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GOVERNMENT OF INDIA

भारत सरकार

MINISTRY OF RAILWAYS

रेल मंत्रालय

Guidelines for

Civil Engg. Inspection, Maintenance and Safety in existing Tunnels

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Geo-technical Engineering Directorate

भू–तकनीकीइंजीनियरीनिदेशालय

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PREFACE

This report is prepared on the basis of field visits & literature survey. Views expressed in this report are subject to modification from time to time in the light of future developments on the subject and as such do not represent the views of the Ministry of Railways (Railway Board