Tunnel Operations, Maintenance, Inspection, and Evaluation Manual: Inspection

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This course was adapted from the Federal Highway Administration (FHWA) agency of the Department of Transportation, document "Tunnel Operations, Maintenance, Inspection, and Evaluation (TOMIE) Manual – Chapter 4: Inspection", which is in the public domain.

TOMIE MANUAL

CHAPTER 4

INSPECTION

Chapter 4 - Inspection

4 Inspection

The Federal Highway Administration (FHWA) developed the National Tunnel Inspection Standards (NTIS), the Tunnel Operations Maintenance Inspection and Evaluation (TOMIE) Manual, and the Specifications for National Tunnel Inventory (SNTI) to help safeguard tunnels and to ensure reliable levels of service on all public roads. The NTIS contains the regulatory requirements of the National Tunnel Inspection Program (NTIP); the TOMIE Manual and the SNTI have been incorporated by reference into the NTIS to expand upon the requirements. The TOMIE Manual is a resource for aiding the development of tunnel operations, maintenance, inspection, and evaluation programs; it provides uniform and consistent guidance. The SNTI contains instructions for submitting the inventory and inspection data to the FHWA, which will be maintained in the National Tunnel Inventory (NTI) database to track the conditions of tunnels throughout the United States. The general requirements of the program can be summarized as:

- Performing regularly scheduled tunnel inspections.
- Maintaining tunnel records and inventories.
- Submitting tunnel inventory and inspection data to FHWA.
- Reporting critical findings and responding to safety and/or structural concerns.
- Maintaining current load ratings on all applicable tunnel structures.
- Developing and maintaining a quality control and quality assurance program.
- Establishing responsibilities for the tunnel inspection organization and qualifications for tunnel inspection personnel.
- Training and national certification of tunnel inspectors.

The NTIS can be obtained from the Federal Registrar using the link below:

https://www.federalregister.gov

4.1 Tunnel Operations Maintenance Inspection and Evaluation Manual

This manual is a resource for developing comprehensive operations, maintenance, inspection, and evaluation programs for highway tunnels. This chapter focuses on the inspection of highway tunnels, but all of the other chapters in this manual are also relevant as follows:

Chapter 1 contains background information regarding the development of the NTIS. This chapter also reviews the fundamentals of highway tunnels including tunnel construction methods and shapes, liner types and finishes, slabs and wearing surfaces, and tunnel systems such as drainage, ventilation, lighting, power, and communication.

Chapter 2 discusses the operation of highway tunnels such as general staff organization, responsibilities, and duties; normal operating procedures; and response to emergency conditions.

Chapter 3 presents information on maintenance of highway tunnels such as causes of deterioration, maintenance strategies, repair techniques, and guidelines for maintenance of structural, civil, and functional systems.

Chapter 4 focuses on developing safety inspections for highway tunnels. Some of the essential requirements of the NTIS are summarized to include the responsibilities of the tunnel inspection organization, qualifications of inspection personnel, inspection procedures and practices, and the different types of tunnel inspections. This chapter also explores health and safety issues for inspectors, inspection equipment, typical tunnel defects, owner defined elements, critical findings, and condition ratings. This chapter concludes with a glossary of selected terms and a list of references.

Chapter 5 discusses the evaluation of tunnel inspection findings; and it presents techniques for obtaining additional information to perform an evaluation, strategies for evaluating defects, and methods of load rating tunnels.

4.2 Specifications for National Tunnel Inventory (SNTI)

The SNTI contains the requirements for coding and reporting inventory and inspection data to be submitted to the FHWA as part of the National Tunnel Inventory (NTI). This data will allow tunnel owners, the FHWA, and the general public to attain information on the condition of highway tunnels in the United States.

The inventory data contains items that are used for tunnel identification such as age, service classification, geometric data, load rating and posting, navigational clearances, and structural type. This data can be obtained from existing records and field verified as needed. The data must be collected and submitted in accordance with the NTIS.

The SNTI includes instructions for recording the condition states of tunnel structural, civil, and functional systems. Structural elements include liners, roof girders, columns, piles, cross passageways, interior walls, portals, ceiling slabs, ceiling girders, hangers and anchorages, ceiling panels, invert slabs, slabs on grade, invert girders, joints and gaskets. Civil elements include wearing surfaces, traffic barriers, and pedestrian railings. Functional systems include the mechanical, electrical, lighting, fire and life safety systems, security equipment, signs, and protective finishes.

4.3 Tunnel Inspection Organization

In accordance with the NTIS, all State, Federal Land, and Tribal governments with one or more tunnels in their jurisdiction are required to establish a tunnel inspection organization. A suitably qualified program manager should take charge of the tunnel inspection program for the responsible jurisdiction and ensure that the requirements of the NTIS are fulfilled.

4.3.1 **Responsibilities**

The tunnel inspection organization is responsible for developing and maintaining inspection policies and procedures within their jurisdiction. Tunnel specific inspections, functional system tests, and critical system checks should be included in these procedures. Critical findings should be reported and corrected in a timely manner. Some of the responsibilities of the tunnel inspection organization include:

- Establishing written policies and procedures.
- Maintaining tunnel inventory and inspection data.
- Regularly reporting NTI data to the FHWA.
- Maintaining qualification records of personnel including national inspector certification.
- Establishing an effective quality control and quality assurance program.

The tunnel inspection organization collects and maintains tunnel inventory and inspection data, addresses critical findings, and maintains a registry of nationally certified tunnel inspectors within their jurisdiction. Reports and electronic files should be generated to document the actions taken in response to the inspection findings. Health and safety procedures are needed to protect the inspection team, tunnel facility personnel, and the users of the tunnel facility.

Quality control and quality assurance programs are used to promote accuracy, ensure consistency, facilitate improvement, and help maintain a high level of reliability. Periodic field reviews of inspection team and their work, quality checks on data, and independent reviews of the inspection results should also be part of the program. The use of checklists is recommended practice. Quality control refers to observations, monitoring, and performance testing to maintain the quality of the tunnel inspections and load ratings; these practices are usually performed continuously by the teams performing the work. Quality assurance is associated with a systematic approach to improve the overall program effectiveness, verify the accuracy of the quality control procedures, and ensure that established standards are met; these procedures are performed independent of the inspection and load rating teams performing the work.

Qualified individuals are needed to carry out the tunnel inspections. The program manager is responsible for the overall inspection program and leads the tunnel inspection organization. Team leaders supervise other subordinate inspection team members, oversee the inspection in the field, and report to the program manager. Team leaders are responsible for data collection and reporting. The tunnel inspection organization is responsible for establishing a certification registry for tunnel inspectors. Each practicing tunnel inspector should be identifiable within the appropriate jurisdiction using a unique identification such as numbering system that correlates an individual inspector with a specific certification record.

When a tunnel is complex, a professional engineer is needed to determine whether special procedures, increased training, or additional qualifications and experience are necessary to lead the inspection. In accordance with the NTIS, the type of construction, functional systems, history of performance, and the physical and operating condition of the tunnel should be considered when determining the inspection requirements for complex tunnels.

Tunnels should be load rated in accordance with the NTIS after an inspection, as appropriate, to determine the safe vehicular load carrying capacity for the roadway. The load rating analysis must be performed by a qualified professional engineer. Tunnels must also be posted or restricted, as appropriate, after conducting the load rating in accordance with the NTIS.

4.3.2 Planning and Scheduling

The planning and scheduling of an inspection includes understanding the requirements of the NTIS, reviewing existing tunnel records, coordinating with appropriate tunnel facility personnel, developing health and safety plans, procuring safety and inspection equipment, reviewing defects common to tunnels, identifying the need for owner defined elements, and developing forms and reports for carrying out the inspection. When appropriate, tunnels must also be load rated. A detailed inspection schedule and work plan should address all of the critical aspects.

The NTIS contains the requirements for inspection personnel, inspection procedures, types of inspections, and the inspection interval. To ensure familiarity with tunnel inspection techniques and practices, the FHWA developed a comprehensive training course for the national certification of tunnel inspectors. Alternate training, that meets FHWA's approval, may be substituted for this tunnel inspection course as mentioned in the NTIS.

The inspection program must be developed sufficiently to be capable of evaluating the tunnel elements and identifying any safety or structural concerns. A successful inspection plan should anticipate the potential problems, streamline processes, and enhance the early detection of defects. Once the overall plan has been developed, the supplementary details for each specific inspection task should be described in detail. The need for specialists to test or inspect any sophisticated components in the tunnel should be evaluated along with the need to disassemble and clean any parts or equipment. The tools and equipment necessary for the job must also be provided. For example, when the bearings of a small motor need to be disassembled and inspected in a dark room, the parts can become lost. In additional to any safety precautions to be implemented, the procedures should address additional lighting, storage of small components, and on-site availability of spare parts for this example.

A pre-inspection visit of the tunnel facility is needed to prepare for the inspection. The general tunnel configuration, current site conditions, methods of access, and traffic conditions must be understood. Areas with access difficulties should be identified so that inspection procedures can properly address these issues. Non-destructive testing, robotic video inspection, and access equipment should be considered. The inspection team should prepare as-built sketches, diagrams, and schematics of electrical, mechanical, and hydraulic systems for use during the inspection.

Health and safety consideration should be evaluated. Coordinate with local and state police, fire departments, ambulatory, and medical services in advance, particularly when dealing with confined space. OSHA requires that a competent person makes frequent and regular inspections of the job sites, materials, and equipment during the course of hazardous work. The term "Competent Person" is used in many OSHA standards and documents. An OSHA "competent person" is defined as "one who is capable of identifying existing and predictable hazards in the surroundings or working conditions which are unsanitary, hazardous, or dangerous to employees, and who has authorization to take prompt corrective measures to eliminate them".

4.3.3 Reviewing Existing Tunnel Records – Tunnel File

The available records at each tunnel facility need to be thoroughly reviewed and evaluated prior to conducting an inspection. Important records that are normally part of the tunnel file include the construction plans, shop drawings, working drawings, as-built drawings, specifications, cost-estimates, correspondence, photographs, material certifications, material test data, and load test data. The history of the operating, inventory, maintenance, inspection, and repair records should also be reviewed. Check for accident records, posting, and permit loads. The goals should be to identify problem areas, formulate appropriate inspection procedures, check assumptions, verify schedules, and develop inspection documents including forms, survey control, and sketches.

The review process might involve sorting through a large number of documents, determining which records are relevant, searching multiple locations or facilities, and resolving conflicts including different formats, measuring units, or stationing. Processes should be developed to preserve the integrity of the existing file records, which can be difficult or impossible to replace. For complex tunnels considerable time and effort may be needed to prepare sketches, electrical, mechanical, or hydraulic schematics, or other pertinent details for the inspection.

4.3.4 **Coordinating with Personnel at the Tunnel Facility**

The tunnel inspection organization must coordinate with the tunnel facility to be inspected to ensure a safe and efficient environment. If critical findings are discovered during the course of an inspection, the appropriate personnel must be immediately notified. As such, communication protocols should be clearly established in advance of the inspection.

Prior to conducting the inspection, the inspection team and tunnel facility personnel should agree on various protocols such as access to the tunnel, health, and safety provisions, equipment staging areas, equipment shutdowns, maintenance of traffic, lane closures, inspection times, and the use of parking facilities. Enclosed spaces like the upper plenum, the fan room, the electrical room, or other such miscellaneous space may need special entry procedures. For example, to test the air flow velocities due to different fan speeds in the plenum, the inspector should coordinate with the tunnel operator to run the fans through all the various settings.

Equipment may need to be operated during the inspection process. Precautionary measures can be implemented to prevent injury to inspectors, tunnel personnel, and motorists. Coordination is necessary when removing equipment from service. This includes powering off, locking out, and tagging-out fans, motors, or other energized equipment as well as testing the power and control systems to validate the procedures. Proper lock-out/tag-out procedures must be implemented.

Communicate with the staff at the tunnel facility to learn if there are any unresolved or lingering problems. If possible, the inspection team should speak with the staff about recent repairs, maintenance schedules, unusual noises, problems, or impact damage. Tunnels that are difficult to access may require assistance or advise from the tunnel facility staff.

4.4 Tunnel Inspection Personnel

The program manager and the team leader are specifically identified in the NTIS; other inspection personnel have been discussed in this chapter to include discipline specific specialists and field inspectors. At the owner's discretion, specialized contract inspectors may be used to assist with complicated or sophisticated tunnel systems. Table 4.1 identifies the typical positions on an inspection team. In accordance with the NTIS, an independent assessment is desired; therefore, the operating and maintenance personnel should not be used for inspection purposes.

Table 4.1 – Inspection Team Members

Team Members	Role	Qualifications
Program Manager	Overall in charge of the inspection program	Mandated
Team Leader	Leads and coordinates inspections in the field	Mandated
Discipline Specialist	Performs inspection of specific systems and elements	Recommended
Inspectors	Assists the team leader and discipline specialists	Recommended
Specialty Contractor	Inspects complex components and electronic systems	Recommended

4.4.1 Program Manager

The program manager is the individual in charge of the tunnel inspection program for a State, Federal Land, or Tribal government that has one or more tunnels within their jurisdiction. This person must be capable of leading the tunnel inspection organization and ensuring that the requirements of the NTIS are fulfilled. The program manager may delegate duties and responsibilities to qualified delegates who take charge of a particular subset of tunnels; however, the program manager for the jurisdiction remains responsible for ensuring compliance.

On behalf of the tunnel inspection organization, the program manager develops written procedures, schedules inspections, procures inspection and safety equipment, coordinates with tunnel facility staff, and advises the team leader as necessary. Ideally, the program manager should have a general understanding of all aspects of tunnel engineering including design, construction, operation, maintenance, inspection, evaluation, load rating, and rehabilitation. Good judgment is essential for this position in order to respond appropriately to safety and structural concerns within the tunnel.

Refer to the NTIS for the complete requirements of this position. The program manager must be a registered professional engineer or have at least 10 years of tunnel or bridge inspection experience. This individual must also be a nationally certified tunnel inspector, which requires comprehensive training, end-of-course assessment, and periodic refresher training.

4.4.2 Team Leader

The team leader is the person on-site who is in charge of the inspection team. This person is responsible for inspection planning, preparing, performing and reporting to include coordinating the field work. The team leader is responsible for evaluating the deficiencies, quality checking of the inspection data, and making sure that the inspection reports are complete, accurate, and legible. The team leader should also conduct safety briefings as needed. The team leader should be able to provide recommendations for the repair of defective items and must initiating appropriate actions when critical findings are discovered.

Refer to the NTIS for the complete requirements. A team leader must be a nationally certified tunnel inspector. Additionally, the team leader is expected to meet at least one of the following:

- Registered professional engineer and at least 6 months of tunnel or bridge inspection experience.
- 5 years of tunnel or bridge inspection experience.
- Appropriate combination of education and experience as described in the NTIS.

In addition to the minimum requirements stated above, the team leader should be a professional engineer when the tunnel is complex or if it has distinctive features or functions. Team leaders must be on site at all times for initial inspections, routine inspections, and in-depth inspections.

4.4.3 **Inspection Assistance from Discipline Specific Specialist and Field Inspectors**

The inspection team should consist of a minimum of two individuals to carry out the field work in a balanced and efficient manner. Discipline specific specialists and trained field inspectors should assist with the inspections as necessary. These individuals on the inspection team should:

- Be knowledgeable of tunnel components and understand their function.
- Be able to climb and/or use equipment to access various areas of the tunnel.
- Be able to use equipment or apply appropriate test methods.
- Be able to print legibly and draw accurate sketches.
- Be able to read and interpret drawings.
- Be able to use appropriate technology as required for data collection.

Discipline Specific Specialists – When complex civil/structural, mechanical, or electrical systems need to be inspected, the team leader should assign discipline specific specialists with suitable training and experience to help conduct these inspections. Ideally, these specialist individuals should be registered professional engineers or at least engineers-in-training.

A) Civil/structural specific inspectors should ideally have the following education, training, and experience:

- Be a nationally certified tunnel inspector.
- Have tunnel or bridge inspection experience with the ability to identify and evaluate defects that diminish the integrity of a structural member.
- Have design experience and be familiar with the type of civil/structural systems installed in the tunnel. Examples of these systems include, but are not limited to:
    - Liners
    - Roof girders, ceiling girders, and invert girders
    - Columns/piles
    - Cross passageways
    - Interior walls
    - Portals
    - Ceiling slabs, invert slabs, and slabs on grade
    - Hangers and anchorages
    - Ceiling panels
    - Joints
    - Wearing surfaces
    - Traffic barriers
    - Pedestrian railings
- Be able to assess the degree of deterioration for concrete, steel, masonry, and timber materials.
- Be aware of the applicable codes and guidelines for structural systems.

B) Mechanical specific inspectors should ideally have the following education, training and experience:

- Be a nationally certified tunnel inspector.
- Have tunnel or bridge inspection experience with the ability to evaluate physical and operational conditions of mechanical systems and equipment.
- Have design experience or be familiar with the type of mechanical systems in tunnels. Examples of these systems include, but are not limited to:
  - Tunnel ventilation
  - Air conditioning
  - Heating
  - Control units
  - Plumbing
  - Tunnel drainage and pumping systems
  - Emergency generators
  - Fire Protection
  - Wells/Septic
  - Flood gates
- Be aware of applicable codes and guidelines for mechanical features.

C) Electrical specific inspectors should ideally have the following education, training, and experience:

- Be a nationally certified tunnel inspector.
- Have tunnel or bridge inspection experience with the ability to evaluate the physical condition, as well as the operational condition of the electrical systems and equipment.
- Have design experience or be familiar with the type of electrical systems installed in tunnels. Examples of these systems include, but are not limited to:
  - Power distribution.
  - Emergency power.
  - Lighting.
  - Emergency lighting.
  - Fire detection.
  - Air-quality monitoring.
  - Cameras and safety systems.
  - Communications.
- Be aware of applicable codes and guidelines for electrical systems to include:
  - NETA MTS-2011 – InterNational Electrical Testing Association (NETA), Maintenance Testing Specifications—developed for those responsible for the continued operation of existing electrical systems and equipment to guide them in specifying and performing the necessary tests to ensure that these systems and apparatus perform satisfactorily, minimizing downtime and maximizing life expectancy.
  - NFPA 70 – National Fire Protection Association 70 – covers installations of electric conductors and equipment within or on public and private buildings or other structures, installations of conductors and equipment that connect to the

supply of electricity, installations of other outside conductors and equipment on the premises, and installations of optical fiber cables and raceways.

- NFPA 70B – National Fire Protection Association 70B – recommended practice for electrical equipment maintenance for industrial-type electrical systems and equipment, but is not intended to duplicate or supersede instructions that electrical manufacturers normally provide.
- NFPA 70E – National Fire Protection Association 70E – addresses those electrical safety requirements for employee workplaces that are necessary for the practical safeguarding of employees.
- NFPA 72 – National Fire Protection Association 72 – national fire alarm code that covers the application, installation, location, performance, and maintenance of fire alarm systems and their components.
- NFPA 502 – National Fire Protection Association 502 – covers fire protection and fire and life safety requirements for limited access highways, road tunnels, bridges, elevated highways, depressed highways, and roadways that are located beneath air-right structures.
- ITA Guidelines for Structural Fire Resistance for Road Tunnels – International Tunneling Association (May 2004) – covers guidelines for resistance to fire for road tunnel structures.
- IES LM-50 – Illuminating Engineering Society, Lighting Measurements–50 – provides a uniform test procedure for determining, measuring, and reporting the luminance characteristics of roadway lighting installations.
- IES RP-22 – Illuminating Engineering Society, Recommended Practices–22 – provides information to assist engineers and designers in determining lighting needs, recommending solutions, and evaluating resulting visibility at vehicular tunnel approaches and interiors.

Field Inspectors – Field inspectors assist the team leader and discipline specific specialists carry out the inspection work. Some duties of the inspector include carrying inspection equipment, filling out inspection forms, taking photographs, and making sketches. The NTIS does not mandate specific qualifications for field inspectors; however, the following qualifications are recommended for field inspectors assigned to civil/structural, mechanical, and electrical inspection work. Ideally, the field inspectors would have an engineering background with education, training, and experience within their respective fields of practice.

A) Civil/structural field inspectors ideally should:
- Be a nationally certified tunnel inspector.
- Be trained in general civil/structural inspection requirements.
- Have tunnel or bridge inspection experience with concrete, steel, timber, and masonry structures.
- Design and maintenance experience is also useful.

B) Mechanical field inspectors ideally should:
- Be a nationally certified tunnel inspector.
- Be trained in general mechanical inspection requirements.

- Have inspection experience with mechanical and plumbing systems.
- Design and maintenance experience is also useful.

C) Electrical field inspectors should:
- Be a nationally certified tunnel inspector.
- Be trained in general electrical and electronic inspection requirements.
- Have inspection experience with electrical systems.
- Design and maintenance experience is also useful.

4.4.4 **Specialty Contractors**

Specialty contractors are beneficial when the regular inspection staff lacks the specialized skills and experience necessary to inspect sophisticated equipment or complex systems such as power distribution systems, fire protection and detection systems, security systems, and SCADA systems. It is advisable to use qualified specialty contractors when inspecting complex units that pose elevated risks to safety such as boiler units, electrical systems, or energized equipment like transformers. This may help to minimize health and safety risks to the inspection crew and prevent damage to very expensive equipment.

Electrical and Electronic Inspectors – To inspect elements with advanced electronic circuitry, the staff furnished by the specialty contractors should have the following education, training and experience:
- Certification by an organization meeting the requirements of the International Electrical Testing Association (NETA); or
- All of the following qualifications:
    - Be nationally recognized as an electrical testing laboratory.
    - Be regularly engaged in the testing of electrical systems and equipment for the past five years.
    - Have at least one professional engineer on staff that is licensed in the State where the work is being done.
    - Have in house or lease sufficient calibrated equipment to do the testing required.

Boiler Inspector – To inspect boilers, boiler room, and pressure vessel located within the tunnel facility, the staff furnished by the specialty contractors should be:

- Listed as an authorized inspection agency by the National Board of Boiler and Pressure Vessel Inspectors; and certified for boiler and pressure vessel work by an organization meeting the requirements of the American Society of Mechanical Engineers (ASME).

4.5 Inspection Procedures

Inspection procedures are the written documentation of policies, methods, considerations, criteria, directions, and other conditions for planning and conducting tunnel inspections. Written procedures are used enhance the overall effectiveness of the tunnel inspection program and to formalize the inspection process. Procedures should be developed to ensure that adequate planning and scheduling takes place prior to conducting the inspection. Written procedures should describe the requirements for:

- Inspection documentation, forms, and reports; see Section 4.12 of this Manual.
- Record keeping and documentation requirements.
- Planning and scheduling to include unique structural or functional system characteristics.
- Inspection "best practices" and inspection techniques; see Section 4.9 of this Manual.
- Requirements for functional system testing, direct observation of critical system checks, and testing documentation.
- General, tunnel-specific, and specialized instructions.
- Specialized procedures, training, and experience for complex tunnels.
- Components to disassemble or clean.
- Measurements and survey control.
- Use of current technology and practices.
- Annual reports to FHWA.
- Addressing critical findings and reporting to FHWA within 24 hours.
- Load rating, posting, and restricting as appropriate for evaluating safe vehicle load.
- Maintenance and protection of traffic during the inspection.
- Parking and staging areas during the inspection.
- Quality assurance and quality control implementation plans.

Inspection procedures need to address the various types of tunnel inspections and define the roles and responsibilities of those performing the inspection to include the team leader. Staff should be used that are not associated with operation or maintenance of the tunnel structure or functional systems. General and tunnel specific tunnel inspection procedures add value to the overall inspection program and help ensure compliance with all of the regulatory requirements. The results will be more accurate with more consistent findings. Inspection procedures convey:

- Important design assumptions for tunnel and account for complexity of tunnel systems.
- Health and safety instructions including emergency response and enforcement rules.
- Composition of inspection team and qualifications of personnel including training, certification, registration, and licensure requirements.
- Communication and reporting protocols.
- Inspection tools and safety gear.
- Use of diagrams, photos, and sketches.

Inspection procedures need to be clearly stated, easily understood, and concisely written. The procedures should reflect the complexity of the structural, civil, and functional systems of the tunnel. See owner defined elements for geotechnical considerations of tunnels that cross navigation channels. Ensure that the procedures identify the:

- Structural elements and functions systems.
- Methods of inspection.
- Frequency of inspection for each inspection method.
- Inspection equipment, access equipment, safety equipment, and traffic coordination.
- Practices to identify and record deficiencies in accordance with the SNTI.

Inspection procedures are needed for discovery of critical structural or safety related deficiencies found during the inspection of the tunnel. The procedures should incorporate the following steps, as deemed appropriate:

- Immediate critical deficiency reporting steps.
- Emergency notification to the police and the public.
- Rapid evaluation of the deficiencies found.
- Rapid implementation of the corrective or protective actions.
- A tracking system to ensure adequate follow-up actions.
- Provisions for identifying other tunnels with similar structural or functional system defects for follow-up inspections.

4.5.1 Inspection Practices

The tunnel inspection organization should develop a set of best practices to help maintain the quality of the tunnel inspection program. Some common types of general inspection practices include cleaning, field measurements, and establishing survey control.

Cleaning – Debris, efflorescence, rust, or other foreign substances should be removed to better observe the condition of the defect. The appropriate tools and equipment should be used to remove corrosion and limit damage to any applied finishes. In many cases, wire brushes may be appropriate to remove corrosion; while in other cases, foreign substances can be removed using water, solvent, compressed air, or another cleaning fluid in conjunction with a soft bristled brush.

Field Measurements – After visually inspecting all exposed surfaces, the defects and deficiencies should be properly measured and recorded. The location of the defect is important for subsequent monitoring and repair work. For example: Spalls in the concrete are characterized by their length, width, and depth. Length and width are noted for cracks. Corrosion of steel members is measured along the length and width. The depth of corrosion is measured. Similar measurements can be made on wood members to document any deterioration. Accurate measurements ensure quality results.

