



NCHRP Project 20-68A
Scan 09-05

Best Practices For Roadway Tunnel Design, Construction, Maintenance, Inspection, And Operations

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Executive Summary

Introduction

Most highway facility components in the United States are governed by design, construction, maintenance, inspection, and operations codes and regulations of the American Association of State Highway and Transportation Officials (AASHTO) and the U.S. Federal Highway Administration (FHWA). However, to date, highway tunnels in the U.S. do not have comparable national codes and regulations. Recent events, such as the July 2006 ceiling collapse of the I-90 Central Artery/Tunnel (CA/T) in Boston, Massachusetts, have called attention to the need for such national standards.

After investigating the CA/T ceiling collapse, the National Transportation Safety Board (NTSB) recommended that the FHWA seek legislation to establish a mandatory tunnel inspection program that would identify critical inspection elements and specify an appropriate inspection frequency. The FHWA requested clearance from the Office of the Secretary of Transportation to proceed with regulatory action to develop National Tunnel Inspection Standards similar to the National Bridge Inspection Standards (NBIS) contained in the Code of Federal Regulations, 23 CFR 650, Subpart C.

An Advance Notice of Proposed Rulemaking was published in the Federal Register in November 2008. In July 2010, a Notice of Proposed Rulemaking that addressed comments received on the ANPRM was published in the Federal Register. As of the writing of this report, FHWA is preparing a Final Rule to address comments received on the NPRM.

Scan Purpose and Scope

Domestic Scan 09 05, *Best Practices for Roadway Tunnel Design, Construction, Maintenance, Inspection, and Operations*, conducted during August and September 2009, is one of the activities initiated to assist in addressing the need for national tunnel standards and a national tunnel inventory. The nine member team consisted of two representatives from FHWA, five representatives from state Departments of Transportation (DOTs), an academic member representing the Transportation Research Board (TRB) Tunnels and Underground Structures Committee (AFF60), and the report facilitator.

The team selected scan hosts that have significant tunnels in their inventories and use innovative approaches; agencies with ongoing or upcoming tunnel construction projects were also of interest. Hosts along the East Coast were the Chesapeake Bay Bridge and Tunnel (CBBT) District, the Massachusetts Turnpike Authority¹, the Port Authority of New York and New Jersey, and the Virginia DOT. Hosts in the western U.S. were the California DOT (Caltrans), the Colorado DOT,

¹ The Massachusetts Turnpike Authority became part of the Massachusetts DOT (MassDOT) effective November 1, 2009.

the Washington State DOT, the City of Seattle (DOT and Fire Department), and the Seattle Sound Transit System. In addition to site visits with scan hosts, the team held Web conferences with representatives from the Alaska DOT, the District of Columbia DOT, and the Pennsylvania DOT.

The scan team investigated tunnels that are part of the state, regional, and local highway systems. While the scan's scope was roadway tunnels, the team also visited the Seattle Transit System.

The scan's focus was inventory criteria used by highway tunnel owners; highway tunnel design and construction standards practiced by state DOTs and other tunnel owners; maintenance and inspection practices; operations, including safety, as related to emergency response capability; and specialized tunnel technologies. The scan also included consideration of fire suppression; traffic management; incident detection and management; and analysis, design, and construction repairs of existing tunnels.

General topics of interest to the scan team were:

- Current criteria owners and states use to identify tunnels in their inventory
- Standards, guidance, and best practices for existing and new roadway tunnels in the U.S.
- Specialized technologies currently used for existing and new U.S. roadway tunnel design, construction, maintenance, inspection, and operations

Summary of Findings and Recommendations

The scan team identified a number of highway tunnel initiatives and practices of interest for nationwide implementation or for further evaluation for potential nationwide implementation, as listed below.

