California High-Speed Train Project

TECHNICAL MEMORANDUM

Service and Maintenance Considerations For High-Speed Train Tunnels TM 2.4.8

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Note: Signatures apply for the latest technical memorandum revision as noted above.

Prepared by

for the California High-Speed Rail Authority

System Level Technical and Integration Reviews

The purpose of the review is to ensure:

- Technical consistency and appropriateness
- Check for integration issues and conflicts

System level reviews are required for all technical memoranda. Technical Leads for each subsystem are responsible for completing the reviews in a timely manner and identifying appropriate senior staff to perform the review. Exemption to the system level technical and integration review by any subsystem must be approved by the Engineering Manager.

System Level Technical Reviews by Subsystem:

Systems:	*Signed document on file* Richard Schmedes	14 Jun 10 Date
Infrastructure:	*Signed document on file* Gordon Clark	11 Jun 10 Date
Operations:	*Signed document on file* Paul Mosier	25 Jun 10 Date
Maintenance:	*Signed document on file* Paul Mosier	25 Jun 10 Date
Rolling Stock:	*Signed document on file* Terry Brunner	16 Jun 10 Date

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ABSTRACT

This technical memorandum identifies inspection, service and maintenance activities that may be required to be performed within each high-speed train tunnel. As each tunnel design is completed, detailed inspection, service and maintenance requirements for the tunnel structure and for the equipment installed within that tunnel will be developed. These requirements will be incorporated into a system-wide "Inspection, Service and Maintenance Manual" for use during high-speed train operation. This memorandum is not a draft for such a manual nor does it include a comprehensive list of all items of equipment and infrastructure to be included in the manual, but notes issues to be addressed in developing a maintenance manual for new high-speed train tunnels.

Elements identified for inspection, service and maintenance include such items as:

- Tunnel and cross-passage structures
- Drainage systems
- Walkways and duct banks
- Track
- Overhead contact system
- Signaling and communications equipment
- Emergency ventilation fans
- SCADA
- Drainage pumps and fire-protection piping
- Tunnel lighting and power supply.

Identified activities include inspections for damage and wear

- Routine testing and servicing of equipment
- Regular preventive maintenance and repair
- Longer-term maintenance
- Major overhauls and replacements.

The process of recording and reporting the results of inspections, testing, service, maintenance and repairs is not addressed in the TM as it is anticipated that a systemwide approach will be developed for all elements of the CHSTP.

The relevance for efficient tunnel maintenance of the locations of cross-over tracks, siding tracks, and maintenance bases relative to the locations of the different tunnels is discussed.

1.0 INTRODUCTION

1.1 PURPOSE OF TECHNICAL MEMORANDUM

This technical memorandum identifies different inspection, service and maintenance activities that may be required to be performed either on a regular or occasional basis within each high-speed train tunnel, depending on the design and equipment installed. In addition, this memorandum has been prepared to ensure that long-term service and maintenance requirements are taken into consideration during selection and development of the tunnel designs, and that the necessity for efficient tunnel maintenance and repair is considered when locating line-wide facilities such as cross-over tracks and maintenance bases.

This technical memorandum does not include required information for the Inspection, Service and Maintenance Programs and Schedules to be developed by others, nor does it include a comprehensive list of all items of tunnel equipment and infrastructure. It notes issues that will need to be addressed and some of the means that might be employed, based on the experience of other high-speed rail systems.

As the design of each tunnel is completed, the detailed inspection, service and maintenance requirements for that tunnel and associated portal structures and for the particular equipment to be installed in that tunnel will be developed. A principal purpose of this Technical Memorandum is to provide guidance on development of these detailed requirements. This material will be incorporated by into a comprehensive, line-wide, “Inspection, Service and Maintenance Manual” for use during operation of the high-speed train system.

1.2 STATEMENT OF TECHNICAL ISSUE

The primary underground infrastructure elements subject to inspection, service and maintenance are as follows:

- Principal tunnel structures - train tunnel structural linings; tunnel portal structures; cross-passage tunnel structural linings; drainage
- Secondary tunnel structures - track-slabs; safety walkways; duct-banks; internal tunnel dividing walls, refuges areas, fixed equipment support structures (including brackets), finishes

There are also systemwide elements which, when they are located underground, are subject to similar inspection, service and maintenance requirements as the primary infrastructure elements listed above. These elements are as follows:

- Trackwork elements - rail; plinths; floating-slabs
- Systems elements - OCS. equipment; signaling equipment, communications equipment, SCADA equipment, instrumentation and monitoring equipment, ; and ducts and cabling for all systems.
- Mechanical elements - emergency ventilation fans and associated equipment; fire-protection piping; drainage pumps and tunnel drainage systems; safety doors
- Electrical elements - lights; power for lighting and mechanical equipment

Note that when these systemwide elements are not located in tunnels, they may be subject to different inspection, service and maintenance requirements.

There are some primary elements associated with the tunnels which are not covered by this TM as they are elements that are not unique to the tunnels, or are not located within the tunnels. These elements include:

- Portal buildings
- Slopes

The principal inspection, service and maintenance activities to be considered for these elements will include:

- Regular inspections for damage, wear or material deterioration,
- Special inspections for damage following an earthquake event,
- Checking and confirming serviceability, and carrying out required performance testing,
- Carrying out routine or interim servicing, maintenance and/or repairs,
- Carrying out long-term maintenance and/or repairs, or major overhauls and replacements.

Service and maintenance activities will require service and maintenance staff to enter the tunnels during non-revenue hours. If necessary, service and maintenance activities will be performed in the non-operating tunnel-bore or trainway during single-track working. Service and maintenance staff may use ATC-equipped rail-mounted equipment.

The process of recording and reporting the results of inspections, testing, service, maintenance and repairs is not addressed in the TM as it is anticipated that a systemwide approach will be developed for all elements of the CHSTP.

1.3 GENERAL INFORMATION

1.3.1 Definition of Terms

Acronyms

ATC	Automatic Train Control
CHSTP	California High-Speed Train Project
HST	High -Speed Train
MOW	Maintenance of Way
OCS	Overhead Contact System
SCADA	Supervisory Communication and Data Acquisition

1.3.2 Units

The California High-Speed Train Project (CHSTP) is based on U.S. Customary Units consistent with guidelines prepared by the California Department of Transportation (Caltrans) and defined by the National Institute of Standards and Technology (NIST). U.S. Customary Units are officially used in the U.S. and are also known in the U.S. as “English” or “Imperial” units. In order to avoid any confusion, all formal references to units of measure should be made in terms of U.S. Customary Units.

2.0 DEFINITION OF TECHNICAL TOPIC

2.1 GENERAL

Inspection, service and maintenance programs and schedules will be developed for all structural elements of the tunnels and associated portal structures, and for all equipment to be installed within the tunnels, to assure safety, serviceability and long-term durability of all elements.

2.1.1 CHSTP Design Considerations

Routine inspection, servicing and preventive maintenance will be planned so that these activities can be conducted in normal non-service hours and thus will not require single-track operations to allow maintenance on the other track during revenue-service hours. However, in order to most efficiently carry out some of the more extensive tunnel maintenance and tunnel repair activities, it may be necessary to conduct this more time-consuming work during train operating hours. Single-track operations may be required on one track through a tunnel while work crews occupy the other track. To accomplish this with the least impacts to train operations, the number and location of cross-over tracks will need to be considered in relation to the locations of the tunnels when planning the rail alignments. Considering the assumed Phase 1 and Full Build out service plans and operating plans, the ability to schedule and operate the system under any single track conditions is currently unknown and will have to be evaluated.

Additionally, opportunities to expand the maintenance window on the shoulders of the operating hours will be considered as this may be required for some of the more extensive repairs or maintenance requirements, particularly as the high-speed train system infrastructure ages and during non-routine events.

Certain inspection, servicing and maintenance activities in the tunnels will require use of equipment to allow working access to the upper part of the tunnels. This equipment may be special ATC-equipped rail-mounted equipment, or high-rail equipment that is operable on both highways and railways. If special rail-mounted equipment is to be used, then the location of any necessary turn-out and storage track relative to the location of the different tunnels will need to be considered. If high-rail equipment is to be operated, then suitably designed road access will be provided in proximity to the different tunnels to allow transfer of equipment to/from road to rail.

Evaluation and documentation of these considerations will be presented in separate documents.

2.1.2 CHSTP Design Parameters

Design parameters for high-speed train tunnels are under development and will be defined in separate documents, including the following technical memoranda:

TM 2.4.2 – Basic Tunnel Configurations

TM 2.4.5 – Tunnel Structural Design

TM 2.4.6 – Tunnel Portal Facilities

2.2 LAWS AND CODES

Initial high-speed train (HST) design criteria will be issued in technical memoranda that provide guidance and procedures to advance the preliminary engineering. When completed, a Design Manual will present design standards and criteria specifically for the design, construction and operation of the CHSTP's high-speed railway.

Criteria for design elements not specific to HST operations will be governed by existing applicable standards, laws and codes. Applicable local building, planning and zoning codes and laws are to be reviewed for the stations, particularly those located within multiple municipal jurisdictions, state rights-of-way, and/or unincorporated jurisdictions.

In the case of differing values, the standard followed shall be that which results in the satisfaction of all applicable requirements. In the case of conflicts, documentation for the conflicting standard is to be prepared and approval is to be secured as required by the affected agency for which an exception is required, whether it be an exception to the CHSTP standards or another agency standards.

Maintenance levels will be in compliance with regulatory requirements.

National Tunnel Inspection Standards (NTIS) for highway tunnels are currently being developed by Federal Highway Administration (FHA) as a result of recommendations made by the National Transportation Safety Board (NTSB) on the fatal July 2006 suspended ceiling collapse in the Central Artery Tunnel in Boston, Massachusetts. An Advance Notice of Proposed Rule Making (ANPRM) has been published for the NTIS and comments received. The comment period closed in 2009. This rulemaking would revise 23 CFR Part 650 -- Bridges, Structures, and Hydraulics, by adding the National Tunnel Inspection Standards (NTIS) under Subpart E. It is anticipated that the NTIS will be modeled after the existing National Bridge Inspection Standards and will include requirements for, among other things, inspection procedures, the qualifications and training of inspectors, and a National Tunnel Inventory. The NTIS will also make reference to the Highway and Rail Transit Tunnel Maintenance and Rehabilitation Manual (2004 Edition) and the Highway and Rail Transit Tunnel Inspection Manual (2005 Edition) issued by FHA and Federal Transit Administration (FTA). This TM incorporates much of these two manuals although they are primarily focused on repair of existing tunnels.