Survey Control – It is important to be able to locate a defect once it has been documented. A survey control system helps to locate defects during follow-up inspections, monitoring or repairs. Most highway tunnels have a baseline or stationing system already established. Using this information, the tunnel inspectors can accurately record the location of the defects and deficiencies. To take this one step further, some tunnel facilities use wall panels that have defined widths that can be used as part of the survey control system. By establishing a grid incorporating the panels, defects can be measured from the panel joints and their location converted to the stationing system.

In addition to locating a defect by panel number and station in the longitudinal direction of the tunnel, the position of the defect within the tunnel cross-section (perpendicular to the tunnel axis) should be recorded. Figures 4.1 to 4.4 show some schemes that have been used successfully for locating defects. The direction to face must be established. For example, a defect in a circular tunnel located at 4 o'clock facing in the direction of traffic would be at 8 o'clock when facing against the direction of traffic. The areas of horseshoe, rectangular, and other shaped tunnels can be divided into convenient sections that uniquely define the location such as the top, left, right, or bottom. For example, a defect in a rectangular tunnel at Station 10+55.33 may be written as "located 3.5 feet up from the bottom right wall when facing up-station" or abbreviated as "3.5BRW/US@10+55.33".

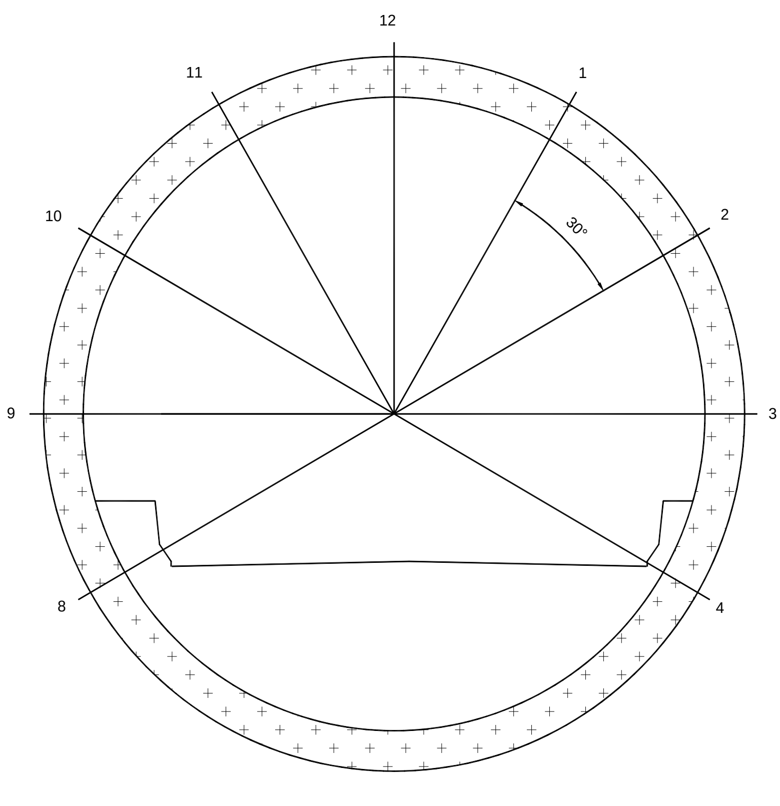

Figure 4.1 – Sample clock system designations used with circular tunnel.

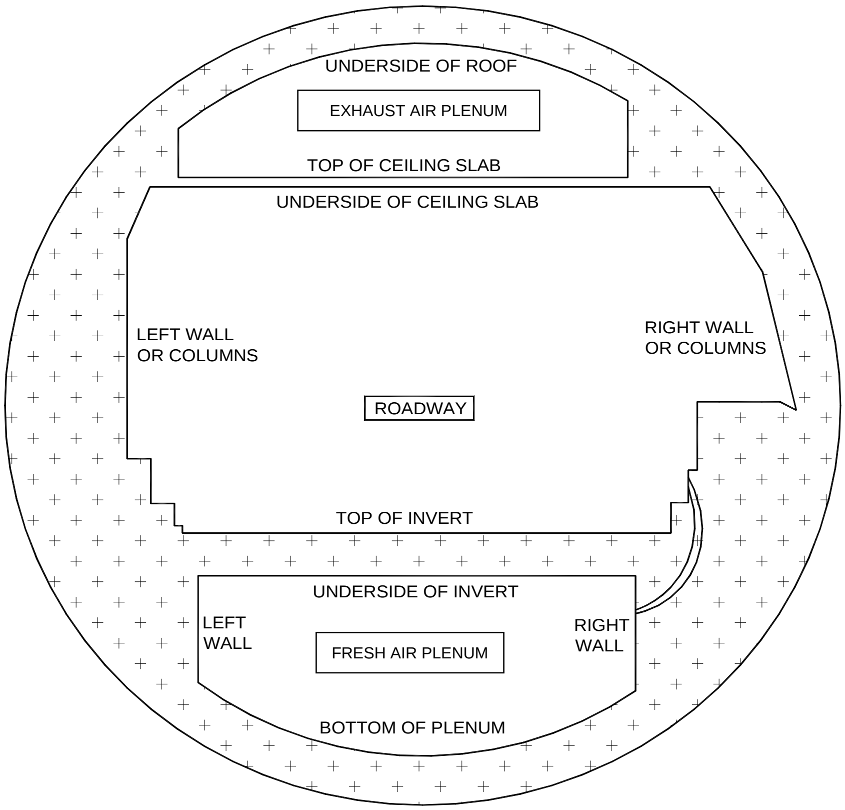

Figure 4.2 – Sample labels used with circular shaped tunnel.

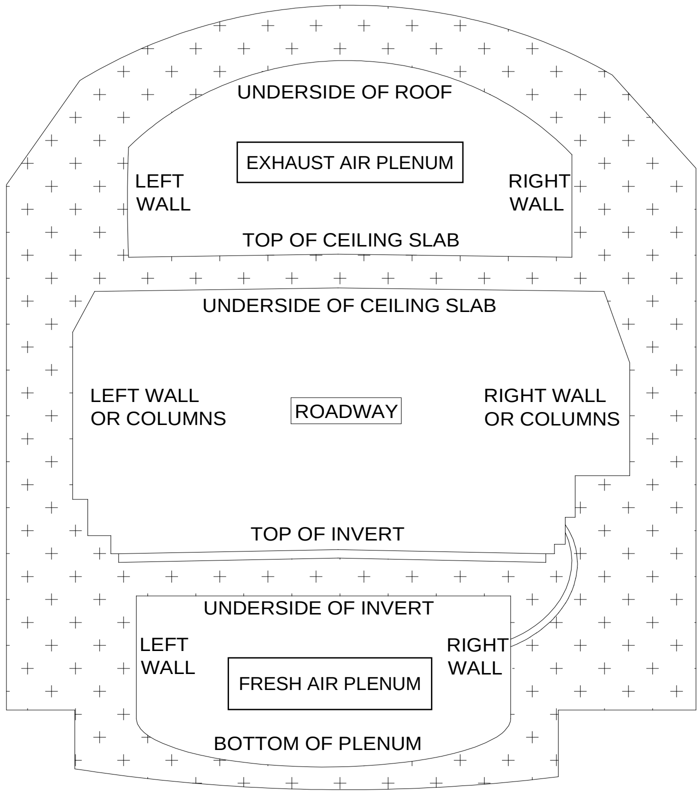

Figure 4.3 – Sample labels used with horseshoe shaped tunnel.

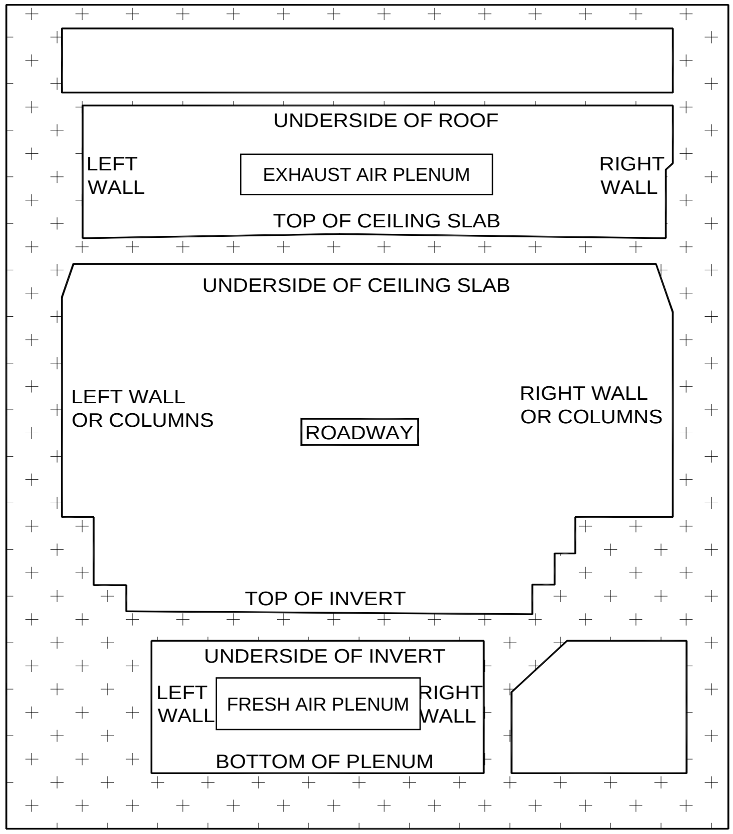

Figure 4.4 – Sample labels used with rectangular shaped tunnel.

4.6 Types of Tunnel Inspections

There are several types of inspections that are regularly performed on highway structures such as tunnels in addition to any general, daily, weekly, or monthly walk-through inspections done by the tunnel operating and maintenance personnel. Similar to other inspection programs, the NTIS identifies initial, routine, damage, in-depth, and special inspections for tunnels. Table 4.2 summarizes these types of inspections for a tunnel.

Table 4.2 – Types of highway tunnel inspections.

Inspection Type	Purpose
Initial	Establish the inspection file record and the baseline conditions for the tunnel.
Routine	Comprehensive observations and measurements performed at regular intervals.
Damage	Assess damage from events such as impact, fire, flood, seismic, and blasts.
In-Depth	Identify hard-to-detect deficiencies using close up inspection techniques.
Special	Monitor defects and deficiencies related to safety or critical findings.

The interval requirements for initial inspection and routine inspections are contained in the NTIS, Table 4.3 summarizes these requirements. The tunnel inspection organization is responsible for establishing the inspection intervals for in-depth inspections based on the particular needs of the tunnel facility. Special and damage inspections are performed at the discretion of the tunnel owner.

4.6.1 **Initial Inspection**

An initial inspection should be performed on existing highway tunnels within the interval specified in the NTIS. On new tunnels, the initial inspection should be conducted after the completion of construction activities and the testing of functional systems but prior to opening the tunnel to traffic. See Table 4.3.

At a minimum, the initial inspection should consist of a sufficient number of observations and measurements to determine the physical and functional condition of the tunnel. These inspections are intended to be comprehensive covering the structural, civil, mechanical, electrical and lighting, fire and life safety, security, signs, and protective systems. The results are to be recorded in accordance with the instructions contained in the SNTI.

The initial tunnel inspection establishes the baseline conditions of the tunnel; and it is used to field verify the initial tunnel inventory data. The baseline results can be used to evaluate changes over time to the tunnel systems and to help identify trends.

Table 4.3 – Interval period contained in the national tunnel inspection standards.

Activity Type	Application	Interval
Initial Inspection	New tunnel	Prior to opening to traffic to the public.
	Existing tunnel	Within 24 months of NTIS effective date.
Routine Inspection	Default condition	Every 24 months over lifetime of the tunnel.
	Approved written justification	Possibly allow extension up to 48 months.
In-depth Inspections	Complex tunnels and for certain structural and functional systems.	Level and frequency to be established by the program manager.

4.6.2 **Routine Inspection**

Following the initial inspection, routine inspections are conducted within the intervals specified in the NTIS. See Table 4.3. Routine inspections are regularly scheduled inspections that help to ensure continued safe, reliable, and efficient service. These inspections are similar in scope to the initial inspection. Routine tunnel inspections record the changes to the tunnel over time and can be used to help identify trends and predict future life expectancy of components.

At a minimum, routine inspections consist of a sufficient number of observations and measurements that can be used to determine the physical and functional condition of the tunnel. These inspections are intended to be comprehensive covering the structural, civil, mechanical, electrical and lighting, fire and life safety, security, signs, and protective systems. The results are to be recorded in accordance with the instructions contained in the SNTI.

4.6.3 Damage Inspection

Damage inspections are performed in response to natural disasters or human activities that damage the tunnel. Damage may occur by motor vehicle impact, fire, flood, earthquake, vandalism or explosions. When severe damage occurs, the tunnel should remain closed until a damage inspection has been completed. Structural analysis and follow-up emergency repairs may be needed. Structural materials may need further evaluation as identified in the Manual for Bridge Evaluation (MBE).

Safety is of paramount importance after an incident. Devices such as breathing apparatus, protective clothing, and specialized equipment may be necessary. Inspection work should be coordinated with emergency responders. It is important that the tunnel inspection organization develop detailed plans and conduct training exercises with tunnel facility personnel in advance of these events.

4.6.3.1 Impact Event

Impact damage from motor vehicles is relatively common within a tunnel. Numerous impacts have been caused by trucks striking the tunnel or equipment attached to a trailer that was not properly secured. This type of damage usually occurs around the portal location, along the roof, and where equipment is located above the roadway. It is also not uncommon for vehicles to crash against railings, curbs, and walkways (Figure 4.5).

Figure 4.5 – Evaluating impact damage.

The following items should be inspected, as appropriate, after an impact event:

1. Tunnel lining for damage and loose tile.
2. Tunnel ceiling.
3. Tunnel lighting.
4. Steel, timber or concrete tunnel supports for damage.
5. Low hanging equipment and their anchorage system, such as jet fans, suspended ceiling system, lighting system, and detection and communication equipment.
6. Elements along the roadway such as railings, curbs, and walkways.

7. Drainage areas. In some instances, fuel can spill from crashed vehicles and flow into the tunnel drainage system and present a fire hazard at the collection points in the drainage system.

4.6.3.2 **Fire Event**

During a fire, the safety of users and responders is the first priority. The tunnel will usually require emergency ventilation measures to exhaust the smoke, vent superheated gasses, and maintain a tenable environment for the evacuees and first responders. Fuels and other combustible materials on board vehicles can increase the severity of the fire. Spilled fuel may also accumulate in collection points in the drainage system and be transported to other parts of the tunnel. Some drainage systems may discharge fluids contaminated with fuels to locations outside the tunnel. Monitors should be used to evaluate the explosive gas levels after a crash.

Figure 4.6 – Evaluating fire damage.

When evaluating damage (Figure 4.6), it is useful to estimate the intensity of the fire. This information can be used to support follow-up evaluations regarding the performance of a particular tunnel system during a fire event. One technique for estimating the highest temperature achieved is to identify objects that have melted and note any color changes in materials. These observations might provide an indication about the maximum temperatures experienced. Melting points for common materials include plastic at 300 – 450 ºF, lead at 620 ºF, glass at 750 – 900 ºF, and aluminum at 1,200 ºF.

Timber – Fire damage is easily evaluated on most timber structures. Fire damage may not be as severe as first expected. The best way to determine the extent of damage is to chip away at the charred remains of the timber at several locations and then measure the remaining section of the unblemished timber. The greatest section loss is often located where two or more members are fastened together.

Concrete – Concrete and masonry usually perform well during fire events; but when temperatures exceed about 570 ºF, permanent damage may result. As the temperature rise, the concrete may experience discolorations that progresses from pink to white to a grey-buff at very high temperatures. The discolorations (Figure 4.7) should be noted in the inspection findings.

Figure 4.7 – Color change can indicate the highest temperature experienced.

A hammer should be used to sound areas of concrete that have been exposed to fire; the concrete should be checked for delamination or damage such as cracking, distortion, spalling, or any other indications of damage. Reinforcement that is exposed should be identified.

Steel – Steel subjected to fire should be carefully examined for evidence of deformation since it tends to lose stiffness at higher temperatures. The straightness of the members should also be checked; and the amount and location of damage should be measured and documented. Members exposed to extreme heat may experience excessive deformations and permanent strength reductions. Steel subjected to fire can be sampled using coupons. The mechanical properties can be tested for brittleness or hardness. Appropriate non-destructive testing may also be beneficial.

It is important to check that the steel connections are not damaged. Look for sheared bolts, loosened rivets, or other damages caused by excessive thermal stress/strain. Welds can be cracked or torn.

4.6.3.3 **Flood Event**

After a flood, the embankments and slopes around the tunnel may become saturated with water. This condition may lead to instability of walls and slopes. A geotechnical engineer should investigate the embankments and slopes in the vicinity of the tunnel after a flood event. Excess water should be pumped from the tunnel, and debris should be removed. Check areas that are difficult to access, such as ventilation ducts, equipment rooms, and emergency corridors for standing water and debris. The potential for electric shock needs to be evaluated by a qualified person prior to restoring power to the tunnel.

After the tunnel is rendered safe, the inspectors should evaluate the effectiveness of the flood gates, if applicable, and document the extent of water damage. Functional systems that have been exposed to flood waters should be checked for damage. Electrical systems can be ruined by floodwaters, especially when saltwater is involved. Check the essential equipment to ensure functionality can be restored. After a flood event, the tunnel may need to be thoroughly washed, particularly in saltwater environments.

4.6.3.4 **Seismic Event**

Tunnels are resilient to seismic shaking; however, large ground movements from a seismic event may still result in extensive damage to major components. The greatest risk of severe damage for a tunnel facility occurs from:

- An active fault intersecting the tunnel;
- A landslide intersecting the tunnel; or
- Liquefiable soils..

It is good practice to have an inspection plan ready for immediate implementation in areas with seismic activity. Following an earthquake of 5.0 or more on the Richter scale, all tunnels within 100 miles of the epicenter should be inspected. The inspection team should use caution following and earthquake since aftershocks may follow; and when the tunnel is located in a low lying coastal area, it could be at risk for a tsunami. After the danger has cleared, inspect for:

1. Cracks, slides, or slope failures in embankments near the tunnel portals.
2. Rock falls and loose rock.
3. Tilt in walls adjacent to the tunnel portals.
4. Fallen or loose material such as tiles that may fall.
5. New cracks or failures in the tunnel lining or road surface.
6. All suspended items and overhead attachments to the tunnel such as suspended ceiling, jet fans, lighting system, and signs, Check for sound anchorages.
7. Offsets due to displacement across a fault.
8. Steel, timber, masonry, or concrete structure elements for damage.
9. Increased or unusual flow of water within the tunnel, especially if tunnel is submerged.
10. Functional systems, such as drainage, ventilation and lighting, communication equipment, and safety systems should be inspected as a general precautionary measure. When flooding occurs because of tsunamis, follow the flood event procedures.

4.6.3.5 **Blast Event**

Blast events can cause widespread or local damage, and this damage can be hard to predict. Experts in urban search and rescue, structural engineers, security, and law enforcement experts will likely be required to be at the scene to ensure safety and evaluate the damage. The tunnel site may be treated as crime scene, and access to the site may be limited by the authority in charge. Before conducting a damage inspection, inspectors should be aware of issues associated with a blast event such as poor air quality, the possibility of hazardous materials, and the potential for spilled fuels and other combustible or dangerous materials.

When damage occurs from a blast event, the impact, fire, and seismic damage procedures should be followed as appropriate. In addition, all potentially impacted windows and doors should be inspected for damage from the shockwave. The tunnel inspection organization, the tunnel facility personnel, and first responders should have procedures in place to deal with blast events as appropriate for the tunnel facility.

4.6.4 In-Depth Inspection

In-depth inspections are close-up, hand-on inspections conducted on one, several, or all of the elements or functional systems. These inspections are used to identify deficiencies that are not readily detectable during initial, routine, or damage inspections. In-depth inspections may involve testing of tunnel system, components, and materials. More extensive disassembly and cleaning of equipment parts may occur. This type of inspection may be used to support a structural analysis or a functional system evaluation where more information is needed. In-depth inspections are scheduled based on the needs of the tunnel facility, inspection findings, and established written procedures.

4.6.5 Special Inspection

A special inspection is typically performed after an initial, routine, damage or in-depth inspection when significant deficiencies have been discovered and need to be monitored. Special inspections are scheduled based on the needs of the tunnel facility, inspection findings, and established written procedures. These types of inspections continue, but perhaps at adjusted intervals or durations, until the deficiency is repaired, the component is removed from service, or further study determines that the conditions are no longer deteriorating at accelerated levels. For example, a light fixture built of dissimilar metals and installed over traffic might have problems with excessive corrosion. As such, this light fixture may be monitored on a regular basis to ensure that it remains securely anchored and safe until repairs can be made.

4.7 Health and Safety Considerations

Tunnel inspection must be conducted in a safe manner. Rescue in tunnel facilities can be complicated because tunnels have limited access points and areas of confined space. Some of the dangers in tunnels include energized equipment, highway traffic, service and emergency vehicles, power supply, rigid objects, sharp edges, working from heights, flying debris, and hazardous materials.

The activities of the inspection team should be closely coordinated with the personnel at the tunnel facility. The traveling public should also be protected from any hazards of the inspection work. Written health and safety procedures should focus on preventing injury, death, and equipment damage to ensure the overall success of the inspection program. The goal should be to complete the inspection with zero accidents.

4.7.1 Key Concerns for Tunnel Inspection Safety

Health and safety plans must address the dangers inherent to the inspection process. The proper attitude, alertness, and common sense are important components of safety. Everyone should be engaged in safety. A competent person should be on-site to identify workplace hazards relating to specific operations, who has the authority to correct any deficiencies [29 CFR 1926.32(f)].

Figure 4.8 – Typical safety placard. This photo shows a sign labeled, "WEAR YOUR VEST," and a notebook containing material safety sheets is hung to the wall for use of inspectors and other tunnel workers.

Inspections of overhead items usually require one or more lane closures and fall protection for the workers. It may be necessary to close the tunnel bore when performing inspections to lessen the risk of accidents. Personal protective equipment is required (Figure 4.8). Applicable laws and regulations should be followed. Written safety procedures need to be developed and implemented. Inspecting plenums and equipment rooms might involve confined space entry procedures to meet Occupational Safety and Health Administration (OSHA) rules.

Some basic safety issues that may arise in inspections are: injury and pain, family hardship, equipment damage, lost production, and medical expenses.

- Injury and pain - Accidents can cause pain, suffering, and even death. Carelessness is often a contributor to jobsite accidents.
- Family hardship - A worker's family may also suffer hardship from an accident. There can be loss of income; the injured person may not be able to participate in family activities; and in the case of a major disability, the burden of caring for the injured person may be borne by family members.
- Equipment damage - Equipment can be very costly to repair. The damage to equipment must be fixed and, depending on the severity of the damage, there may be a lost time if the equipment is not available for use.

- Lost production - The employer loses revenue when the employee is not able to complete the job assignments. Time and money may also be lost retraining a new employee and resupplying the job with equipment that works. Additional training may be needed for the crew to prevent further injuries.

- Medical expenses – Incurred medical expenses impact the tunnel owner, the employer, and the insurance company in most cases.

4.7.2 **Safe Working Environment**

A safe working environment is essential for preventing injury and damage. The health and safety plan should focus on establishing a safe working environment that is facilitated by:

- Establishing written safety procedures that are clear, effective, and thorough.
- Providing adequate levels of safety training.
- Using tools and equipment properly.
- Implementing job site safety plans.
- Ensuring that work is properly supervised.
- Addressing safety incidents.
- Identifying safety incidents and relevant case studies.
- Instructing equipment operators.
- Enforcing safety regulations.
- Requiring emergency action plans that include emergency responders.
- Providing contact information for emergency responders and essential personnel.

Tunnel inspectors should take responsibility for their own safety and that of their co-workers. The following are useful actions for personal safety:

- Recognizing their own physical limitations – Inspection team members must notify the appropriate person, such as the team leader, when they don't feel capable of performing an assigned task. Other team members may not realize the limits of others. An individual, who feels unqualified or uncomfortable performing a particular task, should speak-up and discuss their assignment with their supervisor to prevent putting themselves or others at risk.

- Understand the rules and requirements of the job – If an individual doesn't understand how the work is to be performed, then this person should ask questions to clarify the situation, particularly when a task seems unsafe. When this occurs, the process should be reviewed and discussed to the satisfaction of all those involved, any misunderstandings should be clarified, and a safer alternative procedure developed. The inspection work should not proceed until all safety concerns have been satisfactorily resolved.

- Protecting coworkers – Team members must not endanger the health and safety of coworkers. When unsafe acts are observed, the person committing the unsafe act should be warned and team leaders should take appropriate action to discourage and prevent any reoccurrence.

- Reporting an accident - An accident must be reported to the person designated, such as the team leader or program manager. An injury should be promptly reported in accordance with established written procedures. These actions will promote proper resolution of accident and comply with insurance claim requirements.

    - If possible, a concise journal of events should be kept by anyone who witnesses or is involved in an incident. As soon as possible, observations should be recorded and pertinent information should be jotted down such as the time and date of the incident. It is good practice to also keep track of the name and title of the persons that were notified about the incident including the time, date, and method of reporting the incident, such as telephone, e-mail, or verbally. If any directions or responses were provided, it is advisable to summarize these into the journal as well.

    - It is also important to report near-misses that may help prevent similar incidents that could be worse.

4.7.3 Personal Safety

Personal safety measures are aimed at providing protection and minimizing risks to members of the inspection team. Some of the ways in which team members can be made safer on the job include the proper inspection attire, appropriate safety equipment, accident awareness, and enforced safety rules. It is important that the appropriate safeguards are put into practice and that the safety concerns of the job are clearly communicated and understood.