1. Develop standards, guidance, and best practices for roadway tunnels.

Design criteria for new roadway tunnels should consider:

- Performance-based construction specifications
- Design recommendations for extreme events (manmade and natural [e.g., seismic and storm events]) and tunnel security (e.g., blast resistance and lifeline requirements²)
- Design criteria for vertical clearance, horizontal clearance, and sight distance
- Criteria for tunnel design life and future maintenance for structural, mechanical, electrical, and electronic systems
- Criteria for new tunnel load rating

² Lifeline requirements, which can vary among agencies, recognize the need for certain routes and key facilities, such as bridges and tunnels, to be operational immediately or shortly after a major incident or event, such as an earthquake.

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- Seismic design criteria for one-level versus two-level design events
 - Americans with Disabilities Act (ADA) requirements for emergency egress³
 - Placement and layout of the tunnel operations center
 - Fire and life-safety systems in tunnels

Rehabilitation of existing tunnels should consider obsolescence, tunnel design life, high performance materials, and existing geometry to maximize safety, system operation, and capacity.

Tunnel systems are generally complex and expensive in terms of capital costs. It is critical that any emergency response plan includes the basis of design for how the structure and systems were designed to operate; without this information, the response plan may be incorrect. The use of peer review teams and technical advisory panels with subject matter expertise should be considered in developing site specific criteria. Risk management of complex systems is important, as is system redundancy. The Supervisory Control and Data Acquisition (SCADA) system can be programmed to monitor and control redundant systems and structures

Contract guidelines for roadway tunnels need to be developed to accommodate the various procurement methods (e.g., design bid build, design-build, and design-build operate finance), considering to the extent applicable the Underground Construction Association's *Recommended Contract Practices for Underground Construction*.

Design and construction standards and guidelines need to be developed for tunnel construction methods, such as the use of tunnel boring machines (TBMs) versus conventional tunneling, design criteria that include seismic design, and lifeline requirements.

Conventional tunneling methods include the Sequential Excavation Method (SEM) or New Austrian Tunneling Method (NATM), the analysis of controlled deformations (ADECO) method, and the cut-and-cover method.

Some of the above topics will be addressed in a National Cooperative Highway Research Program (NCHRP) project that began in 2010 and is sponsored by the AASHTO Subcommittee on Bridges and Structures to develop Load and Resistance Factor Design (LRFD) specifications and guidance for new and existing tunnels.

2. Develop an emergency response system plan unique to each facility which takes into account human behavior, facility ventilation, and fire mitigation.

A fire ventilation study should be performed and a fire ventilation plan developed and adopted for each facility. To adequately address emergencies, a tunnel's design should take into account the realistic spread of fire, smoke, toxic gases, and heat in the tunnel and the effect of different

³ The ADA does not currently apply to tunnels.

types of ventilation systems on the fire, including fire suppression, if the tunnel is so equipped. Fire mitigation should include spill control.

In general, the scan team found that facilities should improve their procedures to direct the public to safety. The fire plan should be consistent with the motorists' various responses to a fire, and the operation of all tunnel fire response systems should be consistent with this behavior. Enhancements to direct the public to safety (e.g., better signage and intelligible public address systems) should be considered, including the recommendations for these that were made in the 2005 international tunnels scan⁴.

Further research is needed to understand how fire and smoke spread in a tunnel and how people react in emergencies. The scan team recommends that the research topics related to fire that were developed during the AASHTO workshop on tunnel safety and security research needs (November 2007, Irvine, California) should be considered.

3. Develop and share inspection practices among tunnel owners

The scan team found that the best tunnel inspection programs have been developed from bridge inspection programs. In many cases, bridge inspectors also perform the structural inspection of tunnels. Therefore, the team recommends that tunnel inspection programs be as similar as possible to bridge inspection programs.

Those components of the tunnel that carry or affect traffic (e.g., roadway slabs and floor systems that carry traffic) should be load rated in accordance with the AASHTO *Manual for Bridge Evaluation* to the extent possible. In the analyses, different operational conditions should be considered. Structural analyses should be performed on non-traffic-carrying components (e.g., plenums, plenum walls, and hangers) as their physical conditions change, as they are modified, and as the loads that they are to be subjected to change (e.g., air forces if fans are upgraded).