NFPA 502 Standard for Road Tunnels, Bridges, and Other Limited Access Highways (National Fire Protection Association 2007), Sec. 3.3.38, Clause 2 covers inspection procedures in road tunnels and states .

“Inspections should assess the condition of all structural elements of a tunnel and assess the condition and performance of a tunnel's structural, mechanical, electrical, hydraulic and ventilation systems including operational procedures.”

3.0 ASSESSMENT / ANALYSIS

3.1 GENERAL

Routine inspection, service and maintenance programs and schedules will be developed for all structural elements of the tunnels and associated portal structures, and for all equipment to be installed within the tunnels, to assure safety, serviceability and long-term durability of all elements.

This technical memorandum does not include language or drafts for the Inspection, Service and Maintenance Programs and Schedules which will be required and which will be developed by others in the future, nor does it include a comprehensive list of all items of tunnel equipment and infrastructure that will be involved, but notes some of the issues that will need to be addressed and some of the means that might be employed, based on the experience of other high-speed rail systems.

3.1.1 Special Challenges

Tunnels provide additional challenges for inspections, servicing and maintenance, over and above the efforts that will be required for the balance of the high-speed rail system:

- A tunnel being a continuous structure enclosing the vehicle envelope results in restricted clearances and restricted access for inspecting, servicing and maintaining both the structure itself and the installed equipment. This must be taken into consideration when sizing the tunnels, when placing and sizing the equipment required to be installed within the tunnels, and when planning the inspection, service and maintenance programs.
- To inspect, service and maintain equipment mounted in the upper part of tunnels, or the upper part of the structures themselves, special ATC-equipped rail-mounted service equipment will be needed to provide working access, and adequate tunnel clearances must be allowed for these activities. Storage facilities and ready access to the tunnels for the rail-mounted equipment will also be needed. Ventilation must be provided to the tunnels if diesel-powered equipment is required for maintenance operations.
- Groundwater around the tunnel structure will commonly result in some leakage into the tunnel which will often introduce corrosion problems that affect the tunnel structures and the equipment installed within the tunnels. Design of equipment and inspection, service and maintenance programs for the equipment must address this issue.
- A drainage system will be required to discharge groundwater-leakage, any introduced wash water, water from a fire-fighting incident or practice, or pipe-leakage to a distant portal, or at a mid-tunnel low-point to pump it to a portal or directly to the surface. These additional facilities will require an additional set of inspection, service, and maintenance requirements.
- Except for very short tunnels, the enclosed space requires an emergency ventilation system to remove smoke and maintain breathable air. This may be achieved by fans installed at the portal or equipment such as jet fans located within the length of the tunnels, all requiring routine inspection, testing and maintenance.
- Necessary provisions for emergency egress and emergency response, such as safety cross-passages to a parallel tunnel, or special safety shafts or tunnels to the surface may need to be spaced along the tunnel alignment, depending on tunnel length. All these facilities will need lighting, ventilation and other mechanical equipment, and communications systems, which all require inspections, servicing and maintenance.
- There are different lining types that can be present in tunnel structures and are dependent on tunneling methodology and ground loadings. Lining types can have unusual reinforcement arrangements such as fiber reinforced shotcrete, and different waterproofing details such as compressed EPDM gaskets in precast concrete liners. Damage such as cracking of concrete during construction can result in long term maintenance issues with leakage. Cracking of concrete and leakage can also result from

long term ground movements and seasonal variations in temperature and water pressure.

3.1.2 Routine Inspections, Servicing and Preventative Maintenance

Inspections for damage, wear and material deterioration of tunnel structures and equipment, and testing to confirm serviceability of all installed equipment will be carried-out on a routine basis.

- Routine inspection, servicing, and preventive maintenance will be planned so that it can be conducted in normal non-service hours and thus will not require single-track operations to allow maintenance on the other track during revenue-service hours.
- Servicing and preventive maintenance will be carried-out on a routine basis on all mechanical, electrical and systems equipment installed within tunnels, and will normally be carried-out in conjunction with, and as an extension of, the inspection program.
- Routine inspections, servicing and preventive maintenance programs will be developed so that different tunnel equipment can be dealt with in the same work session to optimize use of tunnel access for maintenance purposes. This will be particularly important if ATC-equipped rail-mounted equipment is required to gain access to equipment.

3.1.3 Major Maintenance and Repairs

Major maintenance and/or repairs, major overhauls and replacements in a tunnel that require single-track train operations to enable a track to be occupied for such purposes during normal train operating hours will need to be planned and coordinated so that a maximum number of such items can be dealt with during any one occupancy. Cross-over tracks may need to be located outside a tunnel or group of tunnels to allow efficient single-track train operations during major tunnel maintenance or non-routine events. Additionally, opportunities to expand the maintenance window on the shoulders of the operating hours will be considered as this may be required for some of the more extensive repairs or maintenance requirements, particularly as the high-speed train system infrastructure ages.

3.1.4 Inspections and Repairs Following an Earthquake or other Non-Routine Event

It will be necessary to develop a plan for conducting emergency inspections of each tunnel or group of tunnels following an earthquake event that may have affected that tunnel or group of tunnels. Similar inspections will be necessary following fire, flood, derailment or other non-routine events. The emergency program would include inspecting all structures and equipment for damage that could directly affect the safety of train operations, and testing all safety-related equipment such as tunnel emergency ventilation fans and emergency crosspassage safety-doors, to assure that they are still fully operational.

Procedures and protocols for inspection and repairs following non-routine events will be included in the high-speed train system Standard Operating Plan and Safety Assurance Plan.

3.1.5 Fire Department Inspections and Testing

Formal inspections and testing of the tunnel emergency ventilation system, fire protection system, emergency egress routes and emergency communications systems will be conducted prior to start-up of operations and periodically thereafter by the responsible fire department and regulating authorities. Periodic in-tunnel training and familiarization sessions for fire-fighters and other emergency response staff will be necessary. All fire department inspections, testing and training will be conducted in non train-operating hours under the direct supervision of qualified high-speed train personnel.

3.2 INSPECTION, SERVICE AND MAINTENANCE REQUIREMENTS

3.2.1 Principal Tunnel Structures

Primary tunnel structure elements may include:

- Pre-cast concrete segmental linings and cast-in-place concrete linings for running tunnels
- Cross-passage tunnel structural linings
- Tunnel Portal Structures

Periodic inspections of all ground-supporting concrete structures will be conducted to locate any cracking or spalling or other signs of stress or deterioration. Any loose material will need to be removed, any exposed steel reinforcement will be appropriately protected by coating or patching, and the location of the damage will be recorded for re-checking in future inspections. Any concentrations of such deterioration would need to be noted and more significant remedial action may need to be considered to repair and strengthen the lining in these locations.

Periodic inspections will record any groundwater leakage into the tunnel through joints or cracks in the linings. Note will be made of whether any such groundwater is reaching tunnel equipment which might result in its eventual deterioration. Appropriate re-sealing efforts may need to be implemented, from re-caulking joints, to chemical grouting of cracks, to additional grouting through the lining if a wider area is affected. Provisions may need to be made to immediately protect equipment from drips and to channel any significant flows to the tunnel drainage system. The total volume of groundwater seepage into any length of tunnel will not normally be allowed to exceed 0.8 gpm per 1000 feet of tunnel.

Instrumentation or survey monitoring points installed in or on tunnel and portal structure elements to monitor identified or potential movements anticipated due to landslide or seismic activities will be read continuously and automatically, and preferably remotely to minimize need for survey personnel within a tunnel. Drains installed through portal structure or tunnel linings to reduce groundwater pressures or permanently lower the groundwater table around structures will need to be regularly checked and cleaned. All instrumentation, ducts, and cabling associated with ground movement and groundwater monitoring will need to be regularly serviced and maintained.

An initial structural inspection and maintenance schedule is included as **Appendix A**.

3.2.2 Secondary Tunnel Structures

Secondary tunnel structure elements include:

- Track slabs
- Safety walkways
- Cross-passage internal structures
- Duct banks
- Internal dividing walls

Periodic inspections of all internal structures will be conducted to locate any cracking or spalling or other signs of stress or deterioration. Any loose material will be removed, any exposed steel reinforcement will be appropriately protected by coating or patching, and the location of the damage will be recorded for re-checking during future inspections.

Periodic inspections will be made of all safety walkways, cross-passage walkways, stairways and ladders to assure that all are maintained, clean, slip-free and clear for emergency use. Handrails will be checked to assure firm attachment and will be maintained in good condition; cross-passage safety doors and sliding safety doors in tunnel dividing walls will be checked, serviced and maintained on a regular basis to assure that they are always useable.

An initial structural inspection and maintenance schedule has been included with this technical memorandum as **Appendix A**.

3.2.3 Trackwork Elements

Trackwork elements in tunnels include:

- Rail
- Plinths
- Floating slabs

The CHSTP will develop inspection and maintenance procedures and schedules for the high-speed rails, support plinths and floating slabs that will be implemented throughout the high-speed train system. Trackwork inspection and maintenance procedures will generally be the same whether or not the trackwork is located in a tunnel. The prime difference will be a tunnel's restricted work access. Several different types of inspection will be needed from which appropriate maintenance programs can be developed:

- Track inspection over a major length of line might be carried out every ten days by a high-speed multi-purpose inspection car operating during normal revenue service hours. Track irregularity data collected would include longitudinal level, twist, cross level, alignment, and gauge.
- Train vibration data under high-speed operations might be collected daily using vibration acceleration meters installed in revenue service trains.
- Rail defects might be checked for by operating a slow speed ultrasonic rail flaw detector car during non-revenue service hours.

Preventive maintenance procedures for the rail carried out during regular non-revenue service hours may include: rail lubrication; rail grinding; joint maintenance and re-gauging. Regular track maintenance to re-align and adjust rail or even to replace shorter sections of worn rail or other worn / deteriorated material will also generally be carried out during non-revenue service hours to avoid impacting operations with single-track working.