Inspection Attire – The proper inspection attire should be worn for the job and be representative of the hazards for the work. Field clothes should be sized for the individual and they should be appropriate for the weather and site conditions. Work clothes should generally fit snug and be comfortable.

The arms, legs, and torso should be protected by sturdy work clothes. The hands and feet should be protected by suitable gloves and boots. For general inspection activities, the inspector should wear leather boots with traction lug soles (non-penetrable soles). For climbing, the inspector is encouraged to wear boots with a steel shank (with non-slip soles without heavy lugs) or boots as per agency policy. Leather gloves that allow the inspector to pick up tools and write notes are recommended. A tool pouch enables the hands of the inspector to be free for climbing and other inspection related tasks such as taking notes and performing tests.

Personal Safety Equipment – Safety equipment or personal protective equipment (PPE) is designed to reduce the occurrences of injury and death. The head is normally protected using hard hat, goggles, ear plugs, and dust mask or respirator as necessary. Harnesses with lanyards offer fall protection when working at heights. Vests provide increased visibility to traffic. Much of this equipment needs to be fitted to the individual. Safety training for using PPE should be provided by a qualified safety representative.

Hard Hat: Serious head injuries may be reduced by wearing a hard hat; it is recommended that everyone in the field wear a hard hat at all times. When moving about in the tunnel, a hard hat provides an increased level of head protection against falling objects and accidental impacts with rigid or sharp objects. Objects to be careful around include:

- Deteriorated tunnel components that can be dislodged during the inspection process.
- Equipment dropped from overhead.
- Airborne debris from passing traffic.

When climbing in the tunnel or using lift equipment, inspectors frequently come close to rigid objects such as utility brackets and structural components. Many of these elements also have sharp-edges. Wearing a hard hat at all times while working can prevent serious injury or even death.

Figure 4.9 – Personal protective equipment: top, eye protection; bottom, respirator.

Reflective Safety Vest: When performing activities near traffic, the inspector should wear an appropriate safety vest. It is good practice to wear the safety vest at all times while conducting the work. The vest should be brightly colored with reflective strips that conform to the latest American National Standards Institute (ANSI) requirements for the type of traffic at the site. The combination of bright colors and reflectivity of light allows fellow workers, equipment operators, and passing motorists, to quickly identify the person and avoid injury. Some tunnel facilities have their own safety vest requirements, and it is best to verify these prior to showing-up in the field.

Safety Goggles: Eye protection is necessary to prevent damage to the eyes from flying particles and debris, see Figure 4.9, top. Glasses with shatterproof lenses should be supplemented with adequate side protection; or the glasses should be covered by safety goggles. Eye protection should usually be worn at all times, but is necessary when:

- Using a hammer or mallet.
- Using a scraper or wire brush.
- Grinding, chipping, cutting, sawing, or drilling.
- Working near moving machinery or equipment.
- Working in ventilation shafts or chambers where the air picks-up debris.
- Working in areas adjacent to traffic where debris is kicked-up by passing vehicles.

Dust Mask / Respirator: A respirator or dust mask can protect the inspector from harmful airborne dust, contaminants, and pollutants, see Figure 4.9, bottom. OSHA and other appropriate requirements should be followed when wearing these devices. Conditions that usually require a respirator include:

- Sandblasting.
- Painting or removing paint.
- Exposure to pigeon droppings (to prevent serious infections such as Histoplasmosis).
- Working in confined areas, around hazardous materials or dusty conditions.
- Cleaning items with compressed air.

Safety Harness and Lanyard: Safety harnesses and lanyards provide protection from falls by tying off the individual to rigid objects. To reduce the potential for back injury, a shock absorber should be incorporated into the lanyard. This shock absorber reduces the g-forces by controlling the rate of extension during a fall and typically uses nylon webbing, pre-folded and sewn together. Prior to wearing the device, the safety harness and lanyard should be thoroughly inspected and fitted to the individual. Any device that is fretted, worn, or expired should not be worn. If a lanyard is deployed in a fall or if it has reached its expiration date, the lanyard must not be used.

The safety harness must be tied-off securely to a solid structural member or a safety line rigged for this purpose. Scaffolding can fail and bring down whoever is tied to it. When working from a man-lift or a lift-bucket, the appropriate cautionary measures should be implemented to prevent injury. For example, if someone is tied off to a stationary object such as the tunnel liner, and the lift basket is moved beyond the length of their lanyard, the individual in the basket may be injured by the maneuver or pulled from the basket. A trained and certified person should always be assigned to evaluate the job-site conditions prior to tying off with lanyards.

Gloves: Gloves protect the hands and, to some degree, the forearms against objects that are rough, sharp, hot, or otherwise harmful. Deteriorated structural members typically have sharp edges and rough surfaces that can easily cut hands and arms, and injuries such as these can be quite painful and can become infected. If an artery is severed, significant blood loss may occur requiring emergency measures.

4.7.4 Accident Prevention

Accidents are often caused by human error from carelessness, improper attitude, or taking shortcuts. The risks to workers are minimized by planning ahead, implementing safety awareness campaigns, and maintaining inspection equipment in proper working order.

Preventable Accidents – Contributing factors to preventable accidents include:

- Improper attitude - distraction, carelessness, or worries over personal matters.
- Personal limitations - lack of knowledge or skill or exceeding physical capabilities.
- Physical impairment - previous injury, illness, side effect of medication, alcohol or drugs.
- Boredom - falling into an inattentive state while performing repetitive or routine tasks.
- Thoughtlessness - lack of safety awareness and not recognizing hazards.
- Shortcuts - sacrificing safety for time.
- Faulty equipment – worn tools, damaged ladder rungs, or frayed cables.
- Failure to use or maintain personal protective equipment.
- Lack of appropriate clothing to protect exposed parts of the body or inappropriate clothing that puts the individual at greater risk.

Safety procedures should minimize the occurrence of safety incidents. Supervision, breaks, check-lists, and drills have been used successfully to focus attention on safety.

Common Sense Safety Precautions – Some common sense safety precautions are listed and briefly discussed below:

- Keep well-rested and alert – The working conditions encountered during an inspection can change; the inspector should be aware of these changes and respond accordingly. The work may become tedious at times and a drowsy inspector is at greater risk for accidents.

- Maintain proper mental and physical condition – Inspection tasks require a number of different motor skills to maintain adequate safety. To perform at acceptable levels, the inspector should be physically fit, free from mental distractions, and focused on the job.

- Use proper tools – Do not use tools and equipment that are not suitable for the work. Make sure the tools are in good working order. Do not use broken or worn tools.

- Keep the work area neat and uncluttered – Tools and equipment scattered about the work area present a safety hazard and demonstrate a general lack of safety awareness.

- Establish systematic procedures – Procedures should be established early in the job and then implemented thoroughly throughout. Procedures should be clear and concise so that everyone knows what to expect and there are no surprises.

- Use lockout/tagged-out procedures – Follow lockout/tag-out procedures when inspecting energized or potentially energized systems. Energized equipment can be dangerous when not treated with proper care and attention. Persons working with energized equipment should be knowledgeable and certified to perform the work.

- Follow safety rules and regulations – Adhere to the safety rules and any appropriate laws and regulations. Audits and checks should be instituted to ensure compliance.
- Use common sense and good judgment – Do not engage in horseplay, and do not take short cuts or foolish chances. Team leaders should take responsibility to enforce procedures to ensure a safe environment.

- Avoid the use of intoxicants or drugs – Intoxicants impair judgment, reflexes, alertness, and coordination. Team members may be subject to drug and alcohol screening or after-accident testing. A policy of zero-tolerance is common for these types of offenses.

- Medication – Prescription and over-the-counter medications can cause drowsiness or other unwanted and potentially dangerous side effects. The inspector should always discuss the medication with the prescribing doctor. It's good practice to carry the prescription and to discuss any potential side effects with the appropriate persons such as the team leader or job-site medic.

- Electricity – Electric currents are very dangerous. It is commonly believed that as little as one amp of electricity can produce fatal heart irregularities in a person. All cables and wires should be assumed to be hot (live) until properly tested and lockout/tagged-out.

    - Even if wires and cables appear to be low-voltage, control, networking, or telephone cables, serious injury or death can result.
    - Tunnels contain many shock hazards such as through steel members, water leaks, humidity in the air, and water sprays.
    - If there are any transmission lines within the tunnel, they should be identified prior to the inspection.

- Buddy system – Inspectors should work in pairs. There should always be someone who can react to an accident. Inspectors should communicate their position with others, and the team leader should know where everyone is working. If anyone appears to be missing or out of place, efforts should be made to locate that person immediately.

- Overhead items – It is best to avoid working above traffic and people. If it cannot be avoided, the inspection crew working overhead should use safety lanyards to secure tools and notebooks from falling onto persons or vehicles below.
- Dark areas – Use a flashlight to illuminate dark areas prior to entering them. It's easy to become injured when entering a dimly lit room due to trips, falls, sharp objects, rigid or unprotected components, and exposed cables. Furthermore, pests such as snakes, insects, spiders, mice, and rats can bite, sting, poison, or startle the inspector.

4.7.5 Hazardous Materials

Asbestos and lead can be found in many older tunnels. Other hazardous materials may also be present. When hazardous materials are suspected at an inspection site, the issues should be thoroughly investigated, necessary precautions taken, and applicable laws and regulations should be followed. *It is advisable to consult with an appropriately qualified health and safety or environmental specialist, who is knowledgeable of applicable laws and regulations, to plan out the work.* Hazardous materials can pose health and safety risks, and environmental laws often control proper actions with work around them.

Asbestos – Asbestos-containing materials (ACM) are present in many tunnels that were constructed before 1980. Newer tunnels typically do not contain asbestos materials. An environmental health and safety specialist should be consulted to help plan out the work around ACMs of any type. Material testing and remediation operations for asbestos are conducted in accordance with the EPA 40 CFR 61, Subpart M.

ACMs are typically categorized as either "friable" or "non-friable". Friable ACMs are the materials that, when dry, are readily crumbled, pulverized, or reduced to a powder by simple hand pressure. Examples of friable ACMs include: pipe insulation, caulk, ceiling tile, wallboard, building insulation, thermal system insulation, and sprayed-on fireproofing. Non-friable ACMs include the materials that cannot be crumbled, pulverized, or reduced to powder by simple hand pressure. Non-friable materials usually contain a binder that combines the asbestos fibers into a matrix. Examples of non-friable ACMs include: vinyl floor tiles, floor tile mastic, most roofing materials, adhesives, cement flue patching, asphalt pavements, expansion joint material, mastic coatings, and cementitious pipes. Most non-friable ACMs can become friable by mechanical operations such as sanding, grinding, drilling, or abrading.

Materials that contain friable or potentially friable ACMs should be avoided. When these materials are suspected or observed during the course of an inspection, they should be noted in the inspection documents and reported to the tunnel owner. It is important that asbestos fibers do not become disturbed or airborne since these fine fibers or dust can be inhaled and, over prolonged periods. The asbestos fibers can cause serious and even fatal illnesses such as lung cancer, mesothelioma, and asbestosis.

Lead – Based on the age of the tunnel, the potential exists for chemical contaminants, particularly lead, to be present in the settled dust of the tunnel plenum. Vehicles emitted lead in their exhaust prior to the 1980s when gasoline contained this additive to boost the octane rating. Many tunnels have since been cleaned of lead. If lead is suspected in a tunnel constructed prior to 1990, or if there is no record of the tunnel being cleaned of lead, then it is advisable to consult with an appropriately qualified health and safety or environmental specialist to help plan out the remediation.

OSHA regulations governing lead exposure should be understood. The General Industry lead standard is contained in 29 CFR 1910.1025. The Construction Industry lead standard is found in 29 CFR 1926.62. The OSHA Permissible Exposure Limit (PEL) is 50 ug/m^3 (micrograms per cubic meter of air), which is averaged over an 8-hour workday. The OSHA action level (AL) exposure limit to lead is 30 ug/m^3. Exposures greater than the AL require lead monitoring for impacted workers.

Site specific work plans should be developed to protect workers from overexposure to lead during the inspections. The following methods and procedures may be explored in further detail to potentially reduce exposure levels:

- Conduct an initial exposure determination according to 29 CFR 1910.1025(d)(6)(i). This consists of conducting personal exposure air monitoring for lead. The analytical and sampling methods are found in the National Institute for Occupational Safety and Health (NIOSH) Method 7300 or OSHA ID 121 or 125G; **or**

- Dust samples can be collected or x-ray fluorescence direct-reading methods can be employed to determine the content of lead in dust. The material should be wipe sampled and analyzed as determined by ASTM E1728, "Standard Practice for Field Collection of Settled Dust Samples Using Wipe Sampling Methods for Lead Determination by Atomic Spectrometry Techniques", or equivalent method, with an acceptable wipe material as defined in ASTEM E1792, "Standard Specification for Wipe Sampling Materials for Lead in Surface Dust." Note: There is no current minimum amount or concentration of lead to trigger a determination of lead and the potential for occupational exposure. However, if the employer has appropriately tested all potential sources for lead (e.g., tested all layers of paints and coatings that may be disturbed) utilizing a valid lead test detection method and found no detectable levels of lead, the standard does not apply.

- If lead is found to be present in the dust, personal protective equipment, including respiratory protection should be issued to personnel in accordance with OSHA 29 CFR 1910.134 or 1926.103. In the absence of an initial exposure determination, minimum personal protective equipment should include air-purifying respirators equipped with P-100 filters and disposable Tyvek™ suits.

- Workers should also be instructed on good personal hygiene practices, including washing hands before eating and showering before leaving the worksite.

4.7.6 Lockout/Tag-out

Lockout/tag-out procedures should be developed during inspection planning. Prior to inspecting any mechanical or electrical equipment with the potential to cause injury or damage the lockout/tag-out procedures should be implemented in coordination with the appropriate tunnel facility personnel. The inspection should not be allowed to proceed until the system is properly de-energized or isolated, locked-out, and tagged out. Figure 4.10 shows a sample lock and tag that may be used as part of this procedure.

Unexpected energized circuits or startup of machinery and equipment, or the release of hazardous energy during service or maintenance activities can sometimes occur after lock-out/tag-out. Therefore, it is important to create a checklist to ensure that safety is maintained. The following procedure can be used as a guide to help develop a lockout/tag-out procedure for machinery and equipment:

Figure 4.10 – Typical lock and tag-out system.

Machines or equipment should be stopped, isolated from all energy sources, and locked out. Employees should not be allowed to congregate near the equipment being removed from service in case of unexpected energizing or the accidental start-up of the machine.

Sequence of Lockout

(1) The shutdown should be coordinated with the appropriate personnel at the tunnel facility. Even if the equipment isn't running at the moment, it may be possible to turn on the equipment at the flick of a switch in another room or by some algorithm written into a computer program. Always use established procedures and qualified personnel for the shutdown.

(2) The person conducting the shutdown should follow the appropriate procedures. The type and magnitude of energy running to the equipment should be identified. The person initiating the shutdown should be competent and appropriately qualified for servicing the particular equipment. The qualifications of this individual should be listed in the written procedures. This person needs to understand how to isolate and control the energy running to the equipment.

(3) Notify all persons (e.g.,, employees, maintenance staff, on-site contractors) working in the vicinity of the equipment being shutdown, as appropriate and in accordance with established procedures. Inform these people that servicing has been scheduled for the equipment and that the machine will be removed from service.

(4) De-activate all sources of energy to the machine and isolate the equipment from all energy sources.

(5) Lockout the energy using isolating devices and provide locks assigned to individuals that prevent these isolating devices from being removed. Use appropriate blocking and shields as necessary to secure the equipment. Add tag designations to the equipment. The locks and tags should contain the appropriate identification and contact information of the person responsible for the shutdown.

(6) Stored or residual energy—from capacitors, springs, elevated machine members, rotating flywheels, hydraulic systems, and air, gas, steam or water pressure—should be dissipated or restrained by appropriate methods such as grounding, repositioning, blocking, or bleeding down. These techniques should be covered in the written procedures.

(7) Perform checks as necessary to ensure that the equipment is properly isolated. One method of checking is to attempt to switch on the equipment. *When attempting to turn back on the equipment, clear everyone to a safe distance, clean up tools and loose parts, and ensure that feeder lines are properly secured. If the lockout/tag-out procedure was inadequate for any reason, it's possible that the equipment will reenergize and endanger the occupants in the room.* By using the normal operating controls, the feeder lines can be tested for energy; and the machine can be observed for signs of power. If the machine turns-on, lights-up, or has moving gauges, then power is likely getting to the equipment and the cause should be further investigated. Successful implementation of this check should increase the level of confidence in the lock-out procedure; and it serves to validate the process. Once this check has been completed, the operating controls should be switched back to the neutral or "off" position.

(8) The equipment should now be effectively locked-out.

Restoring the Equipment to Service

When reenergizing equipment or machines after a shutdown, it is important to follow a carefully controlled process to prevent injury or equipment damage. When the servicing is complete and the machine is ready to be returned to service, the following steps should be considered when instructions are not already available:

(1) Check the equipment and the immediate area to ensure that nonessential items have been removed from the area and that the machine components are operationally intact.

(2) Check the work area to ensure that all employees have been safely positioned or removed from the area.

(3) Verify that the controls are in neutral or “off”.

(4) Remove the lockout devices and tags.

(5) Provide any visual or audible safety warnings deemed necessary prior to re-energizing the equipment.

Note: The removal of some forms of blocking may be necessary prior to re-energizing the machine.

(6) Notify affected employees that the servicing, maintenance, or inspection has been completed and that the machine or equipment has been placed back into service.

4.7.7 Confined Space Entry

Tunnel inspections often include team members entering areas of confined space. Confined space is distinguished by the need to obtain a permit for entry, which is regulated by OSHA. Confined space is large enough for human entry with limited means of egress and not designed for continuous occupancy. Permit-required confined space usually poses a hazard or danger to the occupants. *When planning inspection in a confined space, it is advisable to consult with an appropriately qualified health and safety specialist, who is knowledgeable of applicable laws and regulations.*

There are five major concerns when performing inspections within confined space:

- Lack of oxygen – oxygen content should be maintained within certain limits to ensure the health of the inspectors and to lessen the chance for any explosions.
- Toxic gases – produced by tasks such as painting, burning, welding or operation of internal combustion engines.
- Explosive gases – natural gas, methane, or gasoline vapors may be present.
- Lack of light – many confined spaces are nearly totally dark. Inspectors need to be able to spot potential hazards and dangerous conditions. Adequate light is also necessary to perform the inspection
- Limited means of access – many confined spaces have limited points of access and therefore limited locations for emergency egress.

Figure 4.11 – Air testing and monitoring.

Proper ventilation, additional lighting, and effective communication procedures can help mitigate many of the hazards of confined space; however, some areas of confined space also require permits to enter along with specialized training to meet OSHA requirements.

Safety Procedures for Confined Space – OSHA publishes regulations that govern confined space entry, and these requirements must be followed. When operating in confined space, the proper training, equipment, and permitting are necessary. Equipment such as respirators, tie-off ropes, two-way radios, and meters to measure the gas levels may be required. It is important to monitor gas levels in areas of known ground contamination or where potentially dangerous materials are encountered.

The following safety procedures should be considered when inspecting areas that are characterized as confined space.

Pre-entry air tests (Figure 4.11):

- Test for oxygen with an approved oxygen testing device.
- Test for other gases, such as carbon monoxide, hydrogen sulfide, methane, natural gas, and combustible vapors.

Mechanical ventilation:

- Pre-entry – Oxygen and gas levels should be acceptable for a minimum prescribed time prior to entry.
- During occupancy – Ventilation should be continuous regardless of activities. Test for oxygen and other gases at prescribed intervals during occupancy.

Basic safety procedures:

- Avoid the use of flammable liquids in the confined area.
- Position inspection vehicles away from the entrance areas; and avoid creating carbon monoxide fumes.
- Position generators "down-wind" of operations.
- Operations that involve the production of harmful gases or dust should be performed "down-wind" of personnel.
- Carry an approved rescue air-breathing apparatus (Figure 4.12) as appropriate.
- Use adequate lighting with an appropriate backup system. Lifelines should be considered when entering areas that could become dangerous when dark.
- Inspection should be performed in teams, with a person remaining outside of the dark area or area of confined space. This person should be able to communicate with others if any serious problems develop.
- Use communication devices such as two-way radios or cell phones for general and emergency contact; however, make sure that any devices used are reliable in the areas where the work is being performed. Cellular phones may not work in all parts of the tunnel.
- Be familiar with the confined space entry plan and emergency or rescue procedures.

Figure 4.12 – Rescue air-breathing apparatus.

4.7.8 **Public Safety**

The requirements from the *Manual on Uniform Traffic Control Devices (MUTCD)* should be followed on how to position traffic control devices; this document is published by the Federal Highway Administration (FHWA). It is also available from the Institute of Transportation Engineers (ITE) and the American Association of State Highway and Transportation Officials (AASHTO).

All appropriate State, Federal Land, and Tribal government laws, regulations, and policies should also be followed. Coordination and advance planning is essential. Some jurisdictions may require that state or local police be on-site during the inspection to improve the safety of the inspection team and the travelling public. Suitable warning and protective devices are needed to alert the public of any potential hazards and dangers.

4.8 Inspection Equipment for Tunnels

Inspection tools are an important component of the inspection program. Equipment and tools that are commonly used for tunnel inspections are listed below:

- Aerial Bucket Truck or High Lift - Used to lift the inspector to areas inaccessible by foot or ladders and to provide close-up inspections.
- Awl/Boring Tool - Used to determine extent of deterioration in timber.
- Calipers - Used to measure steel plate thicknesses.
- Camera (35mm or digital) with Flash - Used to take photographs for documentation of the inspection.
- Chalk, Kiel, or Markers - Used to make reference marks on tunnel surfaces.
- Chipping Hammer - Used to sound concrete.
- Clipboard - Used to take notes and fill out paper forms during the inspection.
- Crack Comparator Gauge - Used to measure crack widths in fractions of an inch or millimeters.
- Dye Penetrant or Magnetic Particle Test Kits – Used to detect surface cracks in steel.
- D–Meter - Used to measure the thickness of steel.
- Extension Cord - Used to get electricity to inspection area. Surge protectors are advised.
- Field Forms - Used to document the findings, take notes, and draw sketches for the various structures.
- Flashlights - Used in dark areas to help illuminate objects during inspection.
- Portable Generator - Used when necessary to provide electricity for the inspection (lighting).
- Ladders - Used in lieu of a lifting system to access overhead areas not visible from the ground and to perform close-up inspections.
- Handheld infrared thermometer.
- Light Meter - Used to measure the brightness in the tunnel.
- Portable Lights - Used where tunnel lighting is inadequate during inspection.
- Pencil – Used to take notes and complete field forms.
- Plumb Bob - Used to check verticality of columns and wall faces.
- Pocket Knife - Used to examine loose material and other items.
- Sample Bottles - Used to obtain liquid samples.
- Scraper - Used to determine extent of corrosion and concrete deterioration.
- Screwdriver - Used to probe weep holes to check for clogs.
- Wire Brush, Paint Brush or Brooms - Used to clean debris from surfaces to be inspected.
- Tablet Personal Computer - Used to take notes or draw sketches in lieu of paper forms.
- Tape measures.
    - Pocket Tapes and Folding Rules - Used to measure dimensions of defects.
    - 100 ft. (30 m) Tape (Non Metallic) - Used to measure anything beyond the reach of pocket tapes and folding rules.

Safety equipment that meets appropriate industry standards should be furnished for the inspection team as follows:

- Appropriate devices for traffic control.
- First aid kit.
- Flashlights.
- Hardhats.
- Leather work gloves.
- Safety vests.
- Protective eyewear.
- Knee pads.
- Safety belts or harnesses.
- Work boots.
- Two-way radios appropriate for use in the tunnel. Cellular phones may be used as appropriate; however, these devices may not work in all areas of the tunnel. Only use devices that are fully functional in all areas to be inspected.
- Protective breathing masks if soot and dirt buildup is prevalent on the tunnel surfaces
- Air quality monitoring equipment.

4.8.1 Access Equipment

Access equipment includes man-lifts, bucket trucks, ladders, and/or removable scaffolding. This equipment is generally needed for close-up visual inspection of overhead items. This equipment allows the inspector to view the overhead structural elements and components of functional systems in a close-up, hands-on manner. In rare instances, binoculars may be used to locate surface defects on distant items, but this technique has many drawbacks and should be used on a limited basis.

4.8.2 Non-Destructive Testing

Non-destructive testing (NDT) methods may be used in areas that are difficult to access or in areas that require in-depth evaluations. NDT technology can also be used to characterize the extent of deficiencies in structural elements, and baseline readings from NDT technologies can be used to monitor defects over time. NDT methods are considered effective for evaluating:

- Water leakage.
- Delaminations and spalling of concrete liners due to reinforcing steel corrosion.
- Voids behind and within tunnel linings.
- Concrete permeability.
- Tiles separating from the tunnel liner.
- Detecting integrity of steel liners underneath concrete linings.
- Problems with integrity of ceiling systems and connections to the tunnel lining.

The techniques produce reasonable results when the surface area of the defects is at least 1 square foot and located at depths less than 4 inches below the surface. In some instances, these techniques are effective at deeper depths. NDT technologies are known to provide useful information; however, the limitations should be considered prior to use. Some common NDT technologies are:

- Air-coupled GPR
- Infrared thermography
- Scanners
- Ground-coupled GPR
- Ultrasonic tomography
- Ultrasonic echo
- Ultrasonic surface waves
- Impact echo

More information on NDT technology can be found at:

http://www.ndtoolbox.org/content/tunnels

There are various imaging techniques that can be used to verify the tunnel geometry and identify changes that occur with the tunnel surface over time. Also, infrared imagery is useful for identifying water leaks in the liner and component wear in motors or equipment. Water is relatively cool whereas worn parts on motors are usually hot, and infrared imagery can detect these temperature differences.