Recommended practices for inspection frequencies, minimum code requirements, and a federal coding manual need to be developed. Current practice is a frequency of one to five years for structural inspections and daily to yearly frequencies for mechanical and electrical (M&E) inspections, depending on the level of inspection. Maximum frequencies should be set, and owners should be encouraged to develop actual frequencies based on manufacturer requirements and a risk-based analysis of hazards due to condition, deterioration, and performance history. If the inspection frequency is less than accepted best practices and standards, the owner will take on liability. Inspection frequency should be based at least partially upon the level of risk.

⁴ Underground Transportation Systems in Europe: Safety, Operations, and Emergency Response, U.S. DOT FHWA in cooperation with AASHTO and NCHRP, 2005, http://international.fhwa.dot.gov/links/pub_details.cfm?id=494

A baseline data inventory for tunnels needs to be developed for submission to the FHWA in conjunction with NCHRP 20-07/Task 261 (Best Practices for Implementing Quality Control and Quality Assurance for Tunnel Inspection), Task 4.

Inspection practices need to be shared among tunnel owners in five areas:

1. The scan team identified a best practice for the inspection of submerged tunnels using multi-beam sonar scans.
2. Tunnel inspection training that takes into consideration all aspects of the tunnel structure and systems needs to be developed.
3. Tools to find voids behind tunnel linings need to be developed..
4. Coordinated overnight tunnel closing should be done so that as much maintenance and inspection as is possible can be done.
5. Best inspection practices should be shared

4. Consider inspection and maintenance operations during the design stage.

The scan team found that inviting all disciplines to provide their input during the design phase results in a better product. The design of a tunnel should address future inspection and maintenance of all tunnel systems and equipment by providing for adequate, safe, and unimpeded access to all components. This can be accomplished by bringing together all engineering disciplines that will be accommodated in the tunnel. While the scan team understands that tradeoffs must be made between access and a practical design, these tradeoffs could have cost and safety implications for maintenance and inspection over the life of the tunnel.

5. Develop site specific plans for the safe and efficient operation of roadway tunnels

A concise site specific tunnel operations manual needs to be developed. It should include the design assumptions for fires and other hazards, ventilation procedures, traffic control guidelines, and general maintenance procedures (e.g., washing guidelines and fan and bearing maintenance). The manual should also include training guidelines and training schedules for all personnel and should reference the incident response manual for incident response procedures and training.

Tunnel owners should implement state-of-the-art video surveillance and communication systems, which provide numerous benefits (e.g., incident response, traffic management, and increased security). The scan team found a best practice of lane closure or changing traffic direction (e.g., pneumatically activated lane delineators and zipper barriers that provide for reversible lanes and barriers through tunnels and tunnel approaches). The owners should have an operating procedure that considers safety both for the public and for the owners' personnel.

An incident response manual, separate from the operations manual, should be developed to outline procedures that will require various community, police, fire, and emergency services response in the event of incidents that disrupt traffic and/or increase risks. Periodic drills, including tabletop exercises with appropriate agencies, should be performed.

The scan team findings support restricted transportation of hazardous cargo through tunnels. In the event that no alternate route is available, well-defined emergency response and fire ventilation plans should be in place. Restricting the hours during which hazardous cargo can be transported through tunnels is an option (e.g., from 3 a.m. to 5 a.m. under controlled conditions). The scan also found several preventive operational strategies for hazardous materials; these are covered in Chapter 3.0.

6. A tunnel includes a long term commitment to provide funding for preventive maintenance, system upgrades/replacements, and operator training and retention

The decision to build a tunnel is a long term commitment on the part of the owner. Tunnels that include functional systems, such as ventilation, fire suppression, and electrical and mechanical components, are complex structures with more intensive needs for maintenance and operation than traditional transportation facilities. A proactive operational financial plan that considers life-cycle costs must be developed to address the need for preventive maintenance, system upgrades/replacements, and operator training and retention. The AASHTO SCOBS should establish a target level of condition, system reliability, and performance for the facility to guide operators and owners on current and future decisions that will require manpower or funding.