However, major work such as long lengths of track replacement will inevitably entail single-track working. The location of crossovers and maintenance bases relative to the different tunnels will be important when planning for trackwork inspections involving special inspection cars, and also for major trackwork maintenance and replacement activities involving single-track operations. Considering the assumed Phase 1 and Full Build out service plans and operating plans, the ability to schedule and operate the system under any single track conditions is currently unknown and will have to be evaluated. Incorporation of tie-and-ballast track into a tunnel design would most probably increase the need for more frequent maintenance work in order to preserve the track line and level under conditions where clearances are always critical. This will be especially true in longer tunnels and in tunnels including horizontal curvature.

A reasonably short, straight tunnel where ballasted track is being used outside the tunnel might be an exception, and under these circumstances connecting with ballasted track through the tunnel might be considered.

3.2.4 Systems Elements

Systems elements which may be located in tunnels include:

- OCS equipment
- Signaling equipment
- Communications equipment
- SCADA equipment
- Instrumentation and monitoring equipment

As for trackwork, specialized rail vehicles might be employed for a good proportion of inspection, servicing and maintenance of the systems facilities throughout the railway system, including

through the tunnels. These might include a high-speed multi-purpose inspection car operating during normal revenue service hours to check:

- Height / deviation / gradient / contact loss / current collection of contact wire for the OCS.
- ATC current / ATC frequency / train detection performance of track circuit, characteristics of transponder for the Signaling System.
- Electric field level at telecommunication base, signal / noise levels, changing over characteristics of antenna zone for the Telecommunication System.

Maintenance work on OCS facilities will be conducted during non-revenue hours when power to the OCS can be switched-off. A fleet of specialized electrical maintenance cars, catenary installation cars, crane cars, and work cars might be employed to accomplish the maximum amount of work in the tunnels during the short window of time between revenue operations.

Regular visual and in-depth inspection of the OCS and regular preventive maintenance of the OCS will be conducted through each tunnel. Inspection protocols and parameters for testing of OCS equipment will be developed and for inclusion in inspection manuals prepared and adopted by Operations. Items requiring regular inspection and routine maintenance of components will include:

- Wires, hangers, jumpers and other OCS conductor components
- Insulators
- Pipes, clamps, brackets, cantilever arms and other support assemblies and structures
- Tension weight/ Counter-weight assemblies
- Disconnect switches

All electric and electronic components of the signaling and communications systems will be tested on a continuous basis, and a program for this testing and periodic maintenance will need to be developed. This equipment will commonly be housed in dedicated equipment cross-passages or niches excavated outside the standard tunnel cross-section.

Items will include:

- SCADA interfaces
- Wayside telephones
- Co-axial / BDA communications system
- Train control / signaling elements.

Associated mechanical devices that are operated manually or by electric power will be routinely inspected and consistently maintained, and a regular program will be implemented to lubricate moving components, to remove any debris build-up and to replace items such as light bulbs, as necessary.

3.2.5 Mechanical Elements

Mechanical elements which may be located in tunnels include:

- Emergency ventilation fans and associated equipment
- Fire protection piping
- Drainage pumps, tunnel drainage system including pipes
- SCADA systems and associated equipment

A program for regular inspection and testing of all mechanical equipment within the tunnels will need to be developed and implemented. Emergency ventilation fans for a tunnel will be tested individually and in conjunction with other fans and components of the emergency ventilation system for that tunnel.

A routine preventive maintenance program will be developed that includes every major piece of mechanical equipment contained within the tunnels. Preventive maintenance must be scheduled and regularly conducted.

The tunnel drainage system will have to be checked and flushed clean on a regular basis, and drainage pumps will need to be regularly checked, cleaned and serviced.

If sliding doors for the safety egress doorways through the dividing wall in a twin-track single tunnel have mechanical assistance, then the mechanism must be tested, serviced and maintained on a regular basis.

Additional inspections and operational testing of emergency ventilation fans and fire protection equipment in each tunnel must be coordinated with the local authority having jurisdiction over safety, rescue and fire protection for that tunnel.

An initial mechanical maintenance schedule is included as **Appendix B.**

3.2.6 Electrical Elements

Electrical elements located in tunnels include:

- Tunnel lighting
- Tunnel power systems
- Duct banks and cabling

A program for regular inspection and testing of all electrical equipment within the tunnels will need to be developed and implemented, and coordinated as necessary with the mechanical and systems inspection and testing programs.

A routine preventive maintenance program will also be developed for all electrical equipment within the tunnel, and similarly will be coordinated as necessary with the mechanical and systems programs. Preventive maintenance will be scheduled and conducted regularly.

An initial electrical maintenance schedule is included as **Appendix C**.

3.3 TUNNEL MAINTENANCE ISSUES THAT MAY INFLUENCE ALIGNMENT PLANNING

3.3.1 Location of Crossover Tracks

Although most of the routine tunnel inspection and maintenance activities will be conducted without impacting revenue service, in order to most efficiently carry out some of the more extensive tunnel maintenance and tunnel repair activities, it will be necessary to conduct this more time-consuming work during train operating hours. The short window of time during the night between the daily revenue operations may be inadequate to access the tunnel, set up and perform the work, clean up and remove any equipment and perform the necessary safety checks before re-starting revenue service. This is particularly the case in long tunnels or numerous tunnels with limited access, located in remote locations. Opportunities to expand the maintenance window on the shoulders of the operating hours will be considered as required for some of the more extensive repairs or maintenance requirements.

Single-track operations may also be required on one track through a tunnel while work crews occupy the other track. To accomplish this effectively with the least impacts to train operations, the number and location of cross-over tracks will need to be considered in relation to the locations of the tunnels when planning the rail alignments. Considering the assumed Phase 1 and Full Build out service plans and operating plans, the ability to schedule and operate the system under any single track conditions is currently unknown and will have to be evaluated.

3.3.2 Maintenance Equipment

Certain inspection, servicing and maintenance activities in the tunnels will require use of equipment to allow working access to the upper part of the tunnels. This may be special ATC-equipped rail-mounted equipment, or high-rail equipment that is operable on both highways and railways. Use of this equipment will need to be taken into account when establishing the vehicle clearance envelope for the tunnels.

If special rail-mounted equipment is to be used, then the location of any necessary turnout and storage track relative to the location of the different tunnels will need to be considered. If high-rail equipment is to be operated, then suitably designed road access immediately adjacent to the tracks will need to be provided in proximity to the different tunnels in order to allow transfer of equipment to/from road to rail.

3.3.3 Maintenance Bases

To maintain the railway effectively, maintenance bases where inspection and maintenance vehicles and equipment can be stored and serviced need to be strategically located. The location of these bases relative to the different tunnels, cross-over tracks, turnouts and siding tracks will be important to enable specialized ATC-equipped rail-mounted equipment to be moved quickly to a particular tunnel, perform work and move off the main line during the short non-revenue nighttime periods available for maintenance work that does not affect train operations. For major work in a tunnel on one track when train operations must be affected, and where for a period revenue service is restricted to the adjacent track, the relative locations of tunnel, bases and cross-over tracks will also be important in order to minimize impacts to train operations and to efficiently service the tunnel maintenance work.

The maximum speed of maintenance vehicles, available time window for maintenance, and the proximity to long tunnels, or large numbers of tunnels, should be considered in the siting and spacing of maintenance bases. This document does not establish maintenance base requirements but rather informs of anticipated tunnel service, inspection and maintenance requirements. It is intended to inform the future development of maintenance plans and procedures, and potentially identify the need for additional, site-specific maintenance facility that may be required in proximity of tunnels at distances away from the MOW bases. The ability to locate maintenance siding tracks and unoccupied storage in locations remote from maintenance bases will be considered during design development.

A diagram from an existing high-speed rail system illustrating time that might be available for actual maintenance work with bases at 30-mile spacing and with a 6-hour time window between revenue service hours is attached for information in **Appendix D**.

3.4 CHSTP STANDARD

3.4.1 Applicability

The CHSTP Maintenance Planning Team will specify inspection protocols and inspection parameters. CHSTP Operations will adopt this process as part of the inspection manuals it produces.

3.4.2 Regulatory Requirements

Service and Maintenance procedures inside railway tunnels shall comply with applicable requirements of 49CFR Part 214, relevant OSHA regulations, and requirements of CHSTP Facilities Maintenance and Inspection Plan implemented as part of project-wide System Safety Program Plan.

National Tunnel Inspection Standards (NTIS) for highway tunnels are currently being developed by Federal Highway Administration (FHA) as a result of recommendations made by the National Transportation Safety Board (NTSB) on the fatal July 2006 suspended ceiling collapse in the Central Artery Tunnel in Boston, Massachusetts. After investigating the fatal collapse, the National Transportation Safety Board (NTSB) stated in its report that, ``had the Massachusetts Turnpike Authority, at regular intervals between November 2003 and July 2006, inspected the area above the suspended ceilings in the D Street portal tunnels, the anchor creep that led to this

accident would likely have been detected, and action could have been taken that would have prevented this accident." Among its recommendations, the NTSB suggested that the FHWA seek legislative authority to establish a mandatory tunnel inspection program similar to the NBIS that would identify critical inspection elements and specify an appropriate inspection frequency. Additionally, the DOT Inspector General (IG), in testimony before Congress in October 2007, highlighted the need for a tunnel inspection and reporting system to ensure the safety of the Nation's tunnels, stating that the FHWA ``should develop and implement a system to ensure that States inspect and report on tunnel conditions." Additionally, the IG stated that ``FHWA should move aggressively on this rulemaking and establish rigorous inspection standards as soon as possible."

The NTIS would implement these NTSB and IG recommendations. The FHWA anticipates that NTIS could be modeled after the existing NBIS contained at 23 CFR 650, Subpart C. The FHWA likely would revise 23 CFR Part 650--Bridges, Structures, and Hydraulics, by adding the NTIS under Subpart E. The NTIS would require the proper safety inspection and evaluation of all Federal-aid highway tunnels on public roads. National Tunnel Inspection Standards are needed to ensure that all structural, mechanical, electrical, hydraulic and ventilation systems, and other major elements of tunnels are inspected and tested on a regular basis. The NTIS would also ensure safety for the surface transportation users of highway tunnels, and would make tunnel inspection standards consistent. Additionally, tunnel inspections would help protect Federal investment in such key infrastructure. Timely tunnel inspection is vital to uncovering safety problems and preventing failures. When corrosion or leakage occurs, electrical or mechanical systems malfunction, or concrete cracking and spalling signs appear, they may be symptomatic of dire problems.