Each of these methods requires specialized and often proprietary equipment. Additional specialty equipment may be needed for in-depth tunnel inspections and for conducting mechanical and electrical equipment checks.

4.8.3 **Robotic Inspection**

There are numerous applications for remotely operated vehicles (ROV) for inspection of tunnels. An exhaust tunnel, in-take tunnel or a suspended ceiling may be efficiently inspected by high-resolution video camera attached to sufficiently nimble robotic equipment. Infrared technology can also be added to these devices. ROV inspections can be performed in tunnel sections where there is low oxygen, poisonous gases, dusty conditions from ventilation, or unsafe access for an inspection team.

ROV data collection technology provides safe and relatively accurate dimensioning of voids, leakage points or debris fields in confined spaces. Nevertheless, any nondestructive tests performed by the ROV are usually calibrated against some sort of visual observations to increase their accuracy and reliability. Cameras, sensors, lights, and other devices are commonly included on the platform of the robot. Common types of sensors include water, gas, and obstruction detectors. The robotic equipment can be set up to be operated by remote control. If tracks are permanently mounted within sections of a tunnel, the robot or drone can perform the inspection while the tunnel is in operation. Wheeled and tracked vehicles can also be used.

4.9 Inspection Techniques for Highway Tunnels

Inspectors should understand how defects impact the function and capacity of tunnel systems. Tunnel inspectors should be able to recognize the common deficiencies that impact the structural, civil, and functional systems. The observations and measurements used to carry out the inspection should be comprehensive. For each NTI tunnel element, the SNTI defines the general extent of deficiencies for each of the four condition states: good, fair, poor, and severe.

When taken as a whole, the element level data collected during the tunnel inspection will provide information on the overall safety and reliability of the structural, civil, and functional systems. The structural elements contained in the NTI database include tunnel liners, roof girders, columns and piles, cross passageways, interior walls, portals, ceiling slabs, ceiling girders, hangers and anchorages, ceiling panels, invert slabs, slabs on grade, invert girders, joints, and gaskets. The civil elements included in the NTI database are roadway wearing surfaces, traffic barriers, and pedestrian railings. The functional systems contained in the NTI database include the mechanical, electrical and lighting, fire and life safety, security, systems, sign, and protective systems. The written inspection procedures should cover all of these systems as appropriate for the particular tunnel.

4.9.1 **Structural Elements**

The SNTI defines condition states for tunnel liners, roof girders, columns and piles, cross passageways, interior walls, portals, ceiling slabs, ceiling girders, hangers and anchorages, ceiling panels, invert slabs, slabs on grade, invert girders, joints, and gaskets. Miscellaneous structural elements are not contained in the NTI database but should be inspected periodically to maintain safety. These elements include structural connections, doors, windows, frames, staircases, roofs, floors, brackets and supports, machinery pedestals, structural finishes, ancillary buildings, and auxiliary tunnel structures. The tunnel inspection organization should develop written procedures for inspecting the elements defined by the SNTI and also consult with the tunnel owner to develop procedures for inspecting any additional owner-defined elements.

4.9.1.1 **Structural Materials**

Structural elements are comprised of materials like steel, concrete, timber, and masonry. A number of material evaluation techniques are covered in the MBE. These include various field tests, material sampling, and laboratory tests. The MBE discusses field tests for concrete, steel, and timber. Concrete field tests include strength methods, sonic methods, ultrasonic techniques, magnetic methods, electrical methods, nuclear methods, thermography, radar, radiography, and endoscopes. Steel field tests include radiography, magnetic particle examination, eddy current examination, dye penetrant examination, and ultrasonic examination. Timber field tests include penetration methods, electrical methods, and ultrasonic examination. It is recommended that these methods be considered. Tests can be specifically identified in the inspection procedures of important structural elements to establish baseline conditions and maintain a history of periodic measurements, which might be useful for gaging performance and indicating potential problems.

In addition to any visual inspection procedures, structural members should be periodically sounded with hammers to help identify hidden defects below the surface that may not be apparent from making observations. After striking the surface with a hammer, structural elements will generally produce a fairly distinct sound. A clear ring generally indicates that competent material exists below the surface. Conversely, a dull thud or hollow sound typically indicates that the material below the surface contains a defect.

A dull sound in concrete over an area might signify the presence of a delamination where loose concrete could later spall. A hollow sound in timber might indicate a material with advanced decay. A dull thud from steel might indicate heavy corrosion; or in the case of a thin member, the sound might indicate that the steel member is not securely fastened or mounted. Once a dull sound is detected, the surface of the material should be further sounded to define the extent of the area impacted by the defect.

General inspection techniques are discussed below for common structural materials (e.g., steel, concrete, timber, and masonry).

I. Steel Structures

Steel structures are affected by corrosion, cracks, buckles and kinks. Other defects may also be present such as leaks and protective system failures.

(1) Corrosion

Corroded steel varies in color from dark red to dark brown (Figure 4.13). Initially, corrosion is fine grained, but as it progresses, it becomes flaky or scaly in character. Eventually, corrosion causes pitting in the member. The locations, characteristics, and extent of all corroded areas should be noted. The depth of severe pitting should be measured; and the size of any perforations caused by the corrosion should be recorded as well as the member section remaining.

Figure 4.13 – Minor corrosion along roof girder.

(2) Cracks

Cracks in the steel may vary from hairline thickness to a width sufficient to transmit light. In structural steel members, any type of crack can be serious. It should be reported right away and evaluated by an engineer. Look for cracks radiating from holes, cuts, notches, and welds.

(3) Buckles and Kinks

Buckles and kinks develop mostly because of damage that arises from thermal strains, overload, or other load combinations that produce failure or yielding of the steel such as from collision damage, fire damage, or soil interaction.

(4) Leakage

Steel is impermeable; however, leaks can occur where water is able to penetrate through joints, cracks, or holes in the steel. The seals, gasket materials, and welds should be checked to determine if they are defective. Also differential movements that open up the joint may be taking place.

(5) Protection System

Steel is often protected by paint or galvanizing. Weathering steel can also be used. Paint systems fail by peeling, cracking, corrosion pimples, and excessive chalking. Galvanizing is typically applied in a kettle or vat containing molten zinc where the iron in the steel reacts with the molten zinc to form a tightly bonded alloy coating. Flaking and chipping are common defects.

II. <u>Concrete Structures</u>

Some common concrete defects include scaling, cracking, delamination, spalling, pop-outs, mud balls, efflorescence, staining, and honeycombing. Water leaks may be present with some of these defects, adversely impacting any reinforcing steel exposed to the leak. Additional information on concrete defects, including typical photographs, can be obtained from the American Concrete Institute (ACI).

(1) Scaling

Scaling is the local flaking or peeling of a finished surface of hardened concrete associated with the gradual and continual loss of mortar and aggregate. The scaling is considered light when the coarse aggregate below the surface is not exposed; however, the scaling is considered severe when the coarse aggregate is clearly exposed.

(2) Cracking

A crack is a linear fracture in the concrete created when the tensile forces exceed the tensile strength of the concrete. Cracks can occur during curing (non-structural shrinkage cracks),

ground movement, or external loads (structural cracks). Cracks may extend partially or completely through the concrete member. Cracks may be active or dormant. If the crack is active, it will propagate in length, width or depth over a measured period of time. If the crack is dormant, it will not change with time; however, some dormant cracks can further degrade if not repaired as moisture penetrates into the crack causing additional damage from exposure to freeze/thaw cycles.
The direction of the crack relative to axis of structure should be observed and measured. The location, width, length, depth, and the spacing between cracks should be measured and recorded. Based on various observations and measurements, the cracks can be classified. The common types of cracks found in tunnels include longitudinal, transverse, vertical, diagonal, and random cracks.

- Transverse Cracks – These are fairly straight cracks that run roughly perpendicular to the span direction of the concrete member. These cracks vary in width, length, depth, and spacing. Transverse cracks may extend partially or completely through an element (i.e., slab, beam, curbs).
- Longitudinal Cracks – These are fairly straight cracks that run parallel to the span of the concrete slab or beam. These cracks vary in width, length, depth, and spacing. Longitudinal cracks may extend partially or completely through an element such as a slab, beam, or other element.
- Horizontal Cracks – These cracks occur in walls and vertical members but may also exist on the sides of beams where there are either encased steel flanges or corroded reinforcement. These cracks are similar to transverse cracks.
- Vertical Cracks – Vertical cracks occur in walls and other vertical members; these cracks are similar to longitudinal cracks.
- Diagonal Cracks – These cracks run at roughly diagonal angles relative to the centerline of the structure and are usually parallel to each other, shallow in depth and vary in length, width, depth, and spacing. When found in the vertical faces of beams, they signify the existence of a potentially serious problem.
- Pattern or Map Cracks – These are interconnected cracks that form a network, which vary in size and depth as shown in Figure 4.14. The width of these cracks ranges from barely visible, or fine-cracking, to well-defined, open cracks. These cracks are commonly found in members with broad surfaces such as slabs and walls.
- D-Cracks – D-cracking refers to cracks in a concrete caused by freeze/thaw deterioration of aggregates. D-cracks are closely spaced cracks that begin to form parallel to longitudinal and transverse joints, afterwards, these cracks proliferate outward away from the joints toward the interior of the element.
- Random Cracks – These are meandering irregular cracks on the surface of concrete. They have no particular form and do not necessarily fall into any of the classifications described above.

Figure 4.14 – Map or pattern cracks on the underside of an invert slab.

(3) Delamination

As the concrete hardens, water and air that is trapped below the surface can develop into subsurface voids. This often occurs when bleed water is trapped below the surface due to premature troweling, which reduces the permeability of the surface. These types of voids create weakened zones below the surface that can eventually detach and lead to concrete spalling. This is one area of the concrete surface that produces a hollow sound when struck by a hammer. Determine the extent of these areas and document them.

(4) Spalling

Spalling is the detachment of hardened concrete fragments that leave shallow, roughly circular or oval shaped depression in the concrete surface. Usually, the depression rim cuts roughly perpendicular to the surface; and the base is parallel, or slightly inclined to the surface. Delaminated concrete is subject to spalling. Steel reinforcement may also be exposed where the spalling is severe (Figure 4.15). The inspector should record the location, width, length, and depth of the spalled area and note any exposed reinforcing.

Figure 4.15 – Concrete spalling with exposed reinforcing steel.

(5) Joint Spall

This is an elongated depression along an expansion, contraction, or construction joint. The defect should be inspected as described above for concrete spalling.

(6) Pop-Outs

These are conical fragments that break out at the surface of the concrete and leave a small hole. A shattered aggregate particle will often be found at the bottom of this hole adhering to the small end of the pop-out cone.

(7) Mud Balls

These are small holes that are created in the surface by the dissolution of clay balls or soft shale particles that were introduced into the concrete mix. Mud balls have similar effect on the surface of the concrete as a pop-out.

Figure 4.16 – Moderate cracking and efflorescence on the underside of the liner.

(8) Efflorescence

This is a deposit of water-soluble calcium hydroxide that forms on the concrete surface. It is usually white and emerges from the concrete as solution materials crystallize as salts. Efflorescence may also occur because of contaminates in the ground water or de-icing salts. Salt crystal stalactites can form on tunnel ceilings from severe efflorescence (Figure 4.16).

(9) Staining

Staining is a discoloration of the concrete surface caused by the passing of dissolved materials through cracks and re-depositing the materials on the surface as water emerges and then evaporates. Although staining can be of any color, brown staining usually signifies that corrosion is occurring in the underlying steel reinforcing.

(10) Honeycomb

Honeycombing occurs in concrete when the mortar does not completely fill the voids between coarse aggregate particles. Since the shape of the aggregate is visible, it gives the concrete the honeycombed appearance.

(11) Leakage

Leakage occurs in regions of the concrete surface where water has penetrated through cracks, joints, or other imperfections in the concrete. It is important to note the temperature when checking for leaks. The full effect of leakage might not be known when temperatures are below freezing since ice can mask the effects of leaks. The portions of the concrete structure that are below the water table should be carefully checked at joints for leaks.

III. Timber Structures

(1) Decay

Decay is the primary cause of timber deterioration; it is produced by living fungi that feed on the cell walls of timber (Figure 4.17). Molds, stains, soft rot (least severe), and brown or white rot (most severe) are common types of fungi that cause decay in timber materials. With heavy decay, timber may become discolored and soft, and section loss may occur. The amount of decay and section loss should always be noted in the inspection report.

Figure 4.17 – Examples of defects in timber liners

(2) Insects

The presence of insect infestation should be noted in the inspection records and the type of insect should be recorded if known. An insect may be placed into a container or a picture taken for later identification. Saw dust or powdered dust on or around the timber members could indicate the presence of wood eating insects, and this dust should be noted. Photographs of the insect mounds may be used to document the extent of damage. Termites and carpenter ants are common types of insects that can cause timber deterioration.

(3) Checks/Splits

Checks are cracks in timber, which extend partially through the timber member; the percentage of penetration through the members should be identified with checks. Cracks that extend completely through the member are called splits. Checks and splits result from shrinkage after drying or from seasoning of the timber and should be noted in the inspection report.

(4) Fire Damage

Fires can blacken and char timber and cause appreciable section loss. Fire damage is easily evaluated on most timber structures, but it can be a time consuming process. The best way to ascertain the extent of damage is to chip away at the charred remains in several locations and then measure the section remaining in the undamaged timber. The greatest section loss often occurs where two or more members have been fastened together.

(5) Hollow Area

A hollow area usually indicates either advanced decay in the interior of a timber or the presence of wood eating insects. Hollow areas should be noted in the inspection report to show the size, location, and extent of damage in the area hollowed.

(6) Leakage

Leaks occur in timber where water is penetrating through a joint, check, split, or some other defect in the timber such as a knot.

IV. <u>Masonry Structures</u>

(1) Masonry Units

The individual stones, bricks, or blocks of masonry structures should be checked for displaced, cracked, broken, crushed, or missing units. Some types of masonry surfaces are susceptible to deterioration or weathering.

(2) Mortar

The mortar should be checked to ensure that it is effectively bonded to the masonry unit at the joint. It is particularly important to note cracked, deteriorated, or missing mortar.

(3) Shape

Masonry arches are primarily used in compression applications; flattened curvature, bulges in walls, or other shape deformations may indicate unstable conditions with tension cracks.

(4) Alignment

The vertical and horizontal alignment of the masonry should be checked visually. Plumb bobs and lasers may be useful tools for assessing these conditions.

(5) Leakage

Leaks often occur in regions of the masonry where water penetrates through joints, cracks, or other imperfection. Efflorescence accumulations might help locate areas with active leaks.

4.9.1.2 **Liners**

Tunnels liners were discussed in Chapter 1 of this manual. The tunnel liner supports the ground around the tunnel and restricts groundwater infiltration into the tunnel. Many tunnels have a two-pass liner system consisting of an initial liner (or temporary support) and a final liner (or permanent support). Initial support is typically provided by shotcrete and rock bolts, ribs and lagging, and slurry walls. The final liner is usually made of either cast-in-place concrete liners or bolted and assembled precast concrete segments.

The subsurface conditions can be obtained from published geologic reports, project geotechnical reports and test borings, and construction documents. The ground and groundwater conditions should be plotted along the tunnel profile similar to that shown in Figure 4.18 with the locations of deficiencies noted. A geotechnical engineer should determine if the ground conditions are contributing to the problems and recommend solutions.

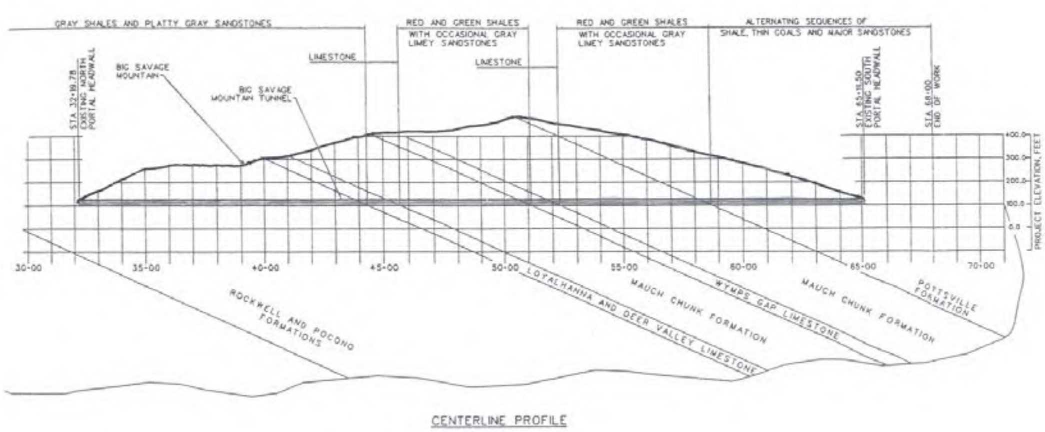

Figure 4.18 – Sample profile of geologic ground conditions.

Steel Liners – Structural steel is often not used as a final liner material due to its relatively high cost, fabrication requirements, and susceptibility to corrosion. Many rock tunnels in mountains have exposed steel liner plate above the springline to prevent rocks from falling onto the roadway, see Figure 4.19. Older tunnels in soft ground, hard rock, or under water may have incorporated steel components as part of their initial support. Common temporary liner components include liner plates, steel ribs, columns, beams, and prefabricated shell elements. Many of these steel elements were not designed to be part of the permanent structural load-carrying component of the tunnel and were not sufficiently protected against corrosion. Typically, the temporary steel elements were covered or encased in concrete final liners. If structural steel components have been incorporated into the tunnel liner, then these steel elements should be inspected using the methods described previously for structural steel materials.

Figure 4.19 – Steel liner plate above the springline.

Concrete Liners and Shotcrete – Precast concrete liners (Figure 4.20 A) and cast-in-place concrete liner (Figure 4.20 B background) make up the bulk of all permanent final lining systems installed in highway tunnels. Because of its availability, ease-of-use, durability, and relatively low cost, concrete liners have been installed in all types of tunnel projects. Shotcrete, also referred to as pneumatically sprayed concrete, is commonly used for temporary support and as final liners in lightly loaded structures (Figure 4.20 B foreground) such as a rock tunnel that supports only the loose rock that could fall onto the roadway.

Figure 4.20 A – Example of precast tunnel liner segments.

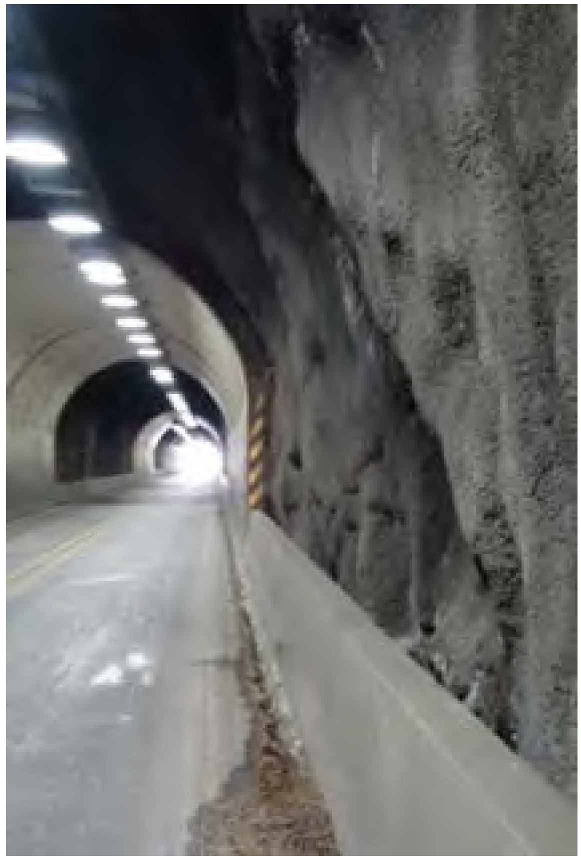

Figure 4.20 B – Shotcrete tunnel liner foreground with adjacent cast-in-place liner concrete liner background.

Photos of some typical deficiencies in concrete liners are shown in Figure 4.21 and Figure 4.22. Concrete liners should be inspected using the methods previously described for structural concrete materials.

Architectural Finish – Many concrete tunnel liners are covered by an architectural finish such as ceramic tiles or metal panels (Figure 4.23). When inspecting these surfaces, it is recommended that the inspector use a hammer to sound the substrate concrete or a rubber mallet to tap on the tile finish. This should be done at multiple locations throughout the tunnel, and it should be done near known defects or when defects are suspected. When hollow sounding areas are detected, the limits of the areas should be defined.

When documenting spalls, the size, maximum depth, and location of the spalls should be noted. If there is exposed reinforcing steel, the amount of section remaining should be noted; also, provide the percentages of section loss. When inspecting cracks, the length, width, depth, and location should be documented. Cracks with moisture or corrosion staining should be noted.

Visually inspect cracks for moisture, leakage, corrosion, staining, and efflorescence. Record the amount of active leakage in number of drips per minute or estimate the continuous rate of flow.

Figure 4.21 – Cracks with rust stains.

Figure 4.22 – Medium width crack in concrete liner.

Figure 4.23 – Water leakage through tunnel liner and missing wall tiles.

Figure 4.24 – Damp cracks in segmental liner due to improper installation techniques.

Segmental Rings – When inspecting precast tunnel segments, the concrete should be inspected using the techniques previously discussed. The joints of the precast concrete liners should be inspected for cracks and leaks (Figure 4.24). Joint hardware such as end plates, bolts, and gaskets should also be inspected for each segment.

- The connection bolts on fabricated concrete liners may be discolored due to moisture and humidity conditions in the tunnel. This condition does not downgrade the structural capacity of the bolt. Particular attention should always be given to bolts in regions of water leaks to check for loss of section. If losses in the section are observed, then this should be noted in the inspection report.

- The cross-sectional shape should be compared against the shape shown in the drawings to evaluate possible changes in cross section.

Timber Liners – Timber liners (Figure 4.25) have been installed in some mountain tunnels to prevent loose rock from falling onto the roadway. The timber liner may be composed of roof or ceiling sections with or without wall elements. Timber liners should be inspected using the methods previously described under structural timber materials.

Figure 4.25 – New timber rib and lagging liner.

Figure 4.26 – Timber liner in state of deterioration.

Masonry Liners – Masonry tunnel liners have not seen much use for highway tunnels since this method was largely supplanted by concrete technology that came into existence before many highway tunnels were built. Nevertheless, masonry structures are quite common at tunnel portals and other ancillary buildings. Masonry materials should be inspected using the methods previously described under structural masonry materials.

Unlined Tunnels in Hard Rock – Tunnels may be unlined in some hard rock applications; however, these tunnels typically need reinforcing to prevent loose rock from falling into the roadway. Rock bolts and dowels are often used for this purpose. Support from timbers, steel plates, or shotcrete may also be used in limited areas of unlined tunnels to prevent rocks from falling onto the roadway. Unlined tunnels are self-supported by the competent rock. Figure4.27 shows unlined rock tunnels.

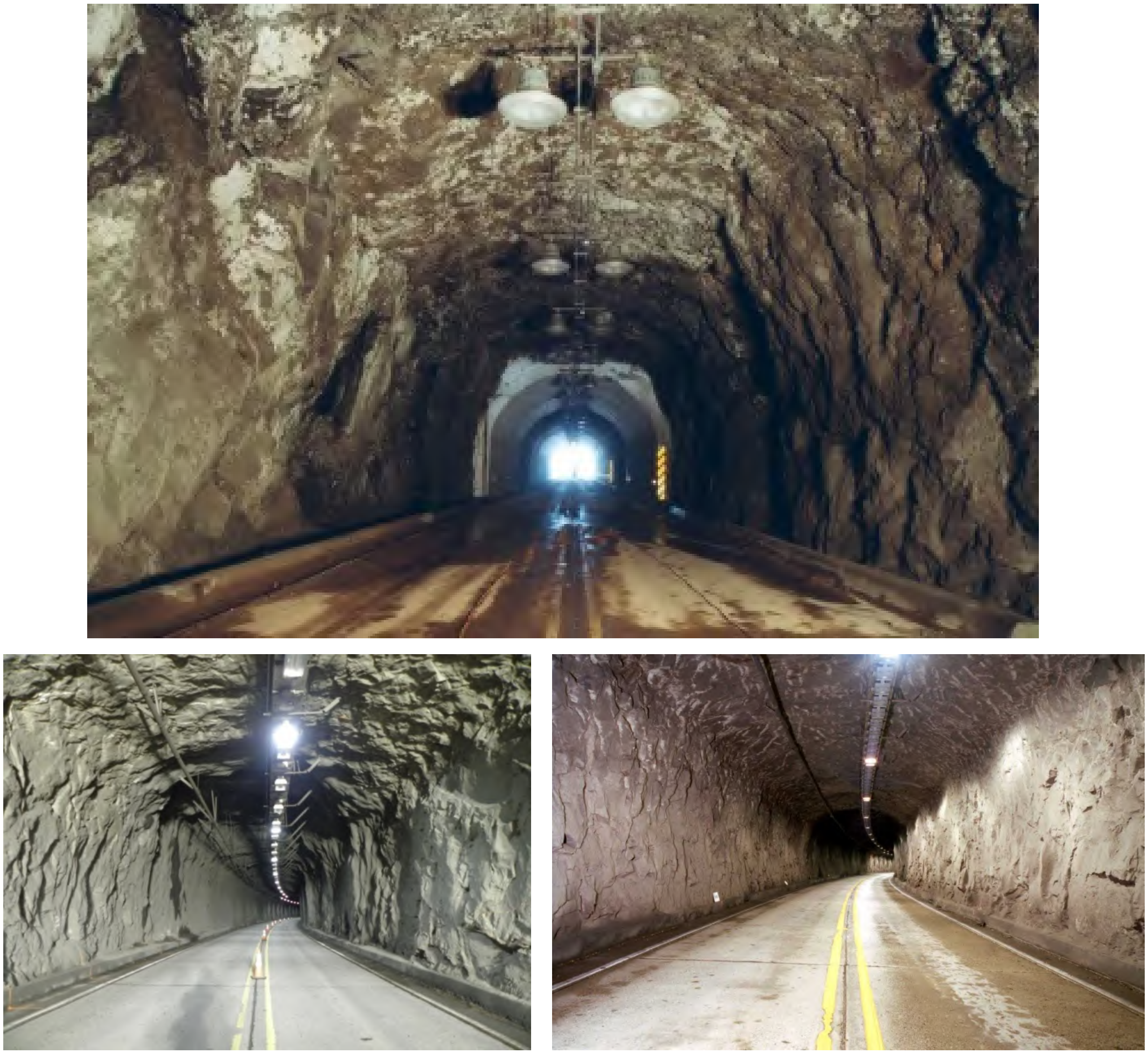

Figure 4.27 – Various unlined rock tunnels.

