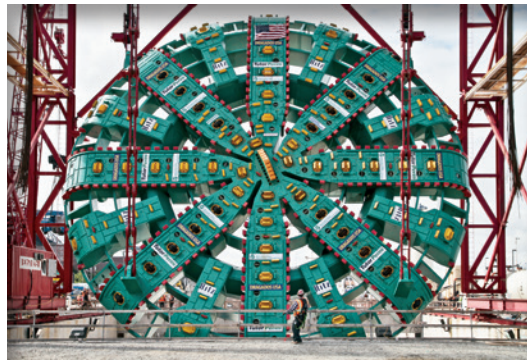
Roadway Tunnels: NCHRP Shines a Light on Underground Assets



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Roadway Tunnels: NCHRP Shines a Light on Underground Assets

Roadway tunnels are complex structures whose design, construction, operation, and maintenance are enhanced by the same kinds of research commonly applied to other transportation assets. However, due to their relative scarcity and limited geographical distribution, tunnels have not always received the same level of attention in research nationally.

In the early 2000s, the Transportation Research Board's (TRB's) National Cooperative Highway Research Program (NCHRP) ramped up its roadway tunnel research in response to two events.

The first of these was the 2001 terrorist attacks on the United States, which brought into stark light the vulnerability of domestic transportation assets. Significant research since then has helped frame both the problem and the mitigation approaches related to security and safety, and tunnel research continues to evolve.

The second of these was a scan of international best practices that the Federal Highway Administration (FHWA) conducted in 2006 with support from NCHRP. This close-up examination of advanced tunnel technology in Europe was eye-opening for state and national agencies in the United States, and it spurred new research in tunnel design, fire safety, and other areas.

The research projects described in this publication show the maturation of knowledge and practice for tunnels between 2001 and 2017. These projects also highlight the ongoing cooperation among state and national entities in the United States to coordinate the research and keep it on track.

Source: Virginia DOT

WHY RESEARCH ROADWAY TUNNELS?

Research has advanced different aspects of roadway tunnels thanks to NCHRP and national partners. Since 2001, NCHRP has administered research that:

- Investigated best practices for **tunnel rehabilitation and preservation**, including tunnel inspection, quality assurance and quality control (QA/QC), common structural problems and rehabilitation techniques, and evidence-based decision making for asset management.
- Developed **design guidance for tunnels** for the American Association of State Highway and Transportation Officials (AASHTO) to complement Load and Resistance Factor Design (LRFD) for other structures.
- Advanced the state of knowledge for **tunnel safety and security**, providing strategies to assess, prevent, and respond to hazards of all kinds.
- Worked in tandem with **national partners to accelerate best practices**, including national and international scanning tours that helped bring such practices to the fore.

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NCHRP does a good job of working with AASHTO's Committee on Bridges and Structures, both to learn what the states see as critical tunnel research needs and to keep us informed about results coming from NCHRP tunnel research."

–Louis Ruzzi, Pennsylvania Department of Transportation
Chair, AASHTO Committee on Bridges and Structures (SCOBS)
Technical Committee T-20, Tunnels

Source: Washington State DOT (CC BY-NC-ND 2.0)

Cutterhead of the tunnel boring machine for Washington State DOT's Alaskan Way Viaduct replacement project in Seattle

SECTION 1

Tunnel Inspection, Rehabilitation, and Preservation

NCHRP Project 20-07/Task 261, Best Practices for Implementing Quality Control and Quality Assurance for Tunnel Inspection. See report to AASHTO on the NCHRP project page.

NCHRP Project 20-07/Task 276, Development of Guidelines for Rehabilitation of Existing Highway and Rail Transit Tunnels. See report to AASHTO on the NCHRP project page.

NCHRP Project 14-27, A Guide for the Preservation of Highway Tunnel Systems. See *NCHRP Report 816*.

As with any highway asset, agencies are charged with maintaining tunnels for a safe and lengthy service life. Over the past decade, NCHRP research has provided guidance in the areas of inspection, rehabilitation, and preservation.

Inspection. FHWA first published its *Highway and Rail Transit Tunnel Inspection Manual* in 2003 to provide tunnel inspection guidelines that address frequency, inspector qualifications, procedures, and documentation. NCHRP Project 20-07/Task 261 built on this work, documenting current practices for tunnel inspection and evaluation of operational safety and emergency response systems.

The research report presented recommendations for DOTs, with detailed guidance on QA/QC that incorporates inspection guidelines and checklists, condition ratings, and equipment calibration.

Rehabilitation. Beyond the need for inspection, older tunnels require higher levels of maintenance and rehabilitation. Although states and contractors have employed various techniques to rehabilitate aging tunnels and improve such features as clearances, ventilation, and drainage, limited national guidance existed in this area.