An Advance Notice of Proposed Rule Making (ANPRM) has been published for the NTIS and comments received. The comment period closed in 2009. This rulemaking would revise 23 CFR Part 650 -- Bridges, Structures, and Hydraulics, by adding the National Tunnel Inspection Standards (NTIS) under Subpart E. It is anticipated that the NTIS will be modeled after the existing National Bridge Inspection Standards and will include requirements for, among other things, inspection procedures, the qualifications and training of inspectors, and a National Tunnel Inventory. These requirements should be reviewed and incorporated in future revisions of this TM as necessary.

The NTIS will also make reference to the Highway and Rail Transit Tunnel Maintenance and Rehabilitation Manual (2004 Edition) and the Highway and Rail Transit Tunnel Inspection Manual (2005 Edition) issued by FHA and Federal Transit Administration (FTA). This TM has incorporated much of these two manuals although they are primarily focused on repair of existing tunnels.

NFPA 502 Standard for Road Tunnels, Bridges, and Other Limited Access Highways (National Fire Protection Association 2007), Sec. 3.3.38, Clause 2 covers inspection procedures in road tunnels and states .

“Inspections should assess the condition of all structural elements of a tunnel and assess the condition and performance of a tunnel's structural, mechanical, electrical, hydraulic and ventilation systems including operational procedures.”

4.0 SUMMARY AND RECOMMENDATIONS

This technical memorandum identifies inspection, service and maintenance activities that may be required to be performed within high-speed train tunnels. Detailed inspection, service and maintenance requirements for the tunnel structures and for the equipment installed within tunnels will be developed during design. It is recommended that these activities:

- Are reviewed by engineering subsystems to ensure completeness
- Serve as the basis for assessing and refining operations and maintenance schedule costs
- Serve as the basis for designers to ensure that design of tunnels and tunnel facilities provide for maintenance requirements, including optimum locations that are practical for cross-over tracks and maintenance bases.
- Incorporate tunnel requirements into a system-wide "Inspection, Service and Maintenance Manual" for use during high-speed train operations

Elements identified for inspection, service and maintenance are presented in Section 6.0.

Initial tunnel maintenance schedules for structural, mechanical and electrical maintenance anticipated for high-speed train tunnels are presented in Appendices A, B and C. Appendix D includes information related to maintenance base locations.

An Advance Notice of Proposed Rule Making (ANPRM) has been published for the National Tunnel Inspection Standards (NTIS) and comments received. The comment period closed in 2009. This rulemaking would revise 23 CFR Part 650 -- Bridges, Structures, and Hydraulics, by adding the NTIS under Subpart E. It is anticipated that the NTIS will be modeled after the existing National Bridge Inspection Standards and will include requirements for, among other things, inspection procedures, the qualifications and training of inspectors, and a National Tunnel Inventory. These requirements should be reviewed and incorporated in future revisions of this TM as necessary.

The process of recording and reporting the results of inspections, testing, service, maintenance and repairs is not addressed in the TM as it is anticipated that a system wide approach will be developed for all elements of the CHSTP. The system wide approach should be checked for consistency with the requirements of this TM and the NTIS.

Although efficient tunnel maintenance and its relationship to the locations of cross-over tracks, siding tracks, and maintenance bases relative to the locations of the different tunnels is discussed in this TM, further design development is required.

5.0 SOURCE INFORMATION AND REFERENCES

This Technical Memorandum has drawn on the following documentation in its development:

1. CHSTP Technical Memorandum 2.4.2 - Basic High-Speed Train Tunnel Configuration, R0
2. CHSTP Technical Memorandum 2.4.6 - High-Speed Train Tunnel Portal Facilities, R0
3. CHSTP Technical Memorandum 3.1.1.3 - Draft Traction Power Facilities, General Standardization Requirements
4. U.S. Department of Transportation [Federal Highway Administration; Federal Transit Administration]:
   - 4.1 Highway and Rail Transit Tunnel Maintenance and Rehabilitation Manual, 2004 Edition.
   - 4.2 Highway and Rail Transit Tunnel Inspection Manual, 2005 Edition.
5. CHSTP Working Paper No.5 (Final) July 2007, Scope 3, [Japan Railway Technical Service].
6. Federal Register: November 18, 2008 (Volume 73, Number 223) Proposed Rules Page 68365-68369 From the Federal Register Online via GPO Access [wais.access.gpo.gov] [DOCID:fr18no08-53]
7. NFPA 502 Standard for Road Tunnels, Bridges, and Other Limited Access Highways
8. Detailed Cross References

TM Section	Section	Reference		
		No.	Documentation	Additional Information
2.2	Laws and Codes	6	Federal Register: November 18, 2008 (Volume 73, Number 223) Proposed Rules	Page 68365-68369
2.2	Laws and Codes	7	NFPA 502 Standard for Road Tunnels, Bridges, and Other Limited Access Highways	Sec. 3.3.38, Clause 2
3.1	General	1	CHSTP Technical Memorandum 2.4.2 - Basic High-Speed Train Tunnel Configuration	-
3.1	General	4.1	Highway and Rail Transit Tunnel Maintenance and Rehabilitation Manual, 2004 Edition.	Chapter 3
3.2.1	Principal Tunnel Structures	4.1	Highway and Rail Transit Tunnel Maintenance and Rehabilitation Manual, 2004 Edition.	Chapter 4
		4.2	Highway and Rail Transit Tunnel Inspection Manual, 2005 Edition	Chapter 4, Section A
3.2.2	Secondary Tunnel Structures	4.1	Highway and Rail Transit Tunnel Maintenance and Rehabilitation Manual, 2004 Edition.	Chapter 3, Sect. E
				Chapter 4
		4.2	Highway and Rail Transit Tunnel Inspection Manual, 2005 Edition	Chapter 4, Section A

3.2.3	Trackwork Elements	4.1	Highway and Rail Transit Tunnel Maintenance and Rehabilitation Manual, 2004 Edition.	Chapter 3, Sect. D1
		4.2	Highway and Rail Transit Tunnel Inspection Manual, 2005 Edition	Chapter 4, Sect. D1
		5	CHSTP Working Paper No.5 (Final) July 2007, Scope 3, [Japan Railway Technical Service].	Sect. 3.2
3.2.4	Systems Elements	4.1	Highway and Rail Transit Tunnel Maintenance and Rehabilitation Manual, 2004 Edition.	Chapter 3, Sect. D2 & D3
		4.2	Highway and Rail Transit Tunnel Inspection Manual, 2005 Edition	Chapter 4, Sect. D2
		5	CHSTP Working Paper No.5 (Final) July 2007, Scope 3, [Japan Railway Technical Service].	Sect. 3.1 & 3.3
3.2.5	Mechanical Elements	4.1	Highway and Rail Transit Tunnel Maintenance and Rehabilitation Manual, 2004 Edition.	Chapter 3, Sect. B
		4.2	Highway and Rail Transit Tunnel Inspection Manual, 2005 Edition	Chapter 4, Sect. B
3.2.6	Electrical Elements	4.1	Highway and Rail Transit Tunnel Maintenance and Rehabilitation Manual, 2004 Edition.	Chapter 3, Sect. C
		4.2	Highway and Rail Transit Tunnel Inspection Manual, 2005 Edition	Chapter 4, Sect. C
3.3	Tunnel Maintenance Issues That May Influence Alignment Planning	2	CHSTP Technical Memorandum 2.4.6 - High-Speed Train Tunnel Portal Facilities	Sect 3.2.9 & 3.2.8
		5	CHSTP Working Paper No.5 (Final) July 2007, Scope 3, [Japan Railway Technical Service].	Sect. 3.4
3.4	CHSTP Standards	6	Federal Register: November 18, 2008 (Volume 73, Number 223) Proposed Rules	Page 68365-68369
3.4	CHSTP Standards	7	NFPA 502 Standard for Road Tunnels, Bridges, and Other Limited Access Highways	Sec. 3.3.38, Clause 2
			CHSTP Technical Memorandum 2.4.8 – HST Tunnel Service and Maintenance Requirements	Appendix D

6.0 DESIGN MANUAL CRITERIA

6.1 HIGH SPEED TRAIN TUNNEL SERVICE AND MAINTENANCE REQUIREMENTS

Routine inspection, service and maintenance programs and schedules will be developed for all structural elements of the tunnels and associated portal structures, and for all equipment to be installed within the tunnels, to assure safety, serviceability and long-term durability of all elements.

This technical memorandum does not include language or drafts for the Inspection, Service and Maintenance Programs and Schedules which will be required and which will be developed by others in the future, nor does it include a comprehensive list of all items of tunnel equipment and infrastructure that will be involved, but notes some of the issues that will need to be addressed and some of the means that might be employed, based on the experience of other high-speed rail systems.

6.1.1 Special Challenges

Tunnels provide additional challenges for inspections, servicing and maintenance, over and above the efforts that will be required for the balance of the high-speed rail system:

- A tunnel being a continuous structure enclosing the vehicle envelope results in restricted clearances and restricted access for inspecting, servicing and maintaining both the structure itself and the installed equipment. This must be taken into consideration when sizing the tunnels, when placing and sizing the equipment required to be installed within the tunnels, and when planning the inspection, service and maintenance programs.
- To inspect, service and maintain equipment mounted in the upper part of tunnels, or the upper part of the structures themselves, special ATC-equipped rail-mounted service equipment will be needed to provide working access, and adequate tunnel clearances must be allowed for these activities. Storage facilities and ready access to the tunnels for the rail-mounted equipment will also be needed. Ventilation must be provided to the tunnels if diesel-powered equipment is required for maintenance operations.
- Groundwater around the tunnel structure will commonly result in some degree of leakage into the tunnel which will often introduce corrosion problems that affect the tunnel structures and the equipment installed within the tunnels. Design of the equipment, and inspection, service and maintenance programs for the equipment must address this issue.
- A drainage system will be required to discharge groundwater-leakage, any introduced wash water, water from a fire-fighting incident or practice, or pipe-leakage to a distant portal, or at a mid-tunnel low-point to pump it to a portal or directly to the surface. These additional facilities will require an additional set of inspection, service, and maintenance requirements.
- Except for very short tunnels, the enclosed space requires an emergency ventilation system to remove smoke and maintain breathable air. This may be achieved by fans installed at the portal or equipment such as jet fans located within the length of the tunnels, all requiring routine inspection, testing and maintenance.
- Necessary provisions for emergency egress and emergency response, such as safety cross-passages to a parallel tunnel, or special safety shafts or tunnels to the surface may need to be spaced along the tunnel alignment, depending on tunnel length. All these facilities will need lighting, ventilation and other mechanical equipment, and communications systems, which all require inspections, servicing and maintenance.
- There are a number of different lining types that can be present in tunnel structures and these are dependent on the tunneling methodology and ground loadings. The lining types can have unusual reinforcement arrangements such as fiber reinforced shotcrete, and different waterproofing details such as compressed EPDM gaskets in precast concrete

liners. Damage such as cracking of concrete during construction can also result in long term maintenance issues with leakage. Cracking of concrete and leakage can also result from long term ground movements and seasonal variations in temperature and water pressures.