A qualified geologist or geotechnical engineer should assist the inspection team when inspecting self-supported tunnels in rock. Identify the deficiencies in the rock mass that could potentially pose safety and stability problems or nuisance issues for maintenance of traffic. The cross-sectional shape of the tunnel should be monitored for potential changes by taking measurements at predetermined intervals (approximately 200 ft. intervals). The distances between the spring line and vertical sidewalls should also be measured at specific points; the locations should be permanently marked.

4.9.1.3 **Roof Girders**

A roof girder is the main horizontal support for a flat tunnel roof (Figure 4.28). The roof girders support the tunnel roof and the loads from the backfill, surcharge, and traffic above. Girders are used to support a deck system (Figure 4.29), and these girders can be steel or concrete. Inspect these elements using the methods previously described for structural concrete or steel materials.

Figure 4.28 – Typical roof girder bay.

Figure 4.29 – Exposed roof girders.

4.9.1.4 **Columns and Piles**

Columns and piles are vertical load bearing elements that are usually comprised of concrete or steel components. Piles are embedded into the ground. Columns are free standing members located above the ground level. Lateral bracing may be incorporated to stiffen the columns. Figure 4.30 shows a typical set of columns with a bent cap. Inspect these elements using the methods previously described for structural steel and concrete materials.

Figure 4.30 – Columns with bent cap.

Figure 4.31 – Emergency corridor with minor leakage.

4.9.1.5 **Emergency Corridors**

Emergency corridors provide a means of escape from the tunnel. Parallel tunnels may be linked by cross passageways. In emergencies evacuees can move to safety through a cross passage and escape through an adjacent tunnel. Therefore, these evacuation passageways should not be cluttered with objects or debris, and doors should be operable. These areas should ideally be slightly pressurized to maintain positive air flow to prevent smoke from entering the escape route, which helps to maintain a tenable environment for evacuees and emergency responders.

The inspector should check for cracks, delaminations, and spalls in the concrete walls, ceilings, and floors. Check for leaks (Figure 4.31). Look for build-up of maintenance debris in the rooms. Examine the utilities, lights, and electrical conduit, and any safety systems for deterioration. If the passageway is pressurized, an operational check of this system is required. Miscellaneous structural checks should be performed on all of the structural connections, doors, windows, frames, roofs, floors, curbs and walkways, staircases, brackets and supports, and structural finishes.

4.9.1.6 **Interior Walls**

The tunnel liner is in contact with the ground; whereas, interior walls are not. Interior walls are usually constructed using concrete materials. These walls separate opposing traffic, the travel way from the ventilation plenum, or the travel way from the emergency egress corridor. Written procedures should address the unique identification of interior walls and the survey control processes for reporting inspection findings. Figure 4.32 shows an emergency egress corridor, lined with concrete interior walls.

Concrete walls should be inspected using the methods previously described under structural concrete materials. Concrete walls should be inspected using a hammer to sound the substrate concrete or a rubber mallet to tap on the tile finish at random locations and at areas adjacent to defects. When hollow sounding areas are detected, the limits of these areas should be defined. Mark out these

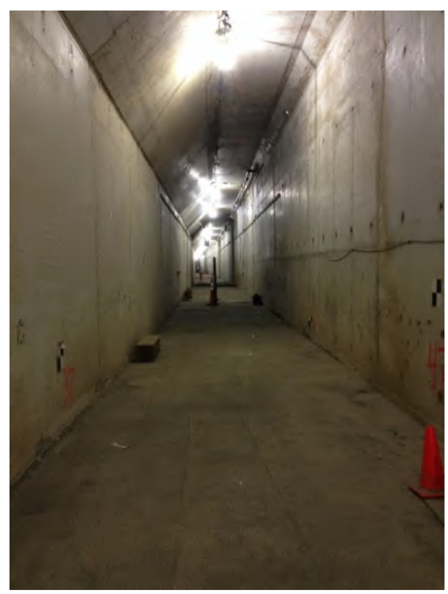

Figure 4.32 – View down emergency corridor. Wall on right is interior wall; wall on left is tunnel liner.

areas using keel or paint. Note the size, maximum depth, and location of the spalls; and note any exposed reinforcing steel. Check and document the percentage of section loss, if present, at exposed reinforcing steel. Document the length, width, depth, and location of cracks. Visually inspect for moisture, leakage, corrosion, staining, and efflorescence. Note any cracks with moisture penetration or corrosion staining. Record the amount of active leakage in number of drips per minute or measure the flow rate.

Figure 4.33 – View of tunnel with metal panel finish covering concrete liner.

Architectural Finishes – Many concrete tunnel walls are not visible because they are covered by architectural finishes such as ceramic tiles or metal panels (Figure 4.33). Tile walls should be checked for cracked, delaminated, or missing tiles that could indicate defects in the underlying substrate concrete. Missing tiles may be the result of moisture and water penetration through the concrete substrate. Check the exposed substrate concrete for cracks, delaminations, and spalls. Look for spalled concrete behind missing tiles and at construction joints between wall segments where reinforcement steel may be exposed. The degree of surface deterioration and condition of anchor bolts should be checked on metal panels. Note all conditions described above in the inspection report.

4.9.1.7 **Portals**

Tunnel portals are located at the entrances and exits of the tunnel (Figure 4.34). When inspecting the portal facades, it is important to consider the condition of the elements that are above the roadway since spalls or falling objects from above could impact the safety of tunnel users. It is also important to document the condition of material outside and above the portals, especially if there are concerns for landslides. A landslide could easily damage the portal façade or portal buildings. A qualified geotechnical engineer or geologist should assist the inspection team when evaluating the potential for landslides.

Inspect the walls, ceilings and floors of the portal building for cracks, delaminations, and spalls using the methods described for the appropriate structural material. Use a hammer to sound the walls at random locations and around defects. Look for build-up of debris in the rooms. Examine the utilities, lights, and electrical conduit within the rooms for deterioration. Miscellaneous structural checks should be performed on all of the structural connections, doors, windows, frames, roofs, floors, staircases, brackets and supports, and structural finishes within the portal buildings and auxiliary structures. Implement miscellaneous structural checks as appropriate.

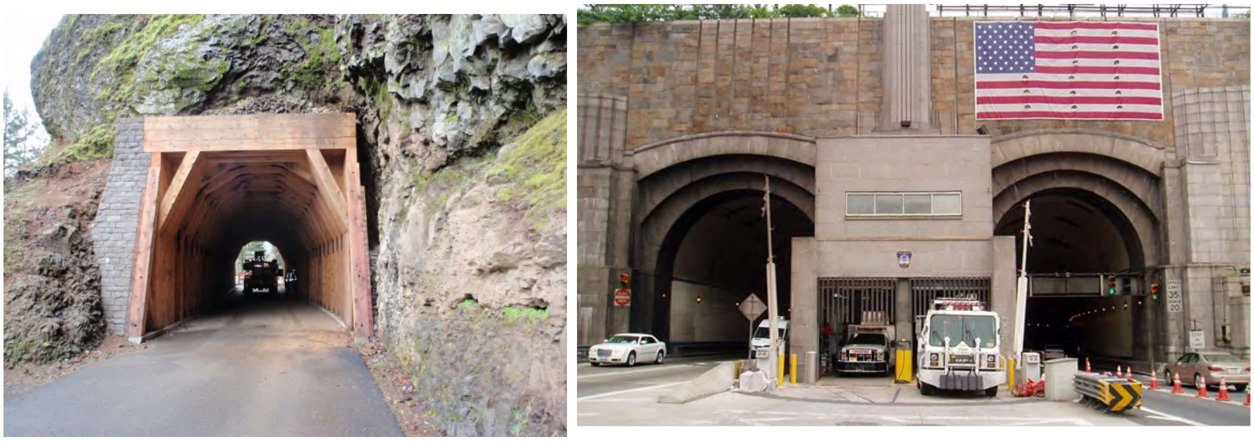

Figure 4.34 – Tunnel portals range from simple (left) to complex (right) structures.

4.9.1.8 **Tunnel Ceiling Structures**

Tunnel ceiling structures consist of slabs or panels that are supported by girders or hangers and anchorages. Many tunnels were installed with ceilings above the roadway to create space for ventilation. This space, commonly referred to as the upper plenum, is used to either exhaust or supply air to the tunnel. Sometimes the upper plenum also contains utilities.

The configuration of the upper plenum depends on the shape of the tunnel. For example, a circular tunnel will have roughly a half moon shape, while a box tunnel will have a box-shaped plenum, see Figures 4.2 through 4.4. The inspector should ensure that all air distribution diffusers, registers, and passages are in good condition and free of debris accumulation.

The structural elements of tunnel ceilings include either reinforced concrete ceiling slabs or precast concrete ceiling panels that are supported by either girders or hangers and anchorages. These structural support systems carry loads from their own weight, ventilation pressures, live loads from personnel, wind pressure from trucks, and earthquakes. Many ceiling structures are relatively heavy, providing stability when large trucks pass through the tunnel and create air pressure waves between the truck and the ceiling. Because the ceilings are located directly above the roadway, the potential exists for these objects to fall onto the roadway below. When inspecting ceiling structures, it is critical to carefully and thoroughly examine each component of the ceiling support system to ensure that the ceiling loads are being transferred into the support members as intended. *It is advised that detailed written inspection and maintenance procedures be fully developed and completely implemented when tunnels have heavy ceilings elements installed over traffic*. Prior to conducting an inspection of ceiling elements, the inspector should review all pertinent drawings and procedures.

Figure 4.35 – Overhead items such as ceiling panels must be inspected to prevent fatalities.

Hangers and Anchorages – If the ceiling structure is supported with hangers and anchorage held by adhesive epoxy anchors, then these anchorages should be repaired in accordance with *FHWA's Technical Advisory – Use and Inspection of Adhesive Anchors in Federal-Aid Projects.* The inspector should refer to FHWA Technical Advisory T 5140.30, which superseded T 5140.26. A copy of this document is found at the link below:

http://www.fhwa.dot.gov/bridge/t514030.cfm

If anchors have pulled out or are loosening, the tunnel owner should be immediately notified since this poses a significant safety concern (Figure 4.35). Remedial action may be necessary such as installing new supports that incorporate mechanical anchorages with the hanger rods, or a similar system that does not rely on epoxy in sustained tension. Figures 4.36 and 4.37 show some common defects in hangers.

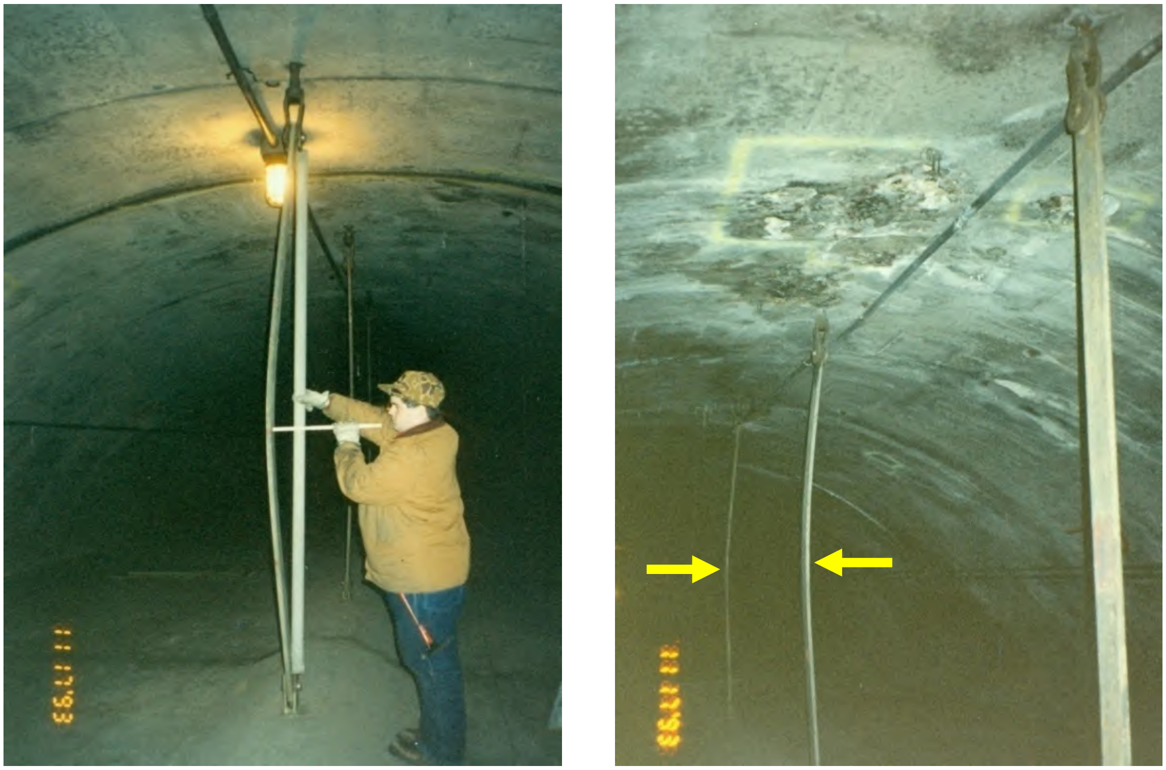

Figure 4.36 – Bent ceiling slab hanger.
Note: Successive hangers are bent.

Figure 4.37 – Hangers and ceiling girders exhibiting moderate to heavy rust and minor section loss.

Exposed steel support system elements should be inspected for corrosion and section loss as well as for missing bolts at the connection points for the support beams or the hangers and anchorages. Document the locations of missing bolts, deteriorated beams, or hangers. Verify that the hanger connections are intact; and ensure that there is no vertical displacement in any of the embedded supports or exposed anchors.

Visually inspect the hangers to determine if they are bowed. A bowed hanger possibly indicates that the ceiling slab was pushed up from either vehicle impact, air pressure, or other means. One method to verify hangers are in tension is by "ringing" each hanger. Ringing a hanger is done by lightly striking it with a mason's hammer. A hanger in tension will vibrate or ring like a bell after being struck; while a hanger that is not loaded in tension because of a loose connection or other defect, will not ring. Rather, a dull thud will be heard. If the hanger does not ring, inspect the hanger carefully and verify that the ceiling system is structurally sound.

Tunnel Roof – If the tunnel has a ceiling support structure with hangers attached to the roof, check the connection locations of these supports at both ends (tunnel roof and ceiling slab or panel) for cracks, delaminations, and spalls. Check the roof area in the vicinity of the hangers for cracks in the concrete, delaminated concrete, and spalls to verify solid embedment. Use a hammer to sound random areas and areas suspected of concrete defects adjacent to the hangers.

Ceiling Girder – A ceiling girder is the main horizontal support for the ceiling panels or slabs. These structural elements are used in place of hangers and anchorages. Ceiling girders use various structural shapes (Figure 4.37). They are usually steel or concrete and should be inspected using the methods previously described for structural concrete and steel materials.

Ceiling Slabs and Panels – Slabs are cast-in-place concrete elements, whereas, panels are precast concrete elements. Both serve the same function in the ceiling system. The topside and underside of the ceiling should be inspected. Note the location of any cracked or deteriorated ceiling panels. Document the length, width and locations of cracks in the ceiling slab. Visually inspect for spalling. Note the size, maximum depth, location and any exposed reinforcing steel details at the locations of the spalls. Note the locations of cracks; look for moisture penetration and corrosion staining. At random locations and adjacent to all defects, a hammer should be used to sound the substrate concrete or a rubber mallet to tap the tile finish.

The top side of the ceiling panels and the ceiling support system are often examined from within the upper plenum. Check the top side of the ceiling panels for cracks, corrosion stains, efflorescence, spalls, disintegrated concrete and evidence of moisture. Observe for displaced seals between the panels. Examine the ceiling support system for corrosion and section loss as well as missing bolts.

At the bottom face of the ceiling panels, inspect concrete surfaces using the methods previously described for structural concrete. Focus on the inspection techniques for scaling, cracks, delamination, and spalling. Check for exposed reinforcing steel at any spalls and document the section loss (Figure 4.38). Visually inspect for moisture and corrosion staining at cracks; and note efflorescence at crack locations.

Figure 4.38 – Delaminated and spalled concrete with deteriorated and exposed reinforcing steel on underside of concrete ceiling slab.

An architectural finish may be placed on the underside of the ceiling slabs or panels in some cases (Figure 4.39). If ceramic tiles, concrete-filled metal pans, or steel composite metal pans make up the underside finish, their condition is evaluated more rigorously than on the walls, since delaminated tiles can fall onto the roadway. Check the ceramic tile finish for cracked, delaminated or missing tiles, which could indicate defects in the substrate concrete. Examine any exposed substrate concrete for cracks, delaminations, and spalls.

Figure 4.39 – Examples of damaged and deteriorated architectural finishes on underside of ceilings. Photo left is of damaged metal ceiling panels; right is deteriorated ceramic tile.

4.9.1.9 **Tunnel Invert Structures – Slabs, Girders, and Slabs on Grade**

Tunnel invert structures consist of slabs that are supported by girders or on grade. When the roadway is a structurally supported slab, then the space below the supported roadway is used for ventilation and drainage. The supported invert slab acts like a bridge deck that carries traffic loads.

When inspecting invert structures, the size and location of the defects should be documented. Check the concrete for cracks, delaminations, and spalls; use a hammer to sound random areas of the invert for delaminated concrete and sound areas around cracks and spalls. Record the sizes and maximum depth of the spalls. Note any section loss for exposed reinforcing steel. If severe spalling is present, a sketch should be prepared to show the extent and location of the spalling. Note exposed reinforcing steel in the spalls and record any section loss. Cores may be needed to determine the chloride ion content prior to making recommendations for repair or replacement. Document the length, width, and location of all cracks and delaminations. Check for signs of moisture penetration. Note all corrosion staining, dampness, map cracking, and efflorescence. Document the severity and locations of all other defects. Provide percentages of total invert area for map cracking, moisture penetration, efflorescence, and delaminations. Check for excess debris accumulation resulting in standing water, and confirm that the lower plenum is draining into the sumps.

Invert Slab – Inspect the topside and underside of the slab. The topside of the slab might be obscured by the wearing surface; nondestructive testing can supplement the inspection process. The tight space below the slab could also preclude direct inspection from below the slab in the lower plenum; and robotic video inspection techniques can be used for inspecting tight spaces like these. Examine the concrete slabs for cracks, delaminations, and spalls. Use a hammer to sound random areas of concrete for delaminations, and sound the concrete adjacent to cracks and spalls. Note exposed reinforcing steel in the spalls and record any section loss. Check for signs of moisture penetration through the concrete. Also note corrosion staining, dampness, and efflorescence. Document the amount of active leakage in number of drips per minute or measure flow rate. Check for areas of potential localized failure due to punching shear at large spall locations and where large potholes occur.

Invert Girder – An invert girder refers to the main horizontal support for the slabs. These steel or concrete girders should be inspected using the methods previously described for structural concrete and steel materials.

4.9.1.10 **Joints and Gaskets**

Joints are integral to many structural elements and are used to simplify construction or accommodate strains from thermal movements. Joints are typically sealed or have gaskets to keep out water.

Joints – Examine joints for deterioration, efflorescence and moisture penetration. Check for joints at the transitions between segments, at the connections to ancillary buildings, and at auxiliary structures. Check the concrete around the joint for cracks, spalls and delaminations. Use a hammer to sound the concrete adjacent to the joint. Check the position and condition of the joint material. Check the condition of sealants between precast panel members. Closely examine the alignment and check for any signs of differential settlement, which can lead to other serious defects. Document the locations and severity of moisture penetration or joint deterioration.

Gaskets – There are many types of gaskets such as lead, mastic, or rubber. Gasket materials can become dislodged from the joint due to water infiltrating though the joint, loosening of fastening bolts, etc. Gaskets can also fail due to chemical or biological deterioration of the material. Structural movements of the liner can also tear or otherwise distort the gasket and cause it to leak. Differential settlement often leads to other defects. Extra time should be spent investigating transition areas such as where the tunnel support conditions change at connections to buildings. The location of these areas should be evident from existing as-built drawings. Note all gasket deficiencies including the length, width and locations of cracks, loose or broken fasteners, or leaks of any kind.

4.9.1.11 **Miscellaneous Structural Checks**

Although these items are not specifically reported to the FHWA, it is good practice to complete miscellaneous structural checks on structural connections, doors, windows, frames, roofs, floors, staircases, brackets and supports, and structural finishes in the tunnel, ancillary buildings, or any auxiliary structures. These items should be included in the written inspection procedures developed by the tunnel owner.

Structural Connections – The connection bolts, rivets, and welds should be carefully checked. Bolts on precast concrete, steel, and cast iron liners may be discolored due to moisture and humidity conditions in the tunnel; however, the discoloration usually does not reduce the structural capacity of the bolt. Particular attention should be given to bolts in regions where leakage occurs as section loss might result. A bolt can be rung with a hammer to determine if it's tight, but it's preferable to use a wrench. Section loss and missing or loose bolts should be noted in the inspection report. Observe the condition of welds for cracks and tears. Dye penetrant inspection may be helpful for detecting cracks. Coatings may protect welds from corrosion.

Doors – During the inspection, all of the doors and windows encountered should be opened and closed to verify their operability. Some door components may be deteriorated, stuck, or inoperable (Figure 4.40). The door hardware should be checked to ensure that the latches sufficiently engage the door frame and that the door can be closed securely. The door and the frame might have corrosion, delamination, or section loss. Security sensors should also be checked to be sure they are operational.

Figure 4.40 – Doors

Windows and Frames – Steel window frames may be corroded, deteriorated, or experience section loss. Some of these may be stuck or inoperable. When concrete window frames are inspected, check for cracks, delaminations, and spalls in the concrete material. The condition of protective coatings should also be documented.

Stairs – Stairs are typically built with either reinforced concrete or steel (Figure 4.41). Reinforced concrete stairs sometimes have steel tread plates incorporated in the concrete. Inspect the rails, posts, and railing anchorages for missing or broken sections, damage and deterioration, cracks or corrosion, and section loss. Inspect for cracked welds at the connections and for loose or missing bolts. Document the severity and location of any defects.

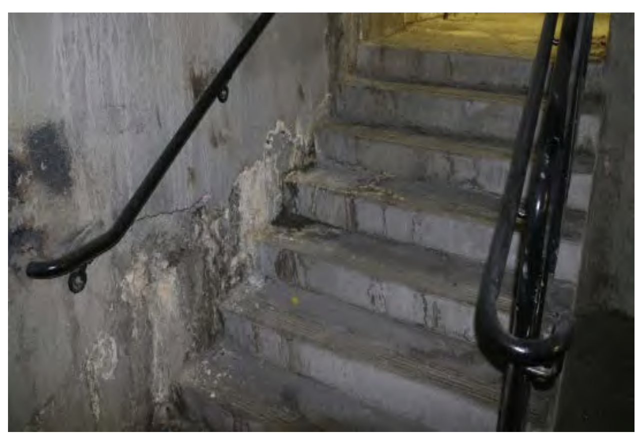

Figure 4.41 – Stairs

Concrete Staircases – Inspectors should check concrete stairs for cracks, delaminations, and spalls. Note exposed reinforcing steel in the spalls and record any observed section loss in the reinforcing steel. Check for signs of moisture penetration, corrosion staining, dampness, and efflorescence. Use a hammer to sound random areas of the stairs and check for delaminated concrete. Also sound areas adjacent to defects such as cracks and spalls. Document the length, width and location of all cracks and delaminations. Record the area, maximum depth and location of all spalls along with the condition of exposed reinforcing steel. Document the severity and locations of all other defects including moisture penetration, efflorescence, and corrosion staining. Examine the steel tread plates, if present, for adjacent spalls and looseness. Use a rubber mallet to tap the tread plates and make note of any separated or missing plates.

Steel Staircases – Inspectors should check steel stairs and ladders for corrosion and section loss of the steps and supports. Examine for crevice corrosion between plates of the stairs. Document the severity and location of corrosion and section loss found. Note the length, location, and distance of spread of all crevice corrosion.

Figure 4.42 – Ancillary building: with metal ladders to roof.

Roof – Check the roof of any Ancillary Buildings (Figure 4.42) or Auxiliary Structures for any deterioration which would allow water to penetrate through the roof into the building. Check that the water drainage system is functioning properly and not clogged with debris. Check the drains in the roof and the overflow scuppers in the barriers for debris accumulation. Inspect the barriers around the perimeter of the roof for deterioration. If present, examine expansion joints in the roof for debris accumulation and deterioration of the joint material. Look at the exterior surface of the exhaust stacks for any defects or deteriorated materials. Note the location and severity of any defects on the roof. Document any locations of water penetration. Record the condition of the roof coating material and the drainage system.