As equipment ages, system components will become obsolete and replacement parts will be difficult to find. In particular, electronic equipment, such as computers, SCADA systems, and sensors, becomes obsolete or is no longer supported by its original manufacturer sooner than mechanical equipment does. Periodic upgrades are vital to keep all systems functioning reliably. For these reasons, funding should not only include buying replacement parts when the tunnel is built, but should also include buying replacement parts that may not be available over time due to obsolescence or other reasons.

Owner agencies should develop tunnel preservation guidelines for funding purposes (e.g., for concrete repair and washing of walls).

A separate fund should be dedicated to tunnels, and agencies should work with local funding, planning, and maintenance organizations to accomplish this task. The financial management plan for tunnels should not only include initial costs for construction, but should also address future preservation and upgrading needs. The scan team found that without this dedicated fund, tunnel upgrades do not compete well with system wide needs, such as traffic signals and pavement preservation.

Training, retention, and a succession plan should be developed for tunnel operators. The scan team found best practices that fostered pride of ownership, a “home away from home” culture and “can do anything” attitude..

7. Share existing technical knowledge within the industry to design a tunnel

Technical knowledge that exists within the industry should be shared with tunnel owners to provide them with a range of practical tunnel design options. This knowledge base would include domestic and international tunnel scan information, past project designs, construction practices, emergency response best practices, and subject matter experts. Value engineering can improve technology transfer with limited owner experience in tunnel systems (e.g., Value Engineering/Accelerated Construction Technology Transfer).

Design documents, including calculations and as-built documents, should be filed electronically, be easily retrievable by the controlling owner, and be appropriately backed up (e.g., on microfilm).

Recognizing the security concerns of tunnel owners, the scan team believes that actual details and best practices used in tunnels should be shared with prospective and existing tunnel owners without identifying the specific facilities where these details and practices are used.

8 Provide education and training in tunnel design and construction.

The scan team findings support training and development for owner agencies. Currently, few civil engineering programs in the U.S. offer a graduate course in tunneling, and it is likely that most civil engineers are not exposed to tunneling. Many DOTs do not have tunnels in their transportation systems; others built their last tunnel 20 to 30 years ago and, therefore, the in-house expertise is either nonexistent or out of date. Information gathered through host presentations, the desk scan, and discussions indicates that the number, magnitude, and complexity of tunneling projects will increase in the next few years. However, the current offering of short courses allows engineers to acquire only tunnel project nomenclature, not the required working knowledge.

Highway tunnel owners and the FHWA should provide their engineers with access to education and training on tunnels that is available through academia and industry. This involvement would also help direct academic research on tunneling. Reputable international online courses and certificates on tunneling would allow engineers to acquire up-to-date information and working knowledge in tunnel design and construction.

Planned Implementation Actions

The implementation of the scan team’s top eight recommendations will be a step in the process of developing national standards and guidance. Scan findings will also provide data for consideration in the development of a national tunnel inventory. These activities will assist the AASHTO Highway Subcommittee on Bridges and Structures (SCOBS) Technical Committee for Tunnels

(T-20) and the FHWA in developing best practices for roadway tunnel design, construction, maintenance, inspection, and operation for existing and new tunnels.

The scan team anticipates that the lead group for implementation of the scan's recommendations will be the AASHTO SCOBS T-20 in conjunction with the FHWA and the TRB AFF60, working with the National Fire Protection Association (NFPA) and other tunnel organizations. The scan team initially presented its findings and recommendations to the AASHTO SCOBS T-20 during the January 2010 TRB Annual Meeting. Scan team efforts also include distribution of the FHWA Tunnel Safety brochure that was developed following the 2005 international tunnels scan and provision of additional information on the FHWA tunnels Web site. Other activities include coordination and development of research statements related to tunnel needs. To disseminate information from the scan, the team is giving technical presentations at national meetings and conferences sponsored by the FHWA, AASHTO, and other organizations; is hosting webinars; and is planning to write papers for various publications.

The full implementation plan with detailed implementation strategies can be obtained through the AASHTO SCOBS T-20.