6.1.2 Routine Inspections, Servicing and Preventative Maintenance

Inspections for damage, wear and material deterioration of tunnel structures and equipment, and testing to confirm serviceability of all installed equipment will be carried-out on a routine basis.

- Routine inspection, servicing, and preventive maintenance will be planned so that it can be conducted in normal non-service hours and thus will not require single-track operations to allow maintenance on the other track during revenue-service hours.
- Servicing and preventive maintenance will be carried-out on a routine basis on all mechanical, electrical and systems equipment installed within tunnels, and will normally be carried-out in conjunction with, and as an extension of, the inspection program.
- Routine inspections, servicing and preventive maintenance programs will be developed so that different tunnel equipment can be dealt with in the same work session to optimize use of tunnel access for maintenance purposes. This will be particularly important if ATC-equipped rail-mounted equipment is required to gain access to equipment.

6.1.3 Major Maintenance and Repairs

Major maintenance and/or repairs, major overhauls and replacements in a tunnel that require single-track train operations to enable a track to be occupied for such purposes during normal train operating hours will need to be planned and coordinated so that a maximum number of such items can be dealt with during any one occupancy. Cross-over tracks may need to be located outside a tunnel or group of tunnels to allow efficient single-track train operations during major tunnel maintenance or non-routine events. Additionally, opportunities to expand the maintenance window on the shoulders of the operating hours will be considered as this may be required for some of the more extensive repairs or maintenance requirements, particularly as the high-speed train system infrastructure ages.

6.1.4 Inspections and Repairs Following an Earthquake or other Non-Routine Event

It will be necessary to develop a plan for conducting emergency inspections of each tunnel or group of tunnels following an earthquake event that may have affected that tunnel or group of tunnels. Similar inspections will be necessary following fire, flood, derailment or other non-routine events. The emergency program would include inspecting all structures and equipment for damage that could directly affect the safety of train operations, and testing all safety-related equipment such as tunnel emergency ventilation fans and emergency crosspassage safety-doors, to assure that they are still fully operational.

Procedures and protocols for inspection and repairs following non-routine events will be included in the high-speed train system Standard Operating Plan and Safety Assurance Plan.

6.1.5 Fire Department Inspections and Testing

Formal inspections and testing of the tunnel emergency ventilation system, fire protection system, emergency egress routes and emergency communications systems will be conducted prior to start-up of operations and periodically thereafter by the responsible fire department and regulating authorities. Periodic in-tunnel training and familiarization sessions for fire-fighters and other emergency response staff will be necessary. All fire department inspections, testing and training will be conducted in non train-operating hours under the direct supervision of qualified high-speed train personnel.

6.2 INSPECTION, SERVICE AND MAINTENANCE REQUIREMENTS

6.2.1 Principal Tunnel Structures

Primary tunnel structure elements may include:

- Pre-cast concrete segmental linings and cast-in-place concrete linings for running tunnels
- Cross-passage tunnel structural linings
- Tunnel Portal Structures

Periodic inspections of all ground-supporting concrete structures will be conducted to locate any cracking or spalling or other signs of stress or deterioration. Any loose material will need to be removed, any exposed steel reinforcement will be appropriately protected by coating or patching, and the location of the damage will be recorded for re-checking in future inspections. Any concentrations of such deterioration would need to be noted and more significant remedial action may need to be considered to repair and strengthen the lining in these locations.

Periodic inspections will record any groundwater leakage into the tunnel through joints or cracks in the linings. Note will be made of whether any such groundwater is reaching tunnel equipment which might result in its eventual deterioration. Appropriate re-sealing efforts may need to be implemented, from re-caulking joints, to chemical grouting of cracks, to additional grouting through the lining if a wider area is affected. Provisions may need to be made to immediately protect equipment from drips and to channel any significant flows to the tunnel drainage system. The total volume of groundwater seepage into any length of tunnel will not normally be allowed to exceed 0.8 gpm per 1000 feet of tunnel.

Instrumentation or survey monitoring points installed in or on tunnel and portal structure elements to monitor identified or potential movements anticipated due to landslide or seismic activities will be read continuously and automatically, and preferably remotely to minimize need for survey personnel within a tunnel. Drains installed through portal structure or tunnel linings to reduce groundwater pressures or permanently lower the groundwater table around structures will need to be regularly checked and cleaned. All instrumentation, ducts, and cabling associated with ground movement and groundwater monitoring will need to be regularly serviced and maintained.

An initial structural inspection and maintenance schedule has been included with this technical memorandum as **Appendix A**.

6.2.2 Secondary Tunnel Structures

Secondary tunnel structure elements include:

- Track slabs
- Safety walkways
- Cross-passage internal structures
- Duct banks
- Internal dividing walls

Periodic inspections of all internal structures will be conducted to locate any cracking or spalling or other signs of stress or deterioration. Any loose material will be removed, any exposed steel reinforcement will be appropriately protected by coating or patching, and the location of the damage will be recorded for re-checking during future inspections.

Periodic inspections will be made of all safety walkways, cross-passage walkways, stairways and ladders to assure that all are maintained, clean, slip-free and clear for emergency use. Handrails will be checked to assure firm attachment and will be maintained in good condition; cross-passage safety doors and sliding safety doors in tunnel dividing walls will be checked, serviced and maintained on a regular basis to assure that they are always useable.

An initial structural inspection and maintenance schedule is included as **Appendix A**.

6.2.3 Trackwork Elements

Trackwork elements in tunnels include:

- Rail
- Plinths
- Floating slabs

The CHSTP will develop inspection and maintenance procedures and schedules for the high-speed rails, support plinths and floating slabs that will be implemented throughout the high-speed train system. Trackwork inspection and maintenance procedures will generally be the same whether or not the trackwork is located in a tunnel. The prime difference will be a tunnel's restricted work access. Several different types of inspection will be needed from which appropriate maintenance programs can be developed:

- Track inspection over a major length of line might be carried out every ten days by a high-speed multi-purpose inspection car operating during normal revenue service hours. Track irregularity data collected would include longitudinal level, twist, cross level, alignment, and gauge.
- Train vibration data under high-speed operations might be collected daily using vibration acceleration meters installed in revenue service trains.
- Rail defects might be checked for by operating a slow speed ultrasonic rail flaw detector car during non-revenue service hours.

Preventive maintenance procedures for the rail carried out during regular non-revenue service hours may include: rail lubrication; rail grinding; joint maintenance and re-gauging. Regular track maintenance to re-align and adjust rail or even to replace shorter sections of worn rail or other worn / deteriorated material will also generally be carried out during non-revenue service hours to avoid impacting operations with single-track working.

However, major work such as long lengths of track replacement will inevitably entail single-track working. The location of crossovers and maintenance bases relative to the different tunnels will be important when planning for trackwork inspections involving special inspection cars, and also for major trackwork maintenance and replacement activities involving single-track operations. Incorporation of tie-and-ballast track into a tunnel design would most probably increase the need for more frequent maintenance work in order to preserve the track line and level under conditions where clearances are always critical. This will be especially true in longer tunnels and in tunnels including horizontal curvature.

A reasonably short, straight tunnel where ballasted track is being used outside the tunnel might be an exception, and under these circumstances connecting with ballasted track through the tunnel might be considered.

6.2.4 Systems Elements

Systems elements which may be located in tunnels include:

- OCS equipment
- Signaling equipment
- Communications equipment
- SCADA equipment
- Instrumentation and monitoring equipment

As for trackwork, specialized rail vehicles might be employed for a good proportion of inspection, servicing and maintenance of the systems facilities throughout the railway system, including through the tunnels. These might include a high-speed multi-purpose inspection car operating during normal revenue service hours to check:

- Height / deviation / gradient / contact loss / current collection of contact wire for the OCS.
- ATC current / ATC frequency / train detection performance of track circuit, characteristics of transponder for the Signaling System.
- Electric field level at telecommunication base, signal / noise levels, changing over characteristics of antenna zone for the Telecommunication System.

Maintenance work on OCS facilities will be conducted during non-revenue hours when power to the OCS can be switched-off. A fleet of specialized electrical maintenance cars, catenary installation cars, crane cars, and work cars might be employed to accomplish the maximum amount of work in the tunnels during the short window of time between revenue operations.

Regular visual and in-depth inspection of the OCS and regular preventive maintenance of the OCS will be conducted through each tunnel. Inspection protocols and parameters for testing of OCS equipment will be developed and for inclusion in inspection manuals prepared and adopted by Operations. Items requiring regular inspection and routine maintenance of components will include:

- Wires, hangers, jumpers and other OCS conductor components
- Insulators
- Pipes, clamps, brackets, cantilever arms and other support assemblies and structures
- Tension weight/ Counter-weight assemblies
- Disconnect switches

All electric and electronic components of the signaling and communications systems will be tested on a continuous basis, and a program for this testing and periodic maintenance will need to be developed. This equipment will commonly be housed in dedicated equipment cross-passages or niches excavated outside the standard tunnel cross-section.

Items will include:

- SCADA interfaces
- Wayside telephones
- Co-axial / BDA communications system
- Train control / signaling elements.

6.2.5 Mechanical Elements

Mechanical elements which may be located in tunnels include:

- Emergency ventilation fans and associated equipment
- Fire protection piping
- Drainage pumps and tunnel drainage system, including pipes
- SCADA systems and associated equipment

A program for regular inspection and testing of all mechanical equipment within the tunnels will need to be developed and implemented. Emergency ventilation fans for a tunnel will be tested individually and in conjunction with other fans and components of the emergency ventilation system for that tunnel.

A routine preventive maintenance program will be developed that includes every major piece of mechanical equipment contained within the tunnels. Preventive maintenance must be scheduled and regularly conducted.

The tunnel drainage system will have to be checked and flushed clean on a regular basis, and drainage pumps will need to be regularly checked, cleaned and serviced.