Through NCHRP Project 20-07/Task 276, researchers sought to develop guidelines for rehabilitating existing highways as well as rail transit tunnels. The research focused on structural aspects of tunnel rehabilitation as well as drainage, leakage, and safety. Researchers identified several of the geologic and structural problems that typically occur and presented a wide range of successful practices used by tunnel owners worldwide to remedy these problems.

Preservation. All tunnel rehabilitation efforts must follow sound principles of asset management and preservation. *NCHRP Report 816* addresses the preservation of highway tunnel systems to assist tunnel owners in making informed decisions about using asset management processes to prioritize highway tunnel preservation actions. Moreover, this guide provides executives with credible, evidence-based information on capital funding needs for tunnel improvements as part of their overall transportation system funding, as well as a means for communicating those needs.

The guide's measure for calculating effectiveness and prioritizing needs was based on a risk-based urgency score, along with capital funding and staffing requirements for accomplishing preservation goals. The guide also serves as a training tool for new personnel.

Source: Kentucky Transportation Cabinet

Rehabilitation of Kentucky's Cumberland Gap Tunnel

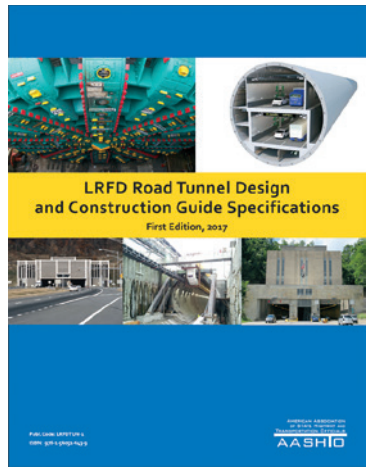
SECTION 2

Tunnel Design

NCHRP Project 12-89, Recommended AASHTO LRFD Tunnel Design and Construction Specifications. See report to AASHTO on the NCHRP project page and AASHTO's *LRFD Road Tunnel Design and Construction Guide Specifications, 1st Edition*.

States have long benefited from AASHTO guidance on design and construction of nearly every kind of transportation asset and process, yet the development of modern national design guidance for highway tunnels has lagged behind guidance for other structures. The tunnel research efforts described earlier culminated in the AASHTO-led NCHRP project to develop LRFD design guidance for tunnels.

Until recently, LRFD tunnel design appeared only within the *AASHTO LRFD Bridge Design Specifications* and only in a limited fashion (Chapter 12, Buried Structures and Tunnel Liners). Under the guidance of AASHTO's SCOBS Technical Committee T-20, NCHRP administered research to develop detailed LRFD design guidance specifically for tunnels. NCHRP Project 12-89 gave consideration to safety, operations, maintenance, and inspection of tunnel systems in its methodology to develop recommended LRFD-based design specifications.



Source: AASHTO

AASHTO's new design guidance for roadway tunnels complements LRFD specifications for other structures.

In writing these specifications, researchers also reviewed existing design codes and standards, project-specific design criteria, reports, and technical publications, and performed calibration of the load factors based on the analysis of a circular bored tunnel.

After review and balloting, AASHTO published its *LRFD Road Tunnel Design and Construction Guide Specifications, 1st Edition* in 2017. The specifications detail guidance for states with highway tunnels, including loads, materials, geotechnical considerations, various tunnel structures, ground support elements, and seismic considerations.

SECTION 3

Tunnel Security and Safety

NCHRP Project 20-59(03), Support for the FHWA/AASHTO Blue Ribbon Panel on Bridge and Tunnel Security. See FHWA report, *Recommendations for Bridge and Tunnel Security*.

NCHRP Project 20-59(02), Bridge/Tunnel/Highway Infrastructure Vulnerability Workshops. See *NCHRP Report 525, Volume 4*.

TCRP Project J-10G/NCHRP Project 20-67, Making Transportation Tunnels Safe and Secure. See combined *NCHRP Report 525* and *TCRP Report 86, Volume 12*.

NCHRP Project 20-05/Topic 41-05, Design Fires in Road Tunnels. See *NCHRP Synthesis 415*.

NCHRP Project 20-07/Task 363, Recommended AASHTO Guidelines for Emergency Ventilation Smoke Control in Roadway Tunnels. See *NCHRP Research Report 836*.

NCHRP Project 20-59(47), Emergency Exit Signs and Marking Systems for Highway Tunnels. See *NCHRP Web-Only Document 216*.

Emergencies of all kinds can create unique vulnerabilities for travelers in tunnels. NCHRP has administered research to enhance tunnel security and safety through incident prevention, preparedness, mitigation, response, and recovery.

Countering Vulnerability and Threats. In the years immediately after 2001, FHWA and AASHTO jointly sponsored work to compile national expertise in bridge and tunnel security. Through NCHRP Project 20-59(03), AASHTO supported a blue ribbon panel of experts from professional practice, academia, federal and state agencies, and toll authorities.