Floors – Check concrete floors for cracks, delaminations, and spalls. Note exposed reinforcing steel in the spalled areas and record any section loss. Check for signs of moisture penetration, corrosion staining, dampness, map cracking, and efflorescence. Use a hammer to sound random areas of the floor and check for delaminated concrete. Also sound areas adjacent to defects to define the extent of the area. Examine the floors for evidence of distortion and settlement. Document the length, width, depth, and location of all cracks and delaminations. Record the area, maximum depth and location of all spalls along with the condition of exposed reinforcing steel. Document the severity and locations of all other defects including moisture penetration, efflorescence, corrosion staining, and settlement.

Brackets and Supports – Brackets and supports are structural elements that are mounted against the ceiling or walls. They are used to support longitudinal ventilation fans, CCTV cameras, ITS signs, traffic signs, over-height detection signs, lighting supports, conduit supports, and fan or motor supports. Check for corrosion, dissimilar metals, cracks, buckles, and kinks. Dissimilar metals may promote corrosion at accelerated rates when not sufficiently insulated from stray electrical currents. Particular attention should be given to bolts in regions where leakage occurs to evaluate any section loss. A bolt can be rung with a hammer, but it's preferable to use a wrench for checking the tightness. Observe the condition of welds for cracks and tears. Dye penetrant inspection may be helpful for detecting cracks. Photos of various brackets and supports with various deficiencies are shown in Figure 4.43 and Figure 4.44.

Figure 4.43 – Sign support with gaps at connection.

Figure 4.44 – Missing bolt at longitudinal fan support.

Machinery Pedestals – Check concrete pedestals (Figure 4.45) for cracks, delaminations, and spalls. Use a hammer to sound random areas of the pedestals to check for delaminated concrete, also sound areas adjacent to defects. Examine the floors for signs of settlement. Note exposed reinforcing steel in the spalls and record any section loss. Check for signs of moisture penetration, corrosion staining, dampness, map cracking, and efflorescence. Document the length, width, and location of all cracks and delaminations. Record the area, maximum depth, and location of all spalls along with the condition of exposed reinforcing steel.

Figure 4.45 – Cracked machinery

Document the severity and locations of all other defects including moisture penetration, efflorescence, and corrosion staining.

Structural Finishes – Tiles should be checked to determine whether they pose a hazard to passing motorists since loose tiles can fall into the roadway. A good technique for inspecting tiles is to tap firmly on a select number of tiles in multiple locations using a rubber mallet. A scraper may facilitate removal or checking loose tiles.

4.9.2 Civil Elements

The SNTI defines condition states for invert wearing surface, traffic barriers, and pedestrian railing systems (Figure 4.46). Although drainage systems are commonly considered civil systems, these are discussed under mechanical systems and pumps. Miscellaneous civil elements are not contained in the NTI database but should be inspected periodically to maintain safety.

Figure 4.46 – Typical civil elements including wearing surface, traffic barrier, and pedestrian rail and walkway.

4.9.2.1 Wearing surfaces

Tunnel roadways have either bituminous or concrete wearing surfaces on the structural invert. When inspecting the wearing surface, examine the skid resistance of the surface, look for grooving or rutting in the wearing surface. A glossy or shiny surface or exposed polished aggregate may be indicators of wear. Check that water properly drains from these surfaces. When wearing surfaces are not properly drained, they can wear prematurely and develop holes and present safety hazards to motorists. The roadway surfaces on tunnel ramps can also be impacted by high groundwater levels.

Concrete – Concrete wearing surfaces should be checked for potholes, cracking, scaling, and delamination (Figure 4.47). Look for exposed reinforcing steel. For spalls, document the size, maximum depth, and location. Also, document any exposed reinforcing steel, and identify section loss. Use a hammer to sound random locations of the concrete wearing surface and areas adjacent to cracks, delaminations, and construction or expansion joints. Document the areas and locations of delaminated concrete. Areas of delaminated concrete may spall and present hazards to traffic. Provide an estimate of total crack length as well as the average length, width, location, and spacing.

Figure 4.47 – Pothole with cracking in concrete wearing surface.

Asphalt – Asphalt wearing surfaces should be checked for cracking, wheel path rutting, surface irregularities, and potholes. Use a hammer to sound random locations of the wearing surface. Note any dull thuds, which could be indicators of future potholes. Also, investigate whether the pavement is drying out, and verify a good seal between the wearing surface and the curbs.

4.9.3 Traffic Barriers

At roadway level the tunnel walls are typically protected from errant vehicles by concrete curbs and barriers. These barriers are usually concrete; however, their vertical surface may be covered with ceramic tiles. A concrete safety walkway is usually provided in the tunnel bore. Document the length, width, and location of all cracks and delaminations. Record the area, maximum depth, and location of all spalls along with the condition of the reinforcing steel if it is exposed. Document the severity and locations of all other defects including moisture penetration, efflorescence, and corrosion staining. Sample photos of these elements with various deficiencies are shown in Figure 4.48.

Figure 4.48 – Traffic barriers.

4.9.3.1 Pedestrian Railings

Pedestrian railings are common where raised sidewalks are used. These are commonly constructed of tubular steel, stainless steel, or aluminum with posts spaced along the walkway to support the lateral railing, and it can be produced using pipe, W-beam, or other shapes. The railing members can be coated with a structural finish such as paint or galvanized metal. Railings are a safety measure to prevent personnel on top of the walkway from falling into vehicles in the adjacent traveled lane. All aspects of the railings should be inspected and deficiencies noted.

During inspection, check the rails, posts and anchorages. Examine the railing for vertical and horizontal misalignment, missing or broken sections, impact damage and deterioration such as cracks or corrosion with section loss. Inspect for cracked welds at the connections and loose or missing bolts. Section loss can be found most commonly in the base of the posts and the anchor bolts, especially if debris accumulation is present. Evaluate the condition of the paint or galvanizing. Document the location and severity of any defects. Sample photos of typical types of deficiencies are shown in Figure 4.49 and Figure 4.50.

Figure 4.49 – Bent post and missing mid-rail.

Figure 4.50 – Bent pedestrian railing with missing railing components.

4.9.3.2 Miscellaneous Civil Checks

Although these items are not specifically reported to the FHWA, it is good practice to perform miscellaneous civil checks on all curbs and sidewalks in the tunnel, ancillary buildings, or ancillary structures. These items should be included in the written inspection procedures.

Curbs and Safety Walkways – Curbs and safety walkways protect the tunnel operation and maintenance staff and users who need to evacuate during emergency conditions.

Curbs – Curbs are typically constructed of concrete. Check the curbs for proper alignment. Improper alignment or a protruding curb section can become a safety hazard for vehicles.

Visually examine these elements for any buildup of dirt or debris that may reduce their effectiveness to transport the surface runoff into the drainage system. Examine the curbs for cracks and spalls. Check spalled areas for exposed reinforcing steel and document any section loss in the steel.

Walkways – The inspector should look for cracks, scaling, delaminations, spalls, tripping hazards, debris accumulation, and ponding of water. Examine spalls for exposed reinforcing steel and report any section loss. Advanced cracks and spalls can undermine the structural integrity of the safety walkways. Document the size and locations of any defects found. Document the length, width and location of all cracks and delaminations. Record the area, maximum depth and location of all spalls along with the condition of the reinforcing steel if it is exposed. Document the severity and locations of all other defects including moisture penetration, efflorescence, and corrosion staining.

Emergency Egress – The quality of the walking surface on every safety walkway or emergency egress should be examined. Under emergency conditions, these walkways may be used for self-rescue or by first responders. Check for locked or inoperable doors and access to refuge areas, considering that some users have reduced mobility. Note in the inspection documents any deficiencies found.

Maintenance walkways – Some of the more complex tunnels have concrete or steel maintenance walkways. Inspect these in accordance with procedures for other steel and concrete elements.

4.9.4 **Mechanical Systems**

The SNTI defines condition states for the ventilation systems and fans, drainage, and pumping systems, emergency generator systems, and flood gates. These items are contained in the NTI database. Miscellaneous mechanical elements are not contained in the NTI database but should be inspected periodically to maintain safety. These elements include items such as plumbing, air conditioning, and heating. The tunnel inspection organization should develop written procedures for the elements listed in the SNTI and consult with the tunnel owner to develop procedures for inspecting owner-defined elements. It is important to review the operating and maintenance logs prior to conducting inspections on mechanical systems. The inspectors should verify the performance of any repairs or replacements noted in the logs. Table 3-4 provides a generalized list of mechanical system maintenance checks that should be reviewed prior to conducting the inspection.

Each piece of equipment or machinery should be carefully inspected and operated; however, this activity should first be coordinated with tunnel facility personnel. The established lockout/tag-out procedures should be implemented to ensure safety and to prevent damage and injury. Any equipment that cannot be operated should be identified, its physical condition noted, and such information reported as soon as practical in accordance with established communication protocols. Boiler units and pressure vessels can be dangerous; it is recommended that qualified specialists or specialty contractors be used as appropriate.

4.9.4.1 **Tunnel Ventilation**

There are two basic types of mechanical ventilation systems: longitudinal and transverse, which can be combined or modified such as with semi-transverse systems. There are also single point extraction systems that supplement the ventilation requirements for emergency conditions. Longitudinal systems use axial fans that discharge air parallel to the axis of the impeller rotation; and transverse systems use centrifugal fans that discharge air at 90 degrees to the rotation.

Tunnel ventilation systems incorporate several mechanical components such as fan motors, louvers, motor-operated dampers, and various drive trains. The fans can be centrifugal or axial (Figure 4.51). The inspection of the ventilation system should include, as a minimum, the following items:

- Review the maintenance records for each piece of equipment and note any special or frequent previous maintenance problems.
- Note the physical condition of fans, airway, louvers, motor-operated dampers, and drive trains.
- Verify that each fan and the associated motor-operated dampers and components are operational.
- Perform vibration analysis on the fans, motors, and bearings during typical fan operations and inspect the fan drive system and bearings.
- Ensure that the airways, where accessible, are free of obstructions and debris.
- Test the operation of the carbon monoxide (CO) monitoring equipment.
- Check airflow (cfm) to ensure that ventilation design criteria are being met.

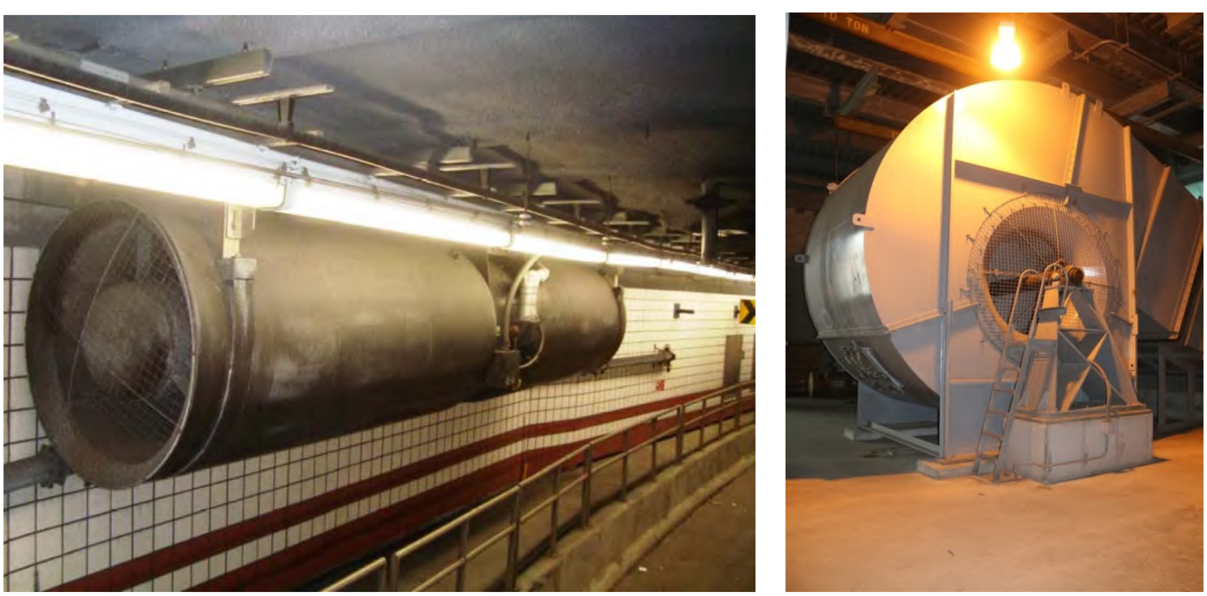

Figure 4.51 – Axial fan, left and centrifugal fan, right.

Fan Motors – The motor exterior and supports should be checked for paint failure and surface corrosion. Use a wrench to verify the tightness of the mounting bolts. Examine the motor, shaft and shaft bearings for leaks (Figure 4.52). Check the motor housings, supports, and surrounding components for grease accumulation. Check the seals to see if they have failed or if they are displaced outward. If grease is present, investigate the cause. Check all flexible conduits for deterioration. Operate the motor to verify that it is functional. While testing, visually check the motor, shaft and shaft bearings; record any abnormal movement. Listen for any unusual noises such as humming or screeching from the motor or bearings. Listen to and feel the motor housing for any abnormal vibrations or temperature.

Figure 4.52 – Staining on the fan pedestal is evidence of lubrication leak.

Tunnel fans should be operated on all speeds and observed at safe distances. Avoid standing near drives. Follow appropriate safety precautions. Note whether a fan requires manual restart or manual control to operate. Watch out for metal on metal contact such as when a fan wheel might contact the scroll or inlet cone and cause sparking.

Use a handheld infrared thermometer to check the operating temperature of the motor. Many motors will be warm when operating properly, but excessive heat might indicate a defect. Inspect the cooling passages and screens for excessive dust and dirt build-up that could impede cooling.

Oil and Lubrication Leakage: Observe signs of oil/grease leakage on the fan or drive housings or on the fan support pads. Leakage could indicate over-filling, defective seals, or out-of-roundness. If the motor is heating up, the leaks might be contributing to the problem. Ensure that the oil or lubricant that is leaked isn’t presenting a fire hazard.

Noise and Vibration: Any excessive noise or vibration should be noted. If possible, identify the source of noise or vibration during fan start-up. Periodic or continuous vibration monitoring should be performed on rotating elements (e.g., fan, motor bearings, and drive components). Review the fan vibration analysis data from the maintenance logs. Note the severity of any defects found. If possible, diagnose the cause of any abnormal movement, noise or vibration.

Paint and Corrosion: Observe the general condition of the fan, drives, supports, and guards. Note the percentage of clean and painted surface as compared to rusted and deteriorated surface. Record any section loss.

Fan Drive Systems – There are two common types of fan drive systems: direct drive and indirect drive. Direct drive fans turn at the same speed as the motor. These are common with axial fans. Indirect drive fans have gears that are driven by belts or chains and sprockets. These are common with centrifugal fans.

For a fan belt drive, check the pulleys and housings for paint failure and surface corrosion. Examine the belts for cracks, uneven wear, separation, abrasion or any other deterioration. Some belts have wear indicators. While operating the motor, visually and audibly check the belt for slippage. Listen for squealing noises while switching speeds. A burning smell or squealing could indicate improper belt tensioning (loose). Make sure the pulleys are aligned and not in contact with the housings.

For the fan chain and sprocket drive (Figure 4.53), check the housings for paint failure and surface corrosion. Examine the housings for oil leaks at any splits or covers. Check the condition of the oil and the oil level in the housing. If possible, open up the housing to check the chains and sprockets for wear. Some chains and sprockets have wear indicators. While operating the motor, listen for chatter noises coming from the chains, which may indicate that the chain is loose. The chain should be taut.

Figure 4.53 – Chain and sprocket drive.

Fan Shaft Bearings – Bearings are critical components for fan operation. Bearing life is usually expressed as the number of hours of operation before the first evidence of metal fatigue develops in the rings or rolling elements. Bearings should be of air handling quality, heavy duty, ball or roller type. Check the condition of any oil or grease and verify that correct levels are maintained. Examine bearing seals for oil leaks and grease accumulation on adjacent components. If lubrication is present, investigate the cause. Lubrication oil samples taken during oil changes assist in identifying:

- Viscosity breakdown caused by excessive time between oil change and excessive heat build-up in bearing or drive.
- Dirt contamination caused by not properly sealed bearing or drive; or by lubricating oil not properly stored or handled prior to use.
- Metal-to-metal wear indicated by high ferrous particle count or high iron count.
- Water contamination.

Check for paint failure and surface corrosion on the bearings housing and supports. Use a wrench to verify tightness of the mounting bolts and cap bolts. Look for signs of uneven tracking or belt and pulley wear. Use a handheld infrared thermometer to check for elevated bearing, belt, and drive temperature. Check extended grease lines for condition and breakage.
During operation, listen for any abnormal sounds, and watch for any abnormal movement or vibrations which indicate possible defects. If possible, diagnose the cause or any irregular noise, movement or vibration.

Fan Drive Coupling – Check the couplings for paint failure and surface corrosion. Examine for lubrication leaks. Use a wrench to check the tightness of the bolts. During operation, observe the coupling for excessive movement through the full range of speeds. In shim-style couplings, inspect for broken shims, delaminations, or other defects.

Figure 4.54 – Corroded fan housing.

Fan Housings – The inspector should check all components of the fan housings for failed paint, corrosion, and section loss (Figure 4.54). Visually and audibly verify that there is no contact between the fan and housing, or that there is no out-of-balance or otherwise abnormal movement of the fan during operation. Contact between the fan and the housing is most noticeable at higher speeds. Listen for debris inside the fan housing or evidence of water that may indicate blocked drain piping. Inspect housing for signs of excessive corrosion or fatigue cracking. Look for excessive dust or dirt build-up, which might indicate lack of maintenance and exercising of the fans. Confirm that all safety guards and access doors and covers are in place. Never reach into or enter fan housings or approach unprotected belts or chain drives without first implementing lock-out tag-out procedures. Inspect the conduit in the fan housing room for corrosion, missing covers, and exposed wires.

Local Fan Controls – Check the local fan controls for proper operation. Examine the enclosure for loose or deteriorating wiring. Ensure that the emergency stop control is functioning properly for each fan. Look for any testing tags that may indicate defective equipment.

Figure 4.55 – Damper blade arrows should point in the same direction.

Dampers and Damper Drives –Verify that the damper drives are operational (Figure 4.55). Check the door chains for signs of distress (Figure 4.56). Ensure that the louvers and the damper doors close completely (Figure 4.57). Check for paint failure and surface corrosion on all components. Use a wrench to verify the tightness of bolts. Examine the motors, shafts, bearings and reducers for lubrication leaks. Check the seals to see if they have failed or if they are displacing outward. If grease is present, investigate the cause of the leak. Check oil levels. Make sure the reducer breather is functioning properly. Ensure that the rubber seals on the damper louvers are intact. Check the alignment of the damper blade indicator.

Figure 4.56 – Door chains.

Figure 4.57 – Louvers in closed position, left; louver with large gap when closed, right.

Sound Attenuators – Noise from the fan is transmitted through the ventilation system. The portion of noise reaching the roadway is usually attenuated to a large degree by the ductwork and the ambient noise level within the tunnel. Sound attenuators are used to protect the surrounding neighborhoods from noise. Sound readings should be taken at a time when the noise level is of most concern, such as during the night when the noise levels in the neighborhood are at their lowest. Noise levels should be taken with the largest number of fans operating under non-emergency conditions.

4.9.4.2 **Tunnel Drainage**

The tunnel drainage system is designed to remove water from the roadway and is made up of grates, scuppers, piping, drainage troughs, and pumps. Check if the drain lines are clear of debris and flush with water to ensure that water drains freely. Look for ponded water. Check the inlet grates for deterioration or broken ribs (Figure 4.58). Ensure the roadway drain piping is in good condition and free of debris. Document the location and extent of the defects.

Pumps (General) – The major components of the tunnel pumps systems are: the pumps, sump pits, pump piping, sump level indicators, and pump controls.

Figure 4.58 – Broken scupper grate.

Operate all pumps to verify that they are all functioning properly (Figure 4.59). During testing, visually and audibly check for abnormal sounds or movement in the pumps and motors. Check that pumps operate at all speeds and in all modes. Shut-off valves should operate freely without binding or unusual noise. Extreme noise and vibration might be a sign of pending bearing or motor failure.

Figure 4.59 – View inside pump room.

Figure 4.60 – Moderate corrosion to pipes, pipe supports and fasteners.

Manually run the pump from the local control panel as well as any remote panel. If possible, with the control in the ‘auto’ position, manually raise the sump float to activate the pump. Note any excessive noise or vibration during pump operation. Confirm indicator lights on the control panels (local and remote) are properly lit. Ensure all local disconnects are not corroded and are functioning properly. If possible, check the tank floats for proper operation. Examine all conduits in the pump room for corrosion or other defects.

Examine the pump motors, shafts and bearings for lubrication leaks. Check if seals are bulging or have failed. If grease is present, investigate the cause of the leak. Check the pump and pipe components for leaks or evidence of leaks. Examine the pump, pump components, pump supports, pipes, and pipe supports for corrosion and section loss (Figure 4.60). Use a wrench to verify the tightness of bolts. Review the most recent pump vibration analysis data. Periodic or continuous vibration monitoring should be considered on pumps rated over 5 horsepower.

Observe the general condition of the pump, motor, supports, and guards. Note the percentage of clean and painted surface as compared to rusted and deteriorated surface. Check the condition and functionality of all valves and gauges. Confirm all valves associated with the pump have been recently lubricated and operate freely. Check piping for security and installation of vibration control and expansion devices. Note any significant leakage around pump seal for base-mounted pumps. Observe any leakage of piping, valves, and pipe accessories.

Assess the general housekeeping of the mechanical space and particularly the area around the pump. Be particularly observant of safety (fall) hazards and obstacles to pump access and maintenance. Also, assess the amount of debris in the sump. Document the severity of all defects.

Sump Pumps – A sump pump is submersed in water and pumps water from a collection basin (Figure 4.61), which are located in a low point where the water drains by gravity; sump pumps are used in the floor of the lower plenum to remove collected water from the tunnel. For a multiple bore tunnel, the same low point sump may be shared between the bores; or each bore could have their own drainage and pumping systems. The sump pump might connect to a holding tank; or it might be directly connected to the sewer system. A one-way check valve prevents the drainage water from flowing back into the system once the pumps are turned off. When inspecting the sump pumps, the drainage drawings should be carefully reviewed to obtain a working understanding of how the drainage system works and where the sump pits are located.

Figure 4.61– Accumulation of calcium deposits at sump pump.

All of the pump components, related supports, and system piping should be checked for damage, corrosion and deterioration. Inspect for excess calcium deposits on all of the components. Inspect the fasteners associated with the pumps and piping for corrosion and security. Confirm the sumps are free of debris and sludge that could hinder the performance or prevent the collection of water. Operate the sump pump to verify that it is functional, free from excessive noise and vibration, and that water is being removed from the sump. Examine the check valve and piping for leaks. Check that the pumps operate on all speed settings and in all modes. Shut-off valves should operate freely and without binding. Extreme noise and vibration might be a sign of pending bearing or motor failure. Document the severity of all defects.

4.9.4.3 **Emergency Generator System**

A standby generator is a back-up electrical generator system that operates when the power grid fails to deliver electricity. Emergency generators (Figure 4.62) may operate on gasoline, diesel fuel, natural gas, or propane.

Generators with internal combustion engines produce dangerous carbon monoxide (CO) gas, which can be deadly if inhaled. Check that the exhaust is properly vented. Natural gas or liquid propane fuel can accumulate to dangerous levels if leaks in fuel supply are not properly vented to the atmosphere.

Figure 4.62 – Emergency Generator.

Emergency generators are used to supply enough electricity to operate the essential equipment and to allow occupants to escape from the tunnel in an emergency, even when power from the grid fails. Emergency generators should have enough fuel to run for at least 24 hours.

The emergency generator system normally supports loads from fans, drainage pumps, fire pumps, alarms and communication systems, traffic control and surveillance, security and control systems, and emergency lighting. It is good practice to review the drawings and evaluate the standby capacity for the emergency generator. Overcapacity, on the order of 25 percent, is typical. When inspecting the emergency generator system, the inspector should:

- Evaluate the ability of the emergency power system to operate when the normal power fails by disabling the normal power supply (i.e., the power supply to any transfer switch or other means of transferring loads) and operating the emergency system with selected emergency loads for a sufficient period.

- Perform an internal inspection, check for hot spots, and note any deficiencies. Review the previous maintenance records to see if prior discrepancies have been corrected. Verify that all tests have been performed and meet industry standards, including NETA MTS-2011 and NFPA 110.

4.9.4.4 Flood Gates

In some tunnels, flood gates are installed at the portals to limit rising waters from flooding the tunnel. Flood gates typically contain a gate house, lifting mechanism, flood gate, seating mechanism in roadway, dewatering valve, and drainage shut-off valve. The gates themselves are constructed of steel and are designed to withstand the hydraulic forces during a flood event. Figure 4.63 shows a typical flood gate.

Check that the lifting mechanism, gates, seals, seating, and all valves associated with the flood gates function as intended. Ideally, flood gates should be tested against a head of water that is equal to the maximum anticipated flood levels. Building a temporary water tight bulkhead is a technique used for building up the water head against the gates for testing purposes.

Figure 4.63 – Flood gate.

4.9.4.5 Miscellaneous Mechanical System Checks

Although these items may not be specifically reported to the FHWA, it is good practice to perform miscellaneous mechanical system checks on all plumbing, air conditioning, and heating systems in the tunnel, ancillary buildings, or auxiliary structures. These items are commonly included in the owner-defined elements.