If sliding doors for the safety egress doorways through the dividing wall in a twin-track single tunnel have mechanical assistance, then the mechanism must be tested, serviced and maintained on a regular basis.

Additional inspections and operational testing of emergency ventilation fans and fire protection equipment in each tunnel must be coordinated with the local authority having jurisdiction over safety, rescue and fire protection for that tunnel.

An initial preventive maintenance schedule is included as Appendix B.

6.2.6 Electrical Elements

Electrical elements located in tunnels include:

- Tunnel lighting
- Tunnel power systems
- Duct banks and cabling

A program for regular inspection and testing of all electrical equipment within the tunnels will need to be developed and implemented, and coordinated as necessary with the mechanical and systems inspection and testing programs.

A routine preventive maintenance program will also be developed for all electrical equipment within the tunnel, and similarly will be coordinated as necessary with the mechanical and systems programs. Preventive maintenance will be scheduled and conducted regularly.

An initial electrical maintenance schedule is included as **Appendix C**.

6.3 TUNNEL MAINTENANCE ISSUES THAT MAY INFLUENCE ALIGNMENT PLANNING

6.3.1 Location of Cross Over Tracks

Although most of the routine tunnel inspection and maintenance activities will be conducted without impacting revenue service, in order to most efficiently carry out some of the more extensive tunnel maintenance and tunnel repair activities, it will be necessary to conduct this more time-consuming work during train operating hours. The short window of time during the night between the daily revenue operations may be inadequate to access the tunnel, set up and perform the work, clean up and remove any equipment and perform the necessary safety checks before re-starting revenue service. This is particularly the case in long tunnels or numerous tunnels with limited access, located in remote locations. Opportunities to expand the maintenance window on the shoulders of the operating hours will be considered as required for some of the more extensive repairs or maintenance requirements.

Single-track operations may also be required on one track through a tunnel while work crews occupy the other track. To accomplish this effectively with the least impacts to train operations, the number and location of cross-over tracks will need to be considered in relation to the locations of the tunnels when planning the rail alignments. Considering the assumed Phase 1 and Full Build out service plans and operating plans, the ability to schedule and operate the system under any single track conditions is currently unknown and will have to be evaluated.

6.3.2 Maintenance Equipment

Certain inspection, servicing and maintenance activities in the tunnels will require use of equipment to allow working access to the upper part of the tunnels. This may be special ATC-equipped rail-mounted equipment, or high-rail equipment that is operable on both highways and railways. Use of this equipment will need to be taken into account when establishing the vehicle clearance envelope for the tunnels.

If special ATC-equipped rail-mounted equipment is to be used, then the location of any necessary turnout and storage track relative to the location of the different tunnels will need to be considered. If high-rail equipment is to be operated, then suitably designed road access immediately adjacent to the tracks will need to be provided in proximity to the different tunnels in order to allow transfer of equipment to/from road to rail.

6.3.3 Maintenance Bases

To maintain the railway effectively, maintenance bases where inspection and maintenance vehicles and equipment can be stored and serviced need to be strategically located. The location of these bases relative to the different tunnels, cross-over tracks, turnouts and siding tracks will be important to enable specialized ATC-equipped rail-mounted equipment to be moved quickly to a particular tunnel, perform work and move off the main line during the short non-revenue nighttime periods available for maintenance work that does not affect train operations. For major work in a tunnel on one track when train operations must be affected, and where for a period revenue service is restricted to the adjacent track, the relative locations of tunnel, bases and cross-over tracks will also be important in order to minimize impacts to train operations and to efficiently service the tunnel maintenance work.

The maximum speed of maintenance vehicles, available time window for maintenance, and the proximity to long tunnels, or large numbers of tunnels should be considered in the siting and spacing of maintenance bases. This document does not establish maintenance base requirements but rather informs of anticipated tunnel service, inspection and maintenance requirements. It is intended to inform the future development of maintenance plans and procedures, and potentially identify the need for additional, site-specific maintenance facility that may be required in proximity of tunnels at distances away from the MOW bases. The ability to locate maintenance siding tracks and unoccupied storage in locations remote from maintenance bases will be considered during design development.

A diagram from an existing high-speed rail system illustrating time that might be available for actual maintenance work with bases at 30-mile spacing and with a 6-hour time window between revenue service hours is attached for information in **Appendix D**.

APPENDICES

Appendices A, B and C present draft tunnel maintenance schedules for structural, mechanical and electrical maintenance anticipated for high-speed train tunnels. Appendix D includes information related to maintenance base locations.

APPENDIX A TUNNEL STRUCTURAL INSPECTION AND MAINTENANCE SCHEDULE

Appendix A presents a sample tunnel maintenance schedules for structural maintenance anticipated for high-speed train tunnels. As each tunnel design is completed, detailed inspection, service and maintenance requirements for the tunnel structure and for equipment installed within that tunnel will be developed.

Primary and Secondary Structures include: Train Tunnel and Crosspassage Linings; Portal Structures; Tunnel Internal Dividing Wall; Safety Walkways; Duct-banks; Track Slabs.

1A- Item:

General inspection of all primary and secondary tunnel structures by walk-through of each tunnel track-way and cross-passage, during regular non-service hours

1B- Schedule:

- Each tunnel, monthly.
- Affected tunnels, immediately following an earthquake event or after any ground or structure movement is detected by instruments.

1C- Action:

- With records in-hand, check known structural defects such as cracks, spalling, corrosion, leakage, differential movement, and look for signs of any new defects or leaks.
- Check all walkways and cross-passages to assure that all are clear of any hazards.
- Check doors to emergency cross-passages (or through internal dividing wall) to assure they open readily.
- Check tunnel drainage systems clear and free of silt.
- Check track-slab meets standard for cleanliness.
- Check all emergency lighting is functioning.
- Check all emergency phones are functioning.
- Check for signs of any animals entering the tunnel.
- Update all records of defects.
- Identify where more detailed inspection is required.
- Identify if immediate urgent action is needed [e.g., a leak dripping on equipment; an area with excessive new cracking; door to emergency crosspassage malfunctioning].

2A- Item:

Detailed Close-Up Inspection of each element of each tunnel structure by visual means, augmented as appropriate by utilizing non-destructive techniques, during regular non-service hours

2B- Schedule:

- Each tunnel, every two-to-five years, depending on age of tunnel.
- An affected tunnel, when notable damage or deterioration has been recorded either during a monthly general inspection walk-through, or during a walk-through following an earthquake or after detection of ground/structure movement.
- Cathodic protection systems will normally be checked annually.

2C- Action:

- A close visual inspection will be made of all exposed surfaces of structural concrete elements
- Concrete may be sounded with hammer strikes to detect suspected hidden defects, or ultrasonic testing may be employed

- All noted defects will be measured and documented for location.
- For example:

    1. Cracks will be documented: Minor – Up to 0.03 ins.; Moderate – Between 0.03 and 0.125 ins.; Severe – Over 0.125 ins.
    2. All severe cracks will be measured in length and width
    3. Spalling will be documented: Minor – Less than 0.5 ins. or 3 ins to 6 ins in diameter; Moderate – 0.5 ins to 1 ins deep or approx. 6 ins in dia.; Severe – more than 1 ins deep and greater than 6 ins in dia., or any spall where rebar is exposed.
    4. All severe spalls will be measured in length, width and depth, and exposed rebar noted.
    5. Missing and loose bolts will be recorded, and note will be taken where deteriorated and any section-loss has occurred: Minor – Discolored, no section-loss; Moderate – Up to 15% section-loss; Severe – Greater than 15% section-loss.
    6. Gaskets: Note if dislodged due to loosening bolt or water infiltration, chemical or biological deterioration, tear or distortion due to structural movements
    7. Any signs of corrosion of metal components of tunnel structural elements or of equipment within the tunnels will be recorded.
    8. Leakage will be documented: Minor – Concrete surface wet but no drips; Moderate – Active with volume less than 30 drips/minute; Severe – Active with volume greater than 30 drips/minute
    9. Leaks where water is dripping on equipment or walkways will be marked for immediate attention, as will any need for conveyance to the tunnel drainage system
    10. Any signs of fine soil particles being carried by water coming through cracks, which might indicate voids being formed behind the tunnel lining
    11. Any signs of corrosion where water is dripping

3A-Item:

Preventive maintenance of identified defects, generally during regular non-service hours

3B- Schedule:

- Items identified during inspections as requiring immediate attention will be treated in a special work-session to be scheduled at the first available opportunity.
- Items not demanding immediate attention will be listed for regularly scheduled maintenance programs according to degree of urgency. The maintenance work on various items in the tunnels will be coordinated so that many different items can be dealt with in a common maintenance work-session to allow for maximum efficiency of working and to minimize any potential impacts on train operations.

3C- Action:

- Examples of commonly-required structural preventive maintenance are:

    1. Preventive maintenance related to groundwater leaks into a tunnel through cracks in the tunnel lining:

        i. Immediate action to protect drips falling on equipment: Attach aluminum or stainless steel channels or sheeting, or neoprene rubber sheeting, to tunnel crown, to protect equipment and to form channels to carry leakage water to the side of the tunnel and into the tunnel drainage system. [Will need to remain outside the vehicle clearance envelope; will need to be able to withstand air pressures developed by the high-speed trains; can sometimes be the permanent solution; can be installed incrementally outside regular train-operating hours.]

ii. A preferred long term solution: Seal each crack individually with chemical grouts such as polyurethanes or acrylate esters. [Effective long-term solution; can be installed incrementally outside regular train-operating hours; on sealing one crack, another can start leaking, so program can become extended.]

iii. If leakage is over a wider area of the tunnel: Drill through the tunnel lining and inject chemical grouts (polyurethanes/acrylate esters) behind the lining to provide a local waterproof barrier between the tunnel lining and the surrounding ground, if the void behind the lining is not large. If larger voids have been detected behind the lining, then less expensive cement grouts would probably be used to fill the void and reduce the flows, using chemical grouts in cracks to stop remaining leakage. [Smaller voids might be able to be treated outside regular train-operating hours; larger voids and more extensive leaks would probably have to be treated during a period when trains can be operated on single track to free the other track for the grouting operation.]

iv. If leakage is through a joint in a segmental tunnel lining: Sometimes the leak can be stopped by re-packing the joint with sealing materials and if necessary installing new gaskets on bolts; sometimes chemical grout might be used as for a crack in the concrete lining. [Can be treated outside regular train-operating hours.]