These individuals convened to examine bridge and tunnel security and to develop strategies and practices for deterring, disrupting, and mitigating potential attacks. Published as FHWA's *Recommendations for Bridge and Tunnel Security*, this publication spelled out actionable guidance in the form of institutional, fiscal, and technical steps agencies can take to safeguard critical tunnel infrastructure.

A related effort was *NCHRP Report 525, Volume 4*, which aimed to assist structures engineers and managers in identifying critical highway assets and their potential vulnerabilities, developing possible countermeasures to prevent or ameliorate threats to these assets, and determining the capital and operating costs of the countermeasures.

NCHRP's flagship work in tunnel security was *Making Transportation Tunnels Safe and Secure* (published jointly as Volume 12 of *NCHRP Report 525* and *Transit Cooperative Research Program (TCRP) Report 86* in 2006). This report provided comprehensive safety and security guidelines for owners and operators of transportation tunnels. The guidance in this publication can be used to identify principal vulnerabilities of tunnels to various hazards and threats; identify physical and operational countermeasures; and deploy integrated systems for emergency-related command, control, communications, and information.

The Port of Miami tunnel employs several advanced signage strategies for emergency exits.

Work in this important area continues to evolve. In the years since these reports were published, NCHRP's approach to tunnel security has matured into a broader all-hazards emergency management framework that focuses on criticality rather than vulnerability.

Fire Control and Emergency Management. NCHRP has also administered extensive targeted research specifically on designing for fire safety and traffic emergencies.

NCHRP Synthesis 415 provided a state-of-the-practice look at design fires in roadway tunnels, focusing on tunnel fire dynamics and design guidance for fire management. More recently, *NCHRP Research Report 836* examined emergency ventilation smoke control for roadway tunnels. Drawing from advances in Europe, the research presented practical guidance for determining the effects of ventilation on tunnel fires, including fire size and the interaction of firefighting and ventilation system operation.

NCHRP Web-Only Document 216 presented targeted guidance on emergency exit signs and marking systems for highway tunnels. The research methodology involved evaluating how well test subjects could see different kinds of signs and markings through simulated smoke. Using green signage—more visible than red in some conditions—and the "running man" icon are a few of the practical recommendations that are making tunnels safer in case of fires.

Travelers isolated in tunnels represent a unique security challenge.

Source: Virginia DOT

SECTION 4

Coordinating National Research and Accelerating Best Practices

NCHRP Project 20-36, Highway Research and Technology—International Information Sharing. See *NCHRP Report 381*.

NCHRP Project 20-68A, U.S. Domestic Scan Project. See *Scan 09-05: Best Practices for Roadway Tunnel Design, Construction, Maintenance, Inspection, and Operations.*

No single entity has all the answers for road tunnels. Advancing the state of practice is a responsibility shared across agencies and jurisdictions, and the work detailed in this publication would not be possible without deliberate coordination among NCHRP, state DOTs (individually and through AASHTO), the federal government, and international agencies.

International Scanning Efforts. Many of the tunnel advances in the United States are owed to technologies and practices overseas. These methods were brought to light through an international scan tour conducted in 2006, a cooperative effort among FHWA, AASHTO, and NCHRP (NCHRP Project 20-36). Participants toured tunnels in eight European countries and had the opportunity to ask designers and managers about planning and design, safety, incident management, maintenance, and project delivery. Some of the major tunnel research efforts in the United States are a direct result of this scan tour, from improved escape route signage to the development of AASHTO design guidance.

A decade later, under the banner of its Global Benchmarking Program, FHWA again conducted a scan of international best practices, this time to learn advanced tunnel practices in Australia and New Zealand. Two state DOT members of AASHTO were able to participate through NCHRP support. The report is slated for publication soon and will highlight successes in Oceania with fixed firefighting systems and other advanced safety techniques.

U.S. Domestic Scan Program. NCHRP's own U.S. Domestic Scan Program, NCHRP Project 20-68A, allowed for information exchange and hands-on learning about best tunnel practices within the United States. A team of representatives from five DOTs, FHWA, and academia learned about the latest techniques used across the country; the scan helped position these agencies to implement the practices in their home states.

Ongoing Coordination. The individuals dedicated to advancing tunnel technology continue to be involved in projects across organizations. For example, AASHTO SCOBS members and FHWA staff commonly sit on NCHRP panels and help oversee NCHRP research through a project's life cycle. In addition, SCOBS as a committee helps direct high-priority research that is funded by the states and administered by NCHRP. Interrelationships like these help make sure that tunnel research is not conducted in a vacuum and that the best ideas from anywhere inform best practices everywhere.

Laser light projected onto a water curtain provides an innovative way to stop tunnel traffic in an emergency while allowing emergency vehicles to pass through the barrier.

Source: LASERVISION

The U.S. Domestic Scan team for tunnel best practices included representatives from state DOTs, FHWA, and academia.

Source: NCHRP U.S. Domestic Scan Program

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