Plumbing – The inspection of the plumbing system should be conducted according to applicable plumbing code requirements, and the following should be checked:

- Review the maintenance records for the plumbing system and note any special or frequent maintenance problems.
- Note the physical condition of the bathroom fixtures, water heaters, and drainage system.
- Verify that the plumbing fixtures are operational.
- Check the pipes for leaks, corrosion, damaged fittings, and loose brackets.
- Ensure that valves, gauges, and gaskets are functioning properly.
- Look for watermarks on tunnel surfaces to identify locations of plumbing system leaks..

Heating, ventilating, and air conditioning (HVAC) units – The components for HVAC elements in support spaces consist of fans and dampers, filters and coils, and controls. The

HVAC equipment should be operated in all speeds and all modes. Confirm change-over from heating to cooling modes occurs as the thermostat is cycled. Confirm fan operation, note any vibration or unusual noise. Observe damper operation noting any binding of dampers or loose or poorly adjusted linkage. Assess damper leakage and confirm gravity back-draft dampers return to the closed position when fans are turned off.

Filter and Coils – Visually assess the cleanliness of the air filters and coils on air handling equipment. Confirm all filters are in place and assess the air leakage around poorly fitting filter racks. For coils equipped with drain pans, observe the cleanliness of the pan, and confirm the drain is flowing freely.

Control – Note temperature/comfort level of space served by the unit. Confirm the unit is maintaining the temperature set point. Cycle thermostat and observe ability of equipment to respond to changing set points. If dampers are interlocked with ventilation fans, observe the response of the interlocked equipment with the primary equipment operation.

Overall Condition – Observe the general condition of the equipment, including interior surfaces of air handling equipment and access doors, latches, and sealing gaskets. Note that all access panels are secure, doors seal tightly, and latches work freely. Note percentage of clean and galvanized/anodized/painted surface as compared to rusted and deteriorated surface. Assess the general cleanliness of the space where the equipment is located.

Air Conditioning – The inspection of the air conditioning systems in control rooms and other locations should include the following items:

- Review the maintenance records for each piece of equipment and note any special or frequent previous maintenance problems.
- Note the physical condition of air handling units, condensing units, packaged units, chillers, pumps, cooling towers, exposed air distribution systems, cooling piping, and terminal units.
- Verify that the system is operational. Note that temperature at the time of the inspection may limit operation or proper verification.
- Perform vibration analysis and inspections on chillers, cooling towers, and pumps.
- At time of scheduled oil changes – perform lubrication oil analysis on all (major) bearing lubricants.

Heating – The inspection of the support area heating system should include the following items:

- Review the maintenance records for each piece of equipment and note any special or frequent maintenance problems.
- Note the physical condition of air handling units, pumps, steam and water distribution systems, terminal units, boilers, exposed air distribution systems, heating piping, and steam converters.
- Boilers can be dangerous; therefore, a qualified boiler inspector certified by the National Board of Boiler and Pressure Vessel Inspectors should inspect each boiler, boiler room,

and pressure vessel. Check the operational efficiency of all boilers and related systems to ensure that these units are operating in the appropriate range. The boiler inspector should verify that all systems related to the boiler (e.g., breeching, make-up, deaeration, steam traps) are functional and operating properly and efficiently.

- Verify that the system is operational. Note that temperature at the time of the inspection may limit operation or proper verification.

4.9.5 Electrical and Lighting Systems

The SNTI defines the elements required for the NTI including the electrical distribution system, the emergency distribution system, tunnel lighting system and fixtures, and the emergency lighting system and fixtures. It is important to review the operating and maintenance logs prior to conducting inspections on electrical and lighting systems. Verify the performance of any recent repairs or replacements noted in the logs. Table 3-5 provides a generalized list of electrical and lighting system maintenance checks that should be reviewed prior to conducting the inspection.

The tunnel inspection organization should develop written procedures for the elements listed in the SNTI and for elements requested by the owner. Written inspection procedures should be developed with the assistance of a qualified electrician or specialty contractor due to the dangers posed by electric current and the inherent risks for electric shock.

4.9.5.1 Electrical Distribution Systems

Electrical systems are complex and contain multiple components that are potentially hazardous. The existing records and schematics should be carefully reviewed prior to conducting an inspection, and it is important that the inspectors understand of the system thoroughly. Determine the need to conduct any short-circuit, load-flow, reliability, and arc-flash studies as part of the inspection process. It is good practice to survey the electrical equipment and develop inspection methods that target the individual components of the system.

Figure 4.64 – Electrical fire.

The electrical system consists of the electrical equipment, wiring, conduit, and cable used for distributing electrical energy from the utility supply (service entrance) to the line terminals of equipment. The system includes transformers, switchgear, switchboards, panel boards, motor control centers, starters, switches, and receptacles. General inspection recommendations include the following**:**

- Take voltage and load readings on the electrical system using any of the installed meters.
- Check that all indicator gauges on the transformers show that fluid levels, temperatures, and pressures are within operating range.
- Check for signs of damage and overheating of all equipment (Figure 4.64).

- Check utility structural support connections for corrosion or missing fasteners.
- Ensure that all enclosures and box covers are in place and secure and that conduits are not broken.
- Evaluate the condition of enclosures and conduit.
- For all large power systems, Electrical Safety Operating Diagrams should be posted to comply with OSHA and NFPA 70E.
- Check for conformity to NFPA 70, 70B, 70E, 72, 502, 520, and NETA MTS-2011.
- Check that adequate working space is provided in accordance with NFPA 70, Article 110, and that area around equipment is clear with no material stored in the working space. Visibly inspect wiring systems for damage and corrosion.
- Ensure that the electrical outlets are functional. Test all ground fault circuit interrupter (GFCI) type outlets to ensure that they trip correctly.
- Examine the conduit support structure, including all clamps and supports. Ensure all conduit clamps are secure (Figure 4.65).
- Check all disconnect switches to ensure that the equipment is properly disconnected.
- Check that all sources of energy are isolated.
- Check all motor controllers for proper operation.
- Perform a thermographic (infrared) inspection for hot spots and an internal inspection; and note any deficiencies. Verify that all tests meet industry standards, including NETA MTS-2011.

Figure 4.65 – Electrical conduits with heavy corrosion and section loss.

Figure 4.66 – Electrical equipment: Single phase insulated transformer.

Electrical Equipment – Each piece of electrical equipment should be carefully inspected and operated; however, this activity should first be coordinated with tunnel facility personnel. The established lockout/tag-out procedures should be implemented to ensure safety and to prevent damage and injury. The electrical equipment should be test operated (e.g., tunnel fans, pumps, lighting). Also check that the generator operates within acceptable limits for output voltage. Any equipment that cannot be operated should be identified and its physical condition noted.

The major components of the tunnel electrical system include switchgear, switchboards, transformers (Figure 4.66), generators, uninterruptible power supplies, panel boards, disconnect switches, and motor control equipment. The electrical equipment should be assessed based upon a combination of visual observations, measurements, and tests as well as operation of the equipment, maintenance reports and daily logs, and any in-depth testing procedures (e.g., thermographic inspection, contact resistance testing, and generator load testing).

Observe the general condition of the electrical equipment, including interior surfaces of equipment and access doors, latches, and sealing gaskets. Check that all access panels are secure, doors seal tightly and latches work freely. Observe the general condition of the electrical equipment enclosures. Note the percentage of clean and galvanized/anodized/painted surface as compared to rusted and deteriorated surface. Assess the general housekeeping of the electrical rooms and support spaces, paying particular attention to the immediate area around the equipment.

Miscellaneous Electrical System Checks – Although these items may not be specifically reported to the FHWA, it is good practice to perform electrical systems check on all miscellaneous electrical components and appliances in the tunnel, equipment rooms, maintenance corridors, plenums, ancillary buildings, and auxiliary structures. Check the condition of any electric receptacles, wires, switches, circuit breakers, meters, etc. for evidence of overloading, overheating, damage, deterioration, and corrosion. Look for evidence of arcing, discoloration, or other signs that might indication the electrical components are defective. These items are commonly included in the owner defined elements.

4.9.5.2 **Emergency Power Distribution Systems**

NFPA produces documents that are useful for maintaining, inspecting, and testing emergency power systems to include *NFPA 110: Standard for Emergency and Standby Power Systems* and *NFPA 111: Standard on Stored Electrical Energy Emergency and Standby Power Systems*. Review the electrical requirements for the tunnel, which vary by location. Generally, this is based on State or local building codes. It is good practice to reference, include, or summarize the requirements in the inspection documentation.

The emergency power distribution system consists of automatic transfer switches, panel boards, electrical equipment, and the associated wiring, conduit, and cable for providing electrical power in case of utility service failure. The major equipment included in this system consists of emergency generators and/or uninterruptible power supply systems (Figure 4.67). Emergency generators should be inspected as previously described under mechanical systems. The emergency power distribution system should also refer to the techniques described for inspecting the electrical distribution system.

- Evaluate the ability of the emergency power system to operate when the normal power fails, by disabling the normal power supply (i.e., the power supply to any transfer switch or other means of transferring loads) and operating the emergency system with selected emergency loads for a sufficient period.
- Perform an internal inspection and an inspection for hot spots, and note any deficiencies. Have the same testing party review the previous maintenance records to see if prior discrepancies were corrected. Verify that all tests meet industry standards, including NETA MTS-2011 and NFPA 110.

Figure 4.67 – Emergency power supply.

4.9.5.3 **Lighting Systems**

Lighting systems are complex elements consisting of multiple components with potentially hazardous equipment (Figure 4.68). A failure of some components may limit the effectiveness of the system as a whole. Review existing records and diagrams carefully prior to initiating the field work. It is important not to double count the emergency lighting fixtures or the normal lighting fixtures. When lighting fixtures are on for both normal use and emergency use, it may be useful to consider these as part of the emergency lighting system to avoid double counting the light fixtures. Written procedures should be developed to address this issue.

The major components of the tunnel lighting system include lamps, ballasts, lenses, housings, wiring, and controls (Figure 4.69). The lighting system conditions should be evaluated with a combination of visual observations, data provided by the tunnel operators via maintenance reports, and in-depth testing procedures including the measurement of lighting levels at the roadway surface.

The most efficient way to test the lighting system is to operate the lighting and associated controls, simulating the sequential operation of the system over a 24-hour cycle from nighttime to daylight, and observing the changes in the illumination levels on the roadway surface as compared to the system design criteria. Following are some processes to consider for lighting system testing:

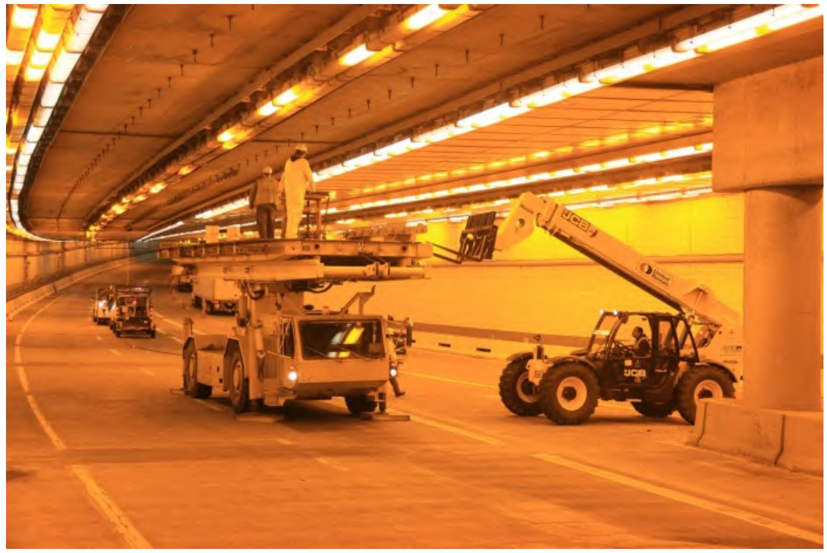

Figure 4.68 – Maintenance and inspection of lighting system.

Figure 4.69 – Lighting control cabinet.

- Measure the light levels within tunnels using an Illuminating Engineering Society (IES) LM-50 device and compare the results against the requirements of IES RP-22.
- Measure the light levels at intervals suggested by IES LM-50.
- Measure the light levels at emergency egress exits and compare with the IES Handbook recommendations.
- Inspect for visible damage, including corroded or damaged housings, loose attachments, broken lenses, and burnt out bulbs. Examine for exposed wiring where the conduit has pulled out of the fixtures. Also, note if lenses should be cleaned.
- Verify the operation of the lighting controls for the different ranges of nighttime and daylight illumination.

Lighting Fixtures – Lighting fixtures include mounting brackets, luminaires, and attachments. These should be watertight, dust-tight, and bug-tight for proper operation and easy maintenance. Tunnels are washed periodically to maintain reflectivity, so check the quality of washing and impacts to the lighting. Observe the general condition of the lenses and housing of the lighting luminaires. Note percentage of clean, broken lenses or housing, and corroded surfaces (Figure 4.70).

Figure 4.70 – Light fixture with damaged lens.

When inspecting lighting luminaires and their attachments, the inspector should look for corrosion damage from environmental conditions and corrosion caused by contact of dissimilar metals. Sites of contact are located between the lighting housing base and luminaire, clips attaching the luminaire to the base, and bolts that hold the base to the substrate.

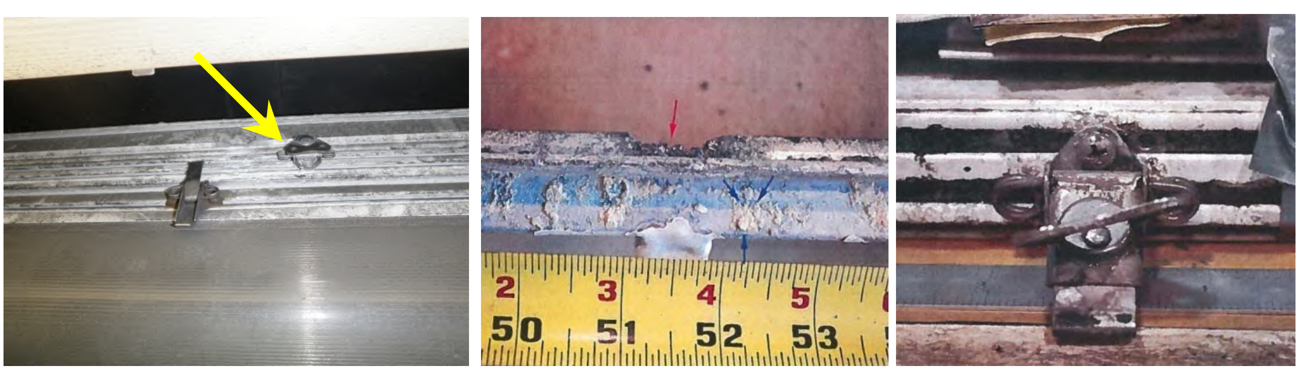

Figure 4.71 – Stainless steel clip severely corroded due to galvanic action.

When two dissimilar metals are placed in a conductive and corrosive solution, touching each other, there will be a flow of electrons (electricity) between them causing corrosion. This form of the corrosion is called Galvanic or Dissimilar Metal/Two-Metal corrosion In the mated pair, the less corrosion-resistant material (anode) will show increased corrosion and the more resistant material (cathode) will show decreased or no corrosion. Figure 4.71 shows a stainless steel clip completely eroded away due to a contact with dissimilar metals.

Miscellaneous Lighting System Checks – Although these items may not be specifically reported to the FHWA , it is good practice to perform miscellaneous lighting systems check on all miscellaneous lights, fixtures, and appliances in the equipment rooms, maintenance corridors, plenums, ancillary buildings, and auxiliary structures. These items should be included in the owner defined elements.

Emergency Lighting Systems and Fixtures – These systems provide egress lighting for safe evacuation, and must operate in the event of a power failure in the electric grid. These lights are powered by the emergency power distribution system. Inspect emergency lighting systems as previously described, and they should also be checked when the main source of power has been turned off and the emergency generating system is in operation. The lighting diagrams and electrical schematics should be adequately reviewed prior to conducting field tests.

4.9.6 Fire and Life Safety, Emergency Systems and Operation

Fire and life safety and emergency systems are complex interconnected systems. The design and as-built records should be carefully reviewed along with the vendor supplied information prior to conducting the inspection. For these systems, the general condition of the system components should be assessed along with the state of general housekeeping. Observe the general condition of the equipment and the enclosures including cabinets and panels. Access panels, doors, seals, and latches should be checked for rusted, deteriorated, broken, or damaged components.

4.9.6.1 Fire Systems

Fire systems can be categorized into those that alert and detect in response to fire and those that provide protection from the harmful effects of fires. NFPA produces several documents that are useful for maintaining, inspecting, and testing fire systems. These include NFPA 502: Standard for Road Tunnels, Bridges, and Other Limited Access Highways; NFPA 70: National Electric Code; NFPA 72: National Fire Alarm and Signaling Code; NFPA 101: Life Safety Code; NFPA 110: Standard for Emergency and Standby Power Systems, NFPA 111: Standard on Stored Electrical Energy Emergency and Standby Power Systems. Review the fire and life safety requirements established by the agency having jurisdictional authority, which varies by location. Generally, this is a written agreement between the State DOT, the state fire marshal, and the local fire department. It is good practice to reference and summarize the requirements in the inspection documentation.

Table 3-6 provides a generalized list of fire and life safety maintenance systems checks. Maintenance logs that document these checks should be reviewed prior to conducting the inspection. Deficiencies in the log book should be noted. When inspecting fire systems, it is good practice to be on the look-out for unprotected electric wires, improper storage of flammable materials, and products, that when burned, produce toxic chemicals (e.g., plastics like PVC or HDPE materials).

Fire Detection – Fire detection systems are the elements that detect and initiate the response to a fire such as fire alarms, manual fire alarm pull-boxes, heat detectors, smoke detectors, CCTV, and other types of surveillance equipment. The major components of the fire detection system include control panels, power supplies, detection devices, and notification devices such as alarms. The fire detection system should meet or exceed the design requirements.

NFPA 72: National Fire Alarm Code provides information on inspecting and testing fire alarms and signaling devices. The following recommendations should be considered**:**

- Inspect the fire detection system by operating the drill switch and ensuring that all of the annunciators and notification appliances operate.
- Check existing records to determine if the system has been tested at regular intervals in accordance with NFPA 72. Review the records available for the last seven years.
- Review the maintenance/inspection records for the system and note any unusual maintenance issues.
- Note the physical condition of the fire protection system. This includes the fire extinguishers, hose connections, pumping systems, piping, circulating pumps, and hose reels.
- Note the physical condition of the fire protection storage tanks, alarms, and level switches.
- Check the fire control panel for faulty detectors, signals, and wiring.
- Check door sensors and other security measures for proper operation and condition.
- Note any ventilation testing performed or exercises with local responders.

Fire Protection – Fire protection systems are the elements that suppress the fire, enhance tenability, and aid rescue. Fire protection systems include fire extinguishers, standpipes, hoses, nozzles, fire suppression system components (i.e., sprinklers, foam systems, pumps, tanks, heaters) and ventilation control. Small fires can be controlled with powder or foam extinguishers, and most motorists likely know how to use these devices. Check that fire extinguishers are in place (Figure 4.72) and that the expiration date, pressure, and seal are present on portable fire extinguishers. A fire suppression system, such as a

Figure 4.72 – Missing fire extinguisher.

sprinkler system (Figure 4.73), is an active fire protection measure with a water supply system that provides an appropriate pressure and flow rate to water distribution piping and sprinkler attachments that spray water onto the fire. There are variations in these systems including deluge systems, foam systems, and mist systems.

Figure 4.73 – Foam sprinkler system test.

Proper inspection of these systems requires familiarity with NFPA 25: Standard for the Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems and other applicable NFPA standards. Local codes may require inspection and commissioning by the fire department or by other qualified fire system inspectors.

4.9.6.2 **Emergency Communication Systems**

The components of the emergency communication system include cameras and camera systems (CCTV), intercom, radios, cell-phones, receivers, wiring, computer analytics, and other technology. Inspection requires testing the communication devices in simulated emergency conditions. This requires examination of issues like system interoperability, scenario-based exercises for different emergencies and conditions, interagency cooperation for response, and even cyber-security. Inspection also includes visual and technical examination of hardware by specialists.

Figure 4.74 – Examples of CCTV camera systems.

4.9.6.3 **Tunnel Security and Operation Systems**

The systems included under security and operation involve surveillance, control, and communication equipment such as CCTV cameras (Figure 4.74), telephones, radios, incident response and detection devices (Figure 4.75), air quality monitors, the control center and systems, and the Supervisory Control and Data Acquisition (SCADA) system.

Inspecting the tunnel security and operation systems should include visual observations and measurements specific to each component. The inspector should:

- Verify that the CCTV cameras, telephones, radios, or other communication devices are operational.
- Inspect traffic signals for proper operation during all phases.
- Verify that any over-height detector systems (Figure 4.76) are not triggering at any heights just below the desired setting and also verify that they are triggering at or just above the desired setting.

Figure 4.75 – Detection equipment.

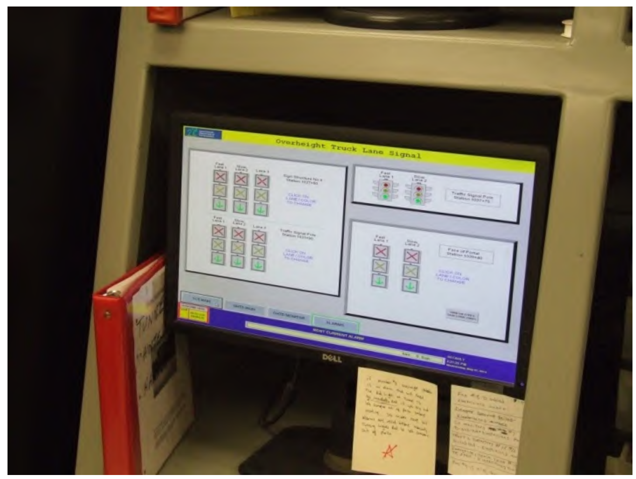

Figure 4.76 – Over-height detection screen.

SCADA – The SCADA system operates using signals over communication channels that provide control of remote equipment. The control systems are combined with a data acquisition system that can be programed to operate the tunnel facility at optimum levels. SCADA systems operate with a minimal amount of hardware maintenance, with the exception of the component level sensors. Software changes for additional programming and periodic upgrades are required to maintain flexibility and reliability of system operation.

4.9.7 Signs

Traffic signs, egress signs, variable message boards, and lane signals and fixtures are included in the NTIS. These elements are used to display information and communicate with the driver so that good decisions can be made when entering, traveling though, and exiting the tunnel for both normal operations and during emergencies.

Figure 4.77 – Damaged sign.

Variable message boards, traffic control devices, and lane signals require written inspection procedures and qualified electrical inspectors because of the dangers posed by electric current and the complexity of these elements.

Traffic and Egress Signs – Inspect signs for reflectivity and clarity, impact damage (Figure 4.77), vandalism, deterioration, and attachment to the tunnel structure. If signs or components are missing, this should be noted. Certain signs are electrically illuminated and contain bulbs (Figure 4.78); therefore, the inspection will need to verify that the sign has power and is functional.

Figure 4.78 – Malfunctioning sign.

Check for corrosion, cracks, buckles, and kinks. Particular attention should be given to bolts in regions where leakage occurs. Document the loss of section and missing or loose bolts.

Traffic Control Devices – Tunnel traffic control devices can be mounted on the tunnel walls, the overhead ceiling, or on the barriers at the portals. These devices are either reflective signs or illuminated display signs using electrified light bulbs. When electric current is involved, check for dissimilar metals, which may corrode metals at accelerated rates when these metals are not sufficiently insulated.

Check the signs for traffic impact damage. Look for missing signs. Verify that the signs have not become illegible from impact damage, vandalism, deterioration, loss of retroreflectivity, or other causes. For illuminated display signs, verify that the sign has power and is functional. Examine the display messages. Check the supports for corrosion and section loss.

Variable Message Boards – Variable message boards or signs (VMS) are electronic traffic signs that are used to convey changing information about events such as traffic congestion, accidents, incidents, roadwork zones, lane closures, speed limits, and emergency conditions. The messages are limited by the type of technology used and by the configuration of the display board (Figure 4.79). The structure is commonly constructed of aluminum and treated with an antiglare facing. Flashers or beacons are devices that are used to draw attention to a sign when an important message is being displayed. These should also be checked.

Figure 4.79 –Typical variable message boards.

In order for these message boards to be effective, the lettering must be legible, and the bulbs that form the letters of the words should be checked. These devices can be complex with display modules, drivers, power supplies, sensors, fans, dust filters, control cabinets, controllers, input/output circuit boards, modems, and computerized controllers. The frames and mounting hardware should be checked carefully. Check for corrosion, dissimilar metals, cracks, buckles, and kinks.

Lane Signals and Fixtures – The components of the tunnel lane signal system include the lane signals themselves (Figure 4.80), the control system, and interfaces to other systems, such as fire detection. The lane signal system conditions should be inspected using a combination of visual observations and measurements. When electric current is involved, check for dissimilar metals, which may corrode at accelerated rates when they are not sufficiently insulated from stray electrical currents.

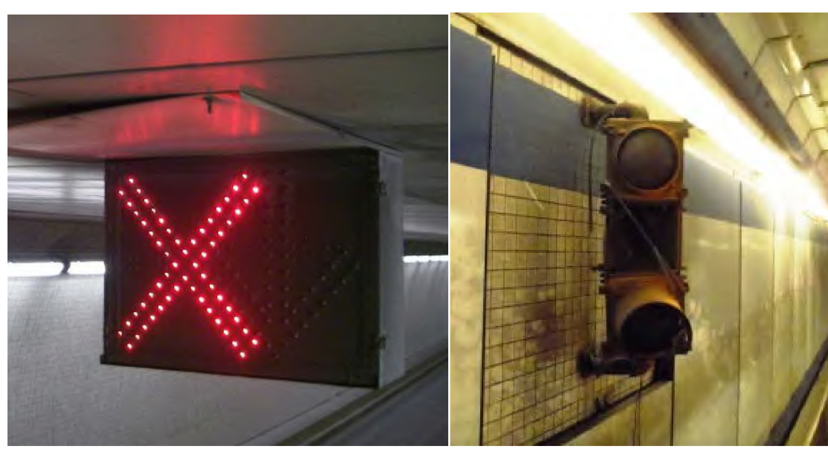

Figure 4.80 – Operable signal, left; inoperable, right.