2. Preventive maintenance related to structural damage of the tunnel concrete lining (after evaluation of the cause and severity of the damage, and following assessment that the structure does not require major repairs or partial replacement and that preventive maintenance is appropriate):

i. Cracks that are dry and where no movement is expected: Fill with epoxy resin. [Can be treated outside regular train-operating hours.]

ii. Cracks that are wet: Seal with chemical grout (as noted above in 1 (ii)

iii. Shallow spall with reinforcement steel exposed and only lightly corroded: Remove all loose or delaminated concrete around the exposed steel; clean steel of any corrosion; sawcut around spalled area on a 20-degree angle if patching is required; coat steel and concrete surface with an anti-corrosion coating; place polymer repair mortar to depth of spall. [Can be treated outside regular train-operating hours.]

iv. Deep spall and heavily corroded steel: As in (iii) above, but add replacement steel as appropriate. [If damage is extensive, then occupation of the track during train operating hours may be necessary to place shotcrete or plasticized concrete.]

APPENDIX B TUNNEL MAINTENANCE SCHEDULE - MECHANICAL

Appendix B presents a draft tunnel maintenance schedules for mechanical maintenance anticipated for high-speed train tunnels, including items that might be installed at tunnel portal areas or in tunnel portal buildings, in addition to those items installed within the train tunnels or cross-passages. As each tunnel design is completed, detailed inspection, service and maintenance requirements for the tunnel structure and for equipment installed within that tunnel will be developed.

APPENDIX B - Preventive Maintenance of Mechanical Systems

Procedure Description	Frequency							
	Weekly	Monthly	Bi-Monthly	Quarterly	Semi-Annually	Annually	Bi-Annually	Tri-Annually
Air Compressor								
Clean or replace air filters if necessary				X				
Clean external cooling fans				X				
Manually oprate safety valves and drain tank				X				
Inspect oil for contamination and change if necessary						X		
Check belt tension, clean motor, and oprate safety valves on receiver						X		
Inspect for air leaks						X		
Tighten or check all bolts and lubricate motor bearings						X		
Inspect and clean compressor valves						X		
Verify operation of low-level oil switch						X		
Check all pressure and safety controls						X		
Air Conditioning Unit								
Clean or replace air filter		X						
Check coils and clean if necessary						X		
Inspect controls and verify proper operation of unit						X		
Boilers (Furnaces)								
Check chimney and flue for obstructions and make sure all joints are well supported and properly sealed						X		
Lubricate pumps and motors as required						X		
Clean entire boiler, inside and out						X		
Replace fuel filter and oil atomizing nozzle						X		
Check hot water levels and fill as necessary						X		
Restart boiler and test burner performance, flue gas CO_2 smoke, and temperature						X		
Verify operation of all limit switches and primary controls						X		
Test relief valve or safety valve (use extreme caution)						X		
Chiller								
Check and lubricate compressors					X			
Check safety controls						X		
Clean and inspect barrel						X		
Check and add chemicals (as indicated or as required)						X		
CO Monitoring Equipment								
Local Sensors (Calibration and/or sensor replacement)					X			
Vacuum Tubing (Leak Test)						X		
Vacuum Pump (lubrication)						X		
Central Sensor Calibration (as required by individual system)						X		
Comparison Gas Refill (as required)								
Cooling Towers					X			
Check and lubricate pumps and fans						X		
Check safety controls				X				
Clean sump					X			
Check and add chemicals (as indicated or as required)		X						

Procedure Description	Frequency							
	Weekly	Monthly	Bi-Monthly	Quarterly	Semi-Annually	Annually	Bi-Annually	Tri-Annually
Domestic Water Pump and Tank								
Visually inspect pump (when accessible)		X						
Lubricate pump and motor						X		
Check pump operation in conjunction with well tanks						X		
Lubricate ejector pumps						X		
Measure water drawdown to verify proper operation						X		
Check air pressure in tank and correct as necessary						X		
Verify start and stop settings of pressure switch (differential should not exceed 172 kPa (25 psi))						X		
Drainage System								
Grate inspection	X							
Flushing of inlet and piping system					X			
Dewatering Pumps (Fixed and Portable)								
Clean and visually inspect					X			
Lubricate pumps (prior to use for portable)						X		
Emergency Eyewash								
If bacteria control solution is not used, flush and clean unit with pure water				X				
Drain unit and flush and clean the storage tank and refill with water and water treatment				X				
Exhaust Fans and Dampers (Not Tunnel Fans)								
Operate fans and motor operated dampers and listen for unusual noises and vibrations		X						
Cheek bearings and inspect V-belts for tightness						X		
Clean centrifugal wheel, inlet, and other moving parts						X		
Lubricate shaft bearing pillow blocks and motor bearings						X		
Fire Extinguishers								
Inspect each fire extinguisher in the tunnel				X				
Fire Hydrants								
Grease top nut					X			
Fire Lines								
Freeze Protection Pumps								
Clean and visually inspect				X				
Lubricate and grease pumps						X		
Heat Tracing equipment								
Verify system operation (prior to system operation)						X		
Fire Pumps								
Visually inspect pump		X						
Operate pump				X				
Lubricate pump, motor, and coupling					X			
Operate pump and measure current					X			
Check shaft endplay					X			
Check and correct pressure gauges as required					X			
Fire Pump Controller								
Exercise isolating switch and circuit breaker		X						
Operate pumps from both alternate and primary power supplies		X						

Procedure Description	Frequency							
	Weekly	Monthly	Bi-Monthly	Quarterly	Semi-Annually	Annually	Bi-Annually	Tri-Annually
Conduct annual test of system including flow and no flow conditions in accordance with NFPA 72						X		
Fire Tank Fill Pump								
Visually inspect pump		X						
Lubricate pump and motor						X		
Fuel Oil Day Tank								
Inspect tank for damage, corrosion, or leakage on both inside and outside of tank. Perform during same week as boiler inspection						X		
Hot Water Pump								
Visually inspect plumbing connections for signs of corrosion				X				
Visually inspect exterior of water heater for signs of leakage				X				
Lubricate pump and motor as required						X		
Septic System								
Pump out tank (as indicated or as required)							X	
Ejector Pumps								
Check local indications (verification of proper functioning from control panel)	X							
Visually inspect pumps						X		
Tunnel Fans								
Check motor bearings	X							
Listen for any unusual noise or vibration	X							
General cleaning of motor, interior and exterior			X					
Disconnect motor from power supply and regrease, making sure chamber is 75 percent full of grease				X				
Operate fan through entire range of speeds and note any noises or vibrations (Balance fan if required)				X				
Inspect inside and outside of housing and impellor for wear, deterioration, or build-up of material				X				
Inspect mounting bolts, anchors, and connections for failures or damage				X				
Change oil in pillow blocks and drive guards (mineral oil is recommended)				X				
Remove inspection cover from drive guard and inspect chain to verify proper lubrication and wear and adjust if necessary				X				
Check all oils and greases for contaminants				X				
Verify that any dampers operate properly through all positions, and lubricate if necessary				X				
Unit Heaters								
Clean unit casing, fan, diffuser, coil, and/or motor thoroughly, and clean and repaint any corrosion spots on casing						X		
Tighten the fan guard, motor frame, and fan bolts, and check fan clearances						X		
Inspect any control panel wiring to ensure that the insulation is intact and that all connections are tight						X		
Examine all heater and relay contacts for pitting or burning and replace if necessary						X		

Procedure Description	Frequency							
	Weekly	Monthly	Bi-Monthly	Quarterly	Semi-Annually	Annually	Bi-Annually	Tri-Annually
Lubricate motor if necessary						X		
Check operation of hydronic controls								
Underground Fuel Oil Tank								
Remove liquid level sensor from reservoir to check low-level alarm				X				
Immerse sensor into bucket of water to activate high-level alarm				X				
Water Storage Tank								
Visually inspect tank exterior				X				
Drain sediment					X			
Observe water system operation and note any abnormal happenings						X		
Measure water draw down to verify proper operation						X		
Check air pressure in tank and correct as necessary						X		
Verify start and stop settings of pressure switch (differential should not exceed 172 kPa (25psi))						X		
Visually inspect tank interior								X

APPENDIX C TUNNEL MAINTENANCE SCHEDULE - ELECTRICAL

Appendix C presents a draft tunnel maintenance schedules for electrical maintenance anticipated for high-speed train tunnels including items that might be installed at tunnel portal areas or in tunnel portal buildings, in addition to those items installed within the train tunnels or cross-passages. As each tunnel design is completed, detailed inspection, service and maintenance requirements for the tunnel structure and for equipment installed within that tunnel will be developed.

APPENDIX C - Preventive Maintenance of Electrical Systems

Procedure Description	Frequency							
	Weekly	Monthly	Bi-Monthly	Quarterly	Semi-Annually	Annually	Bi-Annually	Tri-Annually
Closed Circuit TV								
Clean, align, and focus all cameras after tunnel washing					X			
Emergency Lighting								
Operate test buttons on emergency light fixtures		X						
Operate battery pack for emergency lighting for 90 minutes						X		
Electrical Switchboard and Switchgear								
Inspect switchgear bus and connections by infrared scanning						X		
Perform ultrasonic inspection of medium voltage switchgear bus supports, insulators, and barriers						X		
Visually inspect all equipment for unusual conditions						X		
Check tightness of all connections						X		
Remove and replace defective lighting contacts						X		
Review results of last visual, infrared, and ultrasonic inspection								X
After power shutdown, clean entire switchgear interior								X
Clean all bus insulators and check for cracks and chips								X
Clean, lubricate (if applicable), and verify operation of all control switches, auxiliary relays, and devices								X
Clean, lubricate, adjust, and add anti-oxidant grease to contacts of all disconnect switches								X
Clean and perform insulation resistance testing on all lightning arrestors								X
Perform insulation resistance testing on any bus bars								X
Perform calibration test and verify proper operation of all meters								X
Low Voltage Air Circuit Breakers								
Remove covers m1d thoroughly clean each breaker and contact surfaces								X
Apply anti-oxidant grease to breaker's main contacts								X
Lubricate and verify operation of all mechanisms								X
Apply current equal to 90 to 110 percent of the breaker trip coil setting to verify)2roEer pick-up of tripping mechanism								X
Record trip times for long-time, short-time instantaneous, and ground fault breakers when passing loads equal to multiples of their listed ratings through each phase of the breaker								X
Measure contact resistance and adjust where possible								X
Perform and record results of insulation resistance test from each pole to other two poles and to ground								X
Clean and lubricate breaker carriage and racking mechanism on any draw out breakers								X
Molded Case Circuit Breakers								
Inspect breaker for proper installation								X
Remove cover (if possible) and fully clean interior and exterior								X
Inspect for burning, overheating, wear, and proper alignment								X
Perform contact resistance and insulation resistance measurements and test								X

Procedure Description	Frequency							
	Weekly	Monthly	Bi-Monthly	Quarterly	Semi-Annually	Annually	Bi-Annually	Tri-Annually
Apply current equal to 300 percent of breaker rating to test the long-time element								X
Test and compare any breakers with instantaneous trip units to manufacturer's characteristic curve								X
Automatic Transfer *Switch (600 Volt Class)*								
After total outage is obtained, clean all contact surfaces, apply anti-oxidant contact grease, measure and record contact resistance, and make any adjustments if necessary								X
Lubricate bearings, links, pins, and cams								X
Perform insulation resistance test								X
Test all settings of voltage resistance test								X
Test all settings of voltage, frequency sensing, and timing relays								X
Low Voltage Insulated Cable (Less Than 600 Volts)								X
Perform and record results of insulation resistance test from each phase to the other two and to ground for one minute using a test voltage of 1,000 volts Direct Current (DC). Compare results with previous tests.								X
Electrical Transformer								
Inspect transformer connections by infrared scanning						X		
Perform ultrasonic inspection of medium voltage bus supports, insulators, and barriers						X		
Visually inspect all equipment for unusual conditions						X		
Test transformer and circuit breaker insulating oil						X		
Dry-Type								
Remove cover and visually inspect all cable/bus connections for evidence of overheating or burning, check for tightness and clean windings								X
Liquid-Filled								
Inspect transformers for leaks, deteriorated seals/gaskets, proper oil level, and test oil sample								X
Inspect transformer tank and cooling fins for corrosion, chipped paint, dents, and proper connection to ground								X
Inspect all bushings for cracks/chips, proper tightness, and evidence of overheating								X
Inspect all gauges and alarm devices								X
Clean core, coils, and enclosures and inspect any filters								X
Perform primary and secondary insulation resistance test where possible.								X
Perform polarization index test on transformers 500 KVA and larger								X
Perform turns ratio tests								X
Perform calibration test and verify proper operation of all meters								X
Fire Alarm System								
Perform all tests and inspections in accordance with NFP A 72								
Make and file a permanent record of all inspections and tests conducted								
Open primary power supply to fire alarm panel and note sounding of trouble alarm and light		X						

Procedure Description	Frequency							
	Weekly	Monthly	Bi-Monthly	Quarterly	Semi-Annually	Annually	Bi-Annually	Tri-Annually
Perform fire drill by use of drill switch on fire alarm panels, and check that all visual and audible signals emit a sound and tunnel SCADA system (if any) receives alarm		X						
Visually inspect all supervisory and water flow alarms on any standpipe systems		X						
Test all heat detectors with a calibrated heat source and replace all failed units					X			
Test all smoke detectors by measuring and recording sensitivity; replace all failed units					X			
Clean all smoke and heat detector housings and check battery voltage under load					X			
Verify that proper alarm devices operate for the appropriate initiating device circuit					X			
Verify that all remote annunciators operate				X				
Check all lamps, alarm devices, and printers for proper operation				X				
Make a discharge test of batteries to determine capacity for operating system for 24 hours					X			
Generator								
Operate unit under load for 4 hours and check lubrication levels		X						
Change oil, coolant, and filter				X				
Compare nameplate information and connection with drawings and specifications				X				
Inspect for proper anchorage and grounding				X				
Perfoll11 insulation resistance test on generator winding with respect to ground and determine polarization index				X				
Perform phase rotation test to determine compatibility with load requirements				X				
Functionally test engine shutdown and alarm controls for low oil pressure, overtemperature, overspeed, and other features				X				
Perform vibration base-line test and plot amplitude versus frequency for each main bearing cap				X				
Perform load bank test and record voltage, frequency, load current, oil pressure, and coolant temperature at periodic intervals during test				X				
Monitor and verify correct operation and timing of normal voltage-sensing relays, engine start sequence, time delay upon transfer, alternate voltage-sensing relays, automatic transfer operation, interlocks, limit switch functions, time delay and retransfer upon normal power restoration, and engine cool down and shutdown feature				X				
High Voltage Disconnect								
Inspect disconnect switch bus and connections by infrared scanning						X		
Perform ultrasonic inspection of medium voltage bus supports, insulators, and barriers						X		
Visually inspect all equipment for unusual conditions						X		
Busing Inspection								
Review results of last visual, infrared, and ultrasonic inspection								X
Check for proper tightness of all exposed bus connections								X

Procedure Description	Frequency							
	Weekly	Monthly	Bi-Monthly	Quarterly	Semi-Annually	Annually	Bi-Annually	Tri-Annually
Thoroughly clean and check for cracks/chips of all bus insulators								X
Clean, lubricate (if applicable), and verify operation of all control switches, auxiliary relays, and devices								X
Clean, lubricate, adjust, and add anti-oxidant grease to contacts of all disconnect switches								X
Clean and perform insulation resistance test on all lightning arrestors								X
Perform insulation resistance test on any bus bars								X
Service Enclosed Air Break Switches								
After shutdown, clean and inspect entire switch mechanism								X
Check switch contacts for proper alignment and apply anti-oxidant grease to main contacts								X
Check switch's arcing contacts for proper opening sequence relative to main contacts								X
Inspect fuses and record size and type used								X
Clean all phase isolation barriers and check for contamination and corona damage								X
Thoroughly clean and check for cracks/chips of all insulators								X
Clean and perform insulation resistance test on all lightning arrestors								X
Inspect all ground connections								X
Perform contact resistance and insulation resistance tests and record results								X
Motor Control Center								
Inspect controller bus and connections by infrared scanning						X		
Perform ultrasonic inspection of medium voltage bus supports, insulators, and barriers						X		
Visually inspect all equipment for unusual conditions						X		
Review results of last visual, infrared, and ultrasonic inspections								X
After power shutdown, clean entire controller interior								X
Check for proper tightness of all exposed bus connections								X
Clean all bus insulators and check for cracks and chips								X
Clean, lubricate (if applicable), and verify operation of all switches, auxiliary relays, and devices								X
Clean, lubricate, adjust, and add anti-oxidant grease to contacts of all disconnect switches								X
Perform an insulating resistance and polarization test of thc bus and the motor feeder with the motor connected								X
Test overloads at 125 percent and 600 percent of rating against the tripping curve								X
Perform calibration test and verify proper operation of all meters								X
Lighting Relays and Contractors								
Clean all contacts and replace all worn and pitted contacts								X
Check tightness of contactors								X
Measure load current and verify proper operation								X

Procedure Description	Frequency							
	Weekly	Monthly	Bi-Monthly	Quarterly	Semi-Annually	Annually	Bi-Annually	Tri-Annually
Tunnel Control System								
Check all controls on consoles for proper operation of tunnel lighting and fans						X		
Test all alarm and lights for proper feedback from devices						X		
Check all connections for tightness						X		
Clean cabinets						X		
Tunnel Lights								
Verify proper operation of the lighting fixtures in the tunnel areas	X							
Count and record number of lights out on night lighting and day lighting	X							
Replace any inoperable bulbs or ballasts with similar or increased efficiency	X							
Clean exterior of lenses on all fixtures in the tunnel				X				
If required clean interior of lenses				X				
Perform group relamping for specific lamp types						X		
Underground Tank and Piping Monitor								
Perform built-in test (if any) and verify that each circuit is operational. If not, identify circuit using troubleshooting guide and replace parts as necessary						X		

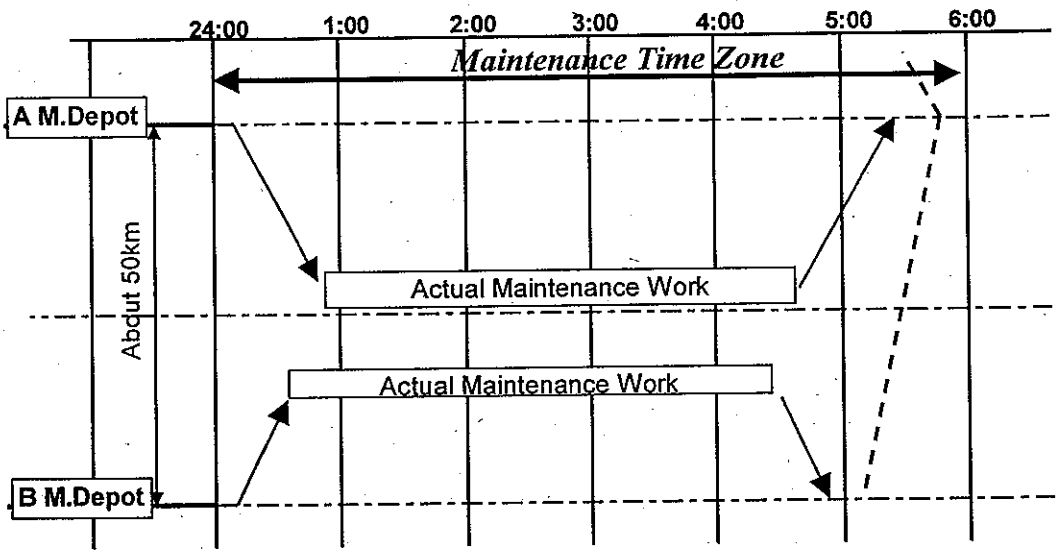
APPENDIX D TUNNEL MAINTENANCE SCHEDULE – MAINTENANCE BASE

Appendix D includes information related to maintenance base locations.

APPENDIX D

Reference Section 3.3.3

Example of time available for tunnel maintenance related to distances between bases/depots.



Distance between depots

Main depot is located every 100 km, and sub-depot at the middle between main depots. So, distance between main depot and sub-depot becomes 50 km .
The max speed of maintenance vehicles widely used in the world is in the range of 70 ~ 110 km/h, namely average speed 45 ~ 70 km/h .
On the other hand speed of maintenance vehicle of large fleet and/or heavy materials such as long welded rail car and ballast hopper car is usually limited to about 30 km/h due to gradient etc.
Since it takes more than 3hours to replace long welded rail and catenary, taking transport time into consideration, allowable distance between working site and depot becomes 25 km , hence depots are allocated at every 50 km .