4.9.8 Finishes and Protective Coatings

Protective systems such as steel corrosion protective coatings, concrete corrosion protective coatings, and fire protective coatings are included in the NTI. The interior finish of a tunnel is very important to the overall function of the tunnel. To improve safety and facilitate maintenance, tunnel finishes should:

- Be designed to enhance tunnel lighting and visibility.
- Be fire resistant.
- Not generate toxic fumes during a fire.
- Be able to attenuate noise.
- Be easy to clean.

Ceramic Tile – Ceramic tiles are the most widely used by tunnel owners because of ease of placement and cost (Figure 4.81). They are extremely fire resistant, easily cleaned, and good reflectors of light due to the smooth, glazed exterior finish; however, tiles are not effective sound attenuators. Typically, tiles are 4 ¼ in. square and can be ordered in many colors. Tunnel tile installation differs from conventional ceramic tile in that they require a more secure connection to the tunnel lining. Tiles should not be allowed to fall onto the roadway and impede or endanger users.

Figure 4.81 – Ceramic tile finish reflecting light.

Porcelain-Enameled Metal Panels – Porcelain enamel is a combination of glass and inorganic metal oxides fused together under extremely high temperatures. This method is used to coat most home appliances. The Porcelain Enamel Institute (PEI) has established guidelines for the performance of porcelain enamel through the following publications:

- Appearance Properties (PEI 501)
- Mechanical and Physical Properties (PEI 502)
- Resistance to Corrosion (PEI 503)
- High Temperature Properties (PEI 504)
- Electrical Properties (PEI 505).

Porcelain enamel is typically applied to either cold-formed steel panels or extruded aluminum panels. For ceilings, the panels are often filled with a lightweight concrete; and for walls, fiberglass boards are frequently used. The attributes of porcelain-enameled panels are similar to those for ceramic tile. These coatings are durable, easily washed, reflective, and come in a variety of colors. As with ceramic tile, these panels are not effective sound attenuators.

Epoxy-Coated Concrete – Epoxy coatings have been used on many tunnels during construction to reduce costs. Durable paints have also been used. The epoxy is a thermosetting resin that is chemically formulated for its toughness, strong adhesion, reflectiveness, and low shrinkage. Experience has shown that these coatings do not withstand the harsh tunnel environmental conditions as well as the other finish types and need to be repaired or rehabilitated more often.

Miscellaneous Finishes – A variety of other finishes can be used on the walls and ceilings of tunnels. Some of these finishes are becoming more popular due to their improved sound absorptive properties, ease of replacement, and other advantages over some of the materials mentioned previously. Some of these systems are listed below:

Coated Cement Board Panels – These panels are not widely used in the United States. The elements consist of lightweight, fiber-reinforced cement board that is coated with baked enamel.

Pre-cast Concrete Panels – This type of panel is often used as an alternative to metal panels. They may use a metal panel veneer or more commonly, ceramic tile for the final finish.

Metal Tiles – This tile system is not common, but it has been used successfully in some tunnel applications. They are coated with porcelain enamel and set in mortar like ceramic tiles.

4.10 Owner Defined Elements

Owner defined elements may be incorporated into the inspection process in order to tailor the program to the specific requirements of the tunnel owner. Plans and procedures to inspect owner defined elements should include any forms or reports needed to collect the data. Owner defined elements are useful when:

- Elements are not contained in the SNTI and inspection of this item would be beneficial to the tunnel owner.
- Elements are contained in the SNTI but more refined elements are desirable.

Geotechnical conditions play a key role in the protection of some tunnels; and the owner should evaluate the geotechnical conditions associated with the tunnel as deemed necessary; this is especially the case with tunnels that cross navigation channels. Submerged tunnels that cross navigation channels are usually covered with a layer of fill that is resistant to erosion and provides protection against impacts from sinking vessels, ship’s anchors, etc. When built, bored tunnel are usually located with sufficient protective cover. Over time, erosion and dredging can take place. As such, the geotechnical conditions should periodically be inspected.

4.11 Critical Finding and Condition State Ratings

Critical findings and condition state ratings are used to represent the condition of tunnel components. A critical finding is a significant safety or structural concern that must be acted upon and reported in accordance with the NTIS. Condition states are used to represent the condition of an element at the time it was inspected. Condition states as defined in the SNTI are: good, fair, poor, and severe.

Structural and civil elements in severe condition usually warrant a structural review to determine if there are any impacts to strength or serviceability. For functional systems in severe condition, evaluate safety and serviceability of the element. Condition states are recorded in the inspection report and database and then submitted to the FHWA. Critical findings require immediate attention in accordance with agency and NTIS requirements.

4.11.1 **Critical Findings**

Critical findings are defined in the NTIS. The owner is required to establish a procedure to ensure that critical findings are addressed in a timely manner and actions have been taken, are underway, or are planned to resolve the issue. The critical findings are to be reported to the FHWA within 24 hours. The FHWA should be updated regularly or as formally established as to the status of each critical finding until the issue is resolved. FHWA is to be provided with an annual summary report of the current status of each critical finding identified within the past year and each unresolved finding from a previous year.

The tunnel inspection organization, in consultation with the tunnel owner, should have established written procedures for dealing with critical findings prior to the inspection. It is imperative that the inspection team have communication protocols in place to ensure that immediate action can be taken to respond a critical finding. Critical findings normally require one or more of the following actions to be taken in a timely manner:

- Close the tunnel until the severe defect is removed or repaired, if the such defect may impact users or user safety.
- Restrict the area from public access until the defect can be removed or repaired.
- Repair the structural member or address the functional or safety issue.

Detailed descriptions and photographs should be provided that describes the safety or structural concern. Identify appropriate actions or follow-up inspections and maintain a record of the actions taken to resolve or monitor the critical finding. For example, with a large concrete spall that is on the verge of falling into the roadway, the inspection team or tunnel operations personnel can block off the traffic; and the maintenance personnel or a specialty contractor can take down and remove the spalled concrete.

4.11.2 **Condition State Ratings**

Element-level inspection techniques are used to rate each tunnel element according to the SNTI. Quantities are developed for each element and condition states are assigned for the percentage of this quantity in each condition state. The four condition states, CS1, CS2, CS3, and CS4, represent good, fair, poor, and severe, respectively. Condition states for tunnel elements will typically be assigned using a particular unit of measure such as linear foot, square foot or each. Accuracy in establishing the condition states is important for safety and their utility in tunnel management systems.

Table 4.4 – Railing Element Coding Example

Element Name	**Quantity**	**CS1**	**CS2**	**CS3**	**CS4**	**Notes**
Railing	1,000 LF	700 LF	150 LF	140 LF	10 LF	No Safety Concerns
	Percent	70%	15%	14%	1%	*SNTI Defined*
Posts	*100 Each*	*75*	*10*	*12*	*3*	*Owner Defined*
	Percent	*75%*	*10%*	*12%*	*3%*	

Table 4.4 illustrates a coding example for a simple railing element. Tunnel elements may have different condition states for the same element. A tunnel with 1,000 linear feet (LF) of railing may have 700 LF of railing in good condition; 150 LF in fair condition; 140 LF in poor condition; and 10 LF in severe condition. The corresponding entry for condition states would be: 70 percent to CS1, 15 percent to CS2, 14 percent to CS3, and 1 percent to CS4. The railing posts are an owner defined subelement. Since the condition states for the post subelements were in line with that of the railing system, no adjustments were made to the overall condition state of the railing. In this particular example, there are no critical findings to report since there were no safety concerns that require immediate action.

4.12 Tunnel Inventory and Inspection Documents

Tunnel inventory and inspection data should be collected and documented using paper forms or electronic tablets; whereas, the initial tunnel inventory can be obtained from the existing records and field verified as needed. Comprehensive tunnel inspection requires field books, forms, photographs, and reports to effectively communicate and document the inspection findings.

4.12.1 **Example Inventory Form**

The preliminary National Tunnel Inventory data includes information on the tunnel identification, age and service, classification, geometric data, inspection, load rating and postings, navigation, and the structure type. Table 4.5 contains a tunnel inventory form that is compatible with the requirements contained in the SNTI.

Table 4.5 – Sample preliminary tunnel inventory data

Identification Items

Item ID	Inventory Item Name	Code
I.1	Tunnel Number	
I.2	Tunnel Name	
I.3	State Code	
I.4	County Code	
I.5	Place Code	
I.6	Highway Agency District	
I.7	Route Number	
I.8	Route Direction	
I.9	Route Type	
I.10	Facility Carried	
I.11	LRS Route ID	
I.12	LRS Mile Point	
I.13	Tunnel Portal's Latitude	
I.14	Tunnel Portal's Longitude	
I.15	Border Tunnel State or Country Code	
I.16	Border Tunnel Financial Responsibility	
I.17	Border Tunnel Number	
I.18	Border Tunnel Inspection Responsibility	

Age and Service Items

Item ID	Inventory Item Name	Code
A.1	Year Built	
A.2	Year Rehabilitated	
A.3	Total Number of Lanes	
A.4	Average Daily Traffic	
A.5	Average Daily Truck Traffic	
A.6	Year of Average Daily Traffic	
A.7	Detour Length	
A.8	Service in Tunnel	

Classification Items

Item ID	Inventory Item Name	Code
C.1	Owner	
C.2	Operator	
C.3	Direction of Traffic	
C.4	Toll	
C.5	NHS Designation	
C.6	STRAHNET Designation	
C.7	Functional Classification	
C.8	Urban Code	

Geometric Data Items

Item ID	Inventory Item Name	Code
G.1	Tunnel Length	
G.2	Minimum Vertical Clearance over Tunnel Roadway	
G.3	Roadway Width, Curb-to-Curb	
G.4	Left Sidewalk Width	
G.5	Right Sidewalk Width	

Load Rating and Posting Items

Item ID	Inventory Item Name	Code
L.10	Height Restriction	
L.11	Hazardous Material Restriction	
L.12	Other Restrictions	

Navigation Items

Item ID	Inventory Item Name	Code
N.1	Under Navigable Waterway	
N.2	Navigable Waterway Clearance	

Structure Type and Material Items

Item ID	Inventory Item Name	Code
S.1	Number of Bores	
S.2	Tunnel Shape	
S.3	Portal Shapes	
S.4	Ground Conditions	
S.5	Complex	

4.12.2 **Sample Inspection Form**

Initial and routine inspections evaluate the condition states of structural, civil, and functional systems. Structural elements are liners, roof girders, columns/piles, cross passageways, interior walls, portals, ceiling slabs, ceiling girders, hangers and anchorages, ceiling panels, invert slabs, slabs on grade, invert girders, joints, and gaskets. Civil elements include wearing surfaces, traffic barriers, and pedestrian railings. Functional systems include the mechanical, electrical and lighting, fire and life safety and security, signs, and protective systems.

Forms should be easy to understand and organized for easy database entry. The forms should be supplemented with photographs and sketches to clearly show the deficiency and other useful information. Supplementary notes from the inspection can be kept in a field book or entered electronically.

Data can be collected by hand using pre-printed forms or directly entered electronically using a tablet, personal computer, or other device. Data collected by hand will later need to be entered into the electronic database. Table 4.6 contains a sample element level inspection form that is compatible with the requirements contained in the SNTI.

Direct electronic entry has the advantage of potential time savings, a mechanism for review of historical data for comparison, automatic error checking, and improved accuracy. The inspection team may assign one individual to enter all field data collected directly into the tablet or personal computer during the inspection.

Table 4.6 – Sample tunnel element collection form for initial and routine inspections

National Tunnel Inventory – Inventory and Element Data

Inventory Data
Identification Items

Item ID	Inventory Item Name	Code
I.1	Tunnel Number	
I.2	Tunnel Name	
I.3	State Code	
I.4	County Code	
I.5	Place Code	
I.6	Highway Agency District	
I.7	Route Number	
I.8	Route Direction	
I.9	Route Type	
I.10	Facility Carried	
I.11	LRS Route ID	
I.12	LRS Mile Point	
I.13	Tunnel Portal’s Latitude	
I.14	Tunnel Portal’s Longitude	
I.15	Border Tunnel State or Country Code	
I.16	Border Tunnel Financial Responsibility	
I.17	Border Tunnel Number	
I.18	Border Tunnel Inspection Responsibility	

Age and Service Items

Item ID	Inventory Item Name	Code
A.1	Year Built	
A.2	Year Rehabilitated	
A.3	Total Number of Lanes	
A.4	Average Daily Traffic	
A.5	Average Daily Truck Traffic	
A.6	Year of Average Daily Traffic	
A.7	Detour Length	
A.8	Service in Tunnel	

Classification Items

Item ID	Inventory Item Name	Code
C.1	Owner	
C.2	Operator	
C.3	Direction of Traffic	
C.4	Toll	
C.5	NHS Designation	
C.6	STRAHNET Designation	
C.7	Functional Classification	
C.8	Urban Code	

Geometric Data Items

Item ID	Inventory Item Name	Code
G.1	Tunnel Length	
G.2	Minimum Vertical Clearance over Tunnel Roadway	
G.3	Roadway Width, Curb-to-Curb	
G.4	Left Sidewalk Width	
G.5	Right Sidewalk Width	

Inspection items

Item ID	Inventory Item Name	Code
D.1	Routine Inspection Target Date	
D.2	Actual Routine Inspection Date	
D.3	Routine Inspection Interval	
D.4	In-Depth Inspection	
D.5	Damage Inspection	
D.6	Special Inspection	

Load Rating and Posting Items

Item ID	Inventory Item Name	Code
L.1	Load Rating Method	
L.2	Inventory Load Rating Factor	
L.3	Operating Load Rating Factor	
L.4	Tunnel Load Posting Status	
L.5	Posting Load – Gross	
L.6	Posting Load – Axle	
L.7	Posting Load – Type 3	
L.8	Posting Load – Type 3S2	
L.9	Posting Load – Type 3-3	
L.10	Height Restriction	
L.11	Hazardous Material Restriction	
L.12	Other Restrictions	

Navigation Items

Item ID	Inventory Item Name	Code
N.1	Under Navigable Waterway	
N.2	Navigable Waterway Clearance	
N.3	Tunnel or Portal Island Protection from Navigation	

Structure Type and Material Items

Item ID	Inventory Item Name	Code
S.1	Number of Bores	
S.2	Tunnel Shape	
S.3	Portal Shapes	
S.4	Ground Conditions	
S.5	Complex	

National Tunnel Inventory – Inventory and Element Data

Element Data

Structural Elements

Element Name	Element Number	Element Parent Number	Total Quantity	Condition State 1 Quantity	Condition State 2 Quantity	Condition State 3 Quantity	Condition State 4 Quantity

Joints & Gaskets

Element Name	Element Number	Element Parent Number	Total Quantity	Condition State 1 Quantity	Condition State 2 Quantity	Condition State 3 Quantity	Condition State 4 Quantity

Civil Elements

Element Name	Element Number	Element Parent Number	Total Quantity	Condition State 1 Quantity	Condition State 2 Quantity	Condition State 3 Quantity	Condition State 4 Quantity

Mechanical System Elements

Element Name	Element Number	Element Parent Number	Total Quantity	Condition State 1 Quantity	Condition State 2 Quantity	Condition State 3 Quantity	Condition State 4 Quantity

Electrical System Elements

Element Name	Element Number	Element Parent Number	Total Quantity	Condition State 1 Quantity	Condition State 2 Quantity	Condition State 3 Quantity	Condition State 4 Quantity

Fire/Life Safety/Security System Elements

Element Name	Element Number	Element Parent Number	Total Quantity	Condition State 1 Quantity	Condition State 2 Quantity	Condition State 3 Quantity	Condition State 4 Quantity

Sign Elements

Element Name	Element Number	Element Parent Number	Total Quantity	Condition State 1 Quantity	Condition State 2 Quantity	Condition State 3 Quantity	Condition State 4 Quantity

Protective Systems Elements

Element Name	Element Number	Element Parent Number	Total Quantity	Condition State 1 Quantity	Condition State 2 Quantity	Condition State 3 Quantity	Condition State 4 Quantity

4.12.2.1 **Sketches**

The documentation of severe defects in any element should contain a sketch showing the pertinent details and a written description of the defect. Each defect should show its length, width, and depth, as well as other information to describe it fully. Label the sketch and provide legends necessary to define abbreviations or terms. For instance, the following scheme can be used to label structural defects:

Description of Defect	Classification
Crack - CR	1 - Minor
Scaling - SC	2 - Moderate
Spall - SP	3 - Severe
Staining - ST	
Exposed Reinforcement - E	
Corrosion - C	
Honeycomb - H	
Patch Failure - PF	
Hollow Area - HA	
Debris - D	
Buckle - B	
Efflorescence - EF	
Leakage - LK	
Check - CK	
Rot - RT	
Fire Damage - FD	
Paint Deterioration – PD	

4.12.2.2 **Photographs**

Photographs provide additional information that may be useful for evaluation by specialists, for quality control, and to establish a historical record. Photographs should be taken for both major defects and typical conditions. A list of photographs taken during the inspection should be recorded on a photo log. Electronic photos are typically assigned a number by the device. Accompanying descriptions should include as much detail as possible. It is helpful to take photographs of the same conditions or defects noted from previous inspections so that the rate of deterioration or effectiveness of repair can be monitored.

4.12.2.3 **Field Record**

Inspection and repair notes to document the inspection should be taken in the field and maintained either electronically or in a bound field book. Information to be recorded and maintained includes notes on safety issues and on discussions with contractors, operations personnel, and other interested parties. Entries should be chronological by date and time, consist of clear, concise, and accurate descriptions of events and contain appropriate sketches. Other information to record and maintain includes: names of inspectors, temperature, weather conditions, and locations that were inspected. These records should be stored electronically.

4.12.2.4 **Inspection Reports**

Inspection reports are formal summaries of inspection findings for each element and system that was inspected. The report should be submitted in accordance with written procedures established by the tunnel inspection organization and the owner. The completed report should be furnished to the tunnel owner along with any repair recommendations.

Following are examples of elements in an inspection report:

- **Critical Finding**
  Critical finding refers to defects that require "immediate" action including possible closure of the tunnel where safety or structural concerns are identified using criteria established in the NTIS. Upon discovering a critical finding, the team leader should immediately notify the program manager and the tunnel owner. A brief summary of these details can be included in the inspection report as necessary.

- **Priority Repair**
  Priority repair refers to conditions for which further investigations, design, and implementation of interim or long-term repairs should be undertaken on a priority basis, i.e., taking precedence over other scheduled work. These repairs will improve the durability and aesthetics of the structure or element and will reduce future maintenance costs. Elements that do not comply with code requirements are also priorities for repair.

- **Routine Repair**
  Routing repair refers to conditions requiring further investigation or remedial work. This work can be undertaken as part of a scheduled maintenance program, scheduled project, or routine facility maintenance. Items identified in the preventive maintenance program can be put in this category.

Below is a suggested outline for an inspection report and a description of each section:

- **Letter of Transmittal –** Formal identification of report and introduction to the recipient.

- **Table of Contents –** This provides information to the reader on where to find information of a particular interest.

- **List of Tables –** Used to identify the title and location of any tables that were used.

- **List of Figures, Drawings, and Sketches –** Used to identify the title and location of any figures or drawings.

- **List of Photographs –** Used to identify the title and location of any photographs. These may be included as an appendix to the report.

- **Executive Summary** – Provides a concise summary of the inspection, findings, and recommended repairs.

- **General Description –** Provides a general description of the tunnel or tunnels that were inspected. This information could include the location of the tunnel(s), age, general geometry, and any other pertinent descriptive information.

- **General System Descriptions** – Provide general descriptions of the structural, civil, and functional systems inspected and the scope of the elements covered by the inspection. This should precede the detailed descriptions for the inspection findings of each element.

- **Inspection Procedures –** The procedures used to inspect the tunnel elements should be explained and illustrated. If extensive written procedures were followed, these may be included as an appendix to the report. Documentation of any specialized testing processes and outside expertise should be included.

- **Inspection Findings –** The condition of all tunnel elements should be documented using the Condition States CS1, CS2, CS3, and CS4 per the instructions and guidelines in the SNTI.

- **Inspection Results –** A detailed description of the results of the inspection should be included for the various tunnel elements below.

    - <u>Structural and Civil</u> – For structural and civil elements, the report should contain descriptions of the various deficiencies found, their locations and their severity. Any special testing, such as concrete strength, freeze-thaw analysis, or petrographic analysis, should be included with the findings for the record.

    - <u>Mechanical</u> – For the mechanical inspections, the general condition and operation of all equipment should be described and deficiencies noted. Specialized testing required to effectively determine the operational condition of the equipment, such as vibration testing and oil analyses, should be included for the record.

    - <u>Electrical</u> – For the electrical inspections, the general condition and operation of all equipment should be described and the deficiencies noted. Any specialized testing needed to effectively determine the operational condition of the equipment, such as power distribution and emergency power, should be included for the record. In addition, comparisons of light level measured to recommended levels should be provided to the owner. Remediation work that may accompany testing and inspection should be included.

- **Recommendations** – This section includes recommendations for repair or rehabilitation of the tunnel components found to be deficient or to not meet current code requirements. Substantial rehabilitation may require a life-cycle cost comparison of repair options. Repair and rehabilitation recommendations should be broken down for each of the main tunnel systems into the categories previously described, critical finding, priority repair and routine repair.

- **Appendices –** The appendices can be used for detailed and extensive inspection summaries that are lengthy, highly technical and detailed (such as structural panel ratings and lighting illuminance levels), and reports from special testing agencies. Detailed information such as special permits, processes or qualifications can go in an appendix. An example of this would be a confined space entry permit. A summary of the inspection operation should be provided with a list of inspection personnel, identification of the team leader, the inspection tools used, the access equipment required, and the schedule maintained. This information is useful for planning future inspections as well as for documenting the inspection.

4.13 Glossary of Selected Items

AASHTO	-	American Association of State Highway and Transportation Officials
AC	-	Alternating Current
ATSSA	-	American Traffic Safety Services Association
CCTV	-	Closed Circuit Television
Chord	-	A line segment that joins two points on a curve
CO	-	Carbon Monoxide
DC	-	Direct Current
ETS	-	Emergency Trip Switch
FHWA	-	Federal Highway Administration
Gunite	-	Term commonly used for fine-aggregate shotcrete
gpm	-	Gallons per minute
IES LM-50	-	Illuminating Engineering Society, Lighting Measurements – 50
IES RP-22	-	Illuminating Engineering Society, Recommended Practices – 22
ITE	-	Institute of Transportation Engineers
Km/h	-	Kilometers per hour

mph	-	Miles per hour
MTS	-	Maintenance Testing Specifications
MUTCD	-	Manual on Uniform Traffic Control Devices
NATM	-	New Austrian Tunneling Method (synonymous with SEM)
NBIS	-	National Bridge Inspection Standards
NBS	-	National Bureau of Standards
NEMA	-	National Electric Manufacturers Association
NETA	-	National Electrical Testing Association
NFPA	-	National Fire Protection Association
OSHA	-	Occupational Safety and Health Administration
PEI	-	Porcelain Enamel Institute
SEM	-	Sequential Excavation Method (synonymous with NATM)
TBM	-	Tunnel Boring Machine
TSS	-	Track Safety Standards
UPS	-	Uninterruptible Power Supply

References

American Association of State Highway and Transportation Official, *The Manual for Bridge Evaluation, Second Edition*, 2011.

American Concrete Institute (ACI) 201.1R-08, *Guide for Conducting a Visual Inspection of Concrete in Service*, 2008.

American Railway Engineering and Maintenance-of-Way Association (AREMA), *Bridge Inspection Handbook,* 2008.

American Railway Engineering and Maintenance-of-Way Association (AREMA), *2010 Manual for Railway Engineering - Part 8*, 2010.

Arnoult, J. D., *Culvert Inspection Manual* Publication No. FHWA-IP-86-2, Federal Highway Administration, 1986.

ASTM E1728 - Standard Practice for Collection of Settled Dust Samples Using Wipe Sampling Methods for Subsequent Lead Determination.

ASTM E1792 - Standard Specification for Wipe Sampling Materials for Lead in Surface Dust.

Bickel, J.; E. King, and T. Kuesel, *Tunnel Engineering Handbook, Second Edition,* Chapman & Hall, New York, 1996.

Federal Highway Administration, December 2009, *Technical Manual for Design and Construction of Road Tunnels – Civil Elements,* Publication No. FHWA-NHI-10-034, Washington, DC.

Haack, A.; J. Schreyer, and G. Jackel, *State-of-the-art of Non-destructive Testing Methods for Determining the State of a Tunnel Lining*, Tunneling and Underground Space Technology, 10.4 (1995): 413-431.

Hartle, R. A.; Ryan, T. W.; Mann, E. J.; Danovich, L. J.; Sosko, W. B.; Bouscher, J. W., *Bridge Inspector's Reference Manual*, 2002, Publication No. FHWA-NHI-03-001.

Maryland Transportation Authority: Office of Engineering and Construction, *Facilities Inspection Manual, First Edition,* 2010.

National Fire Protection Association, *NFPA 502:Standard for Road Tunnels, Bridges, and Other Limited Access Highways*, 2001.

National Institute for Occupational Safety and Health (NIOSH) Method 7300

Occupational Safety and Health Standards (OSHA)*, Standard 1910.147 App A: "Typical minimal lockout procedures",* Washington, DC.

SYSTRA Consulting, *Electric Traction Catenary Inspection Field Manual*, AMTRAK, 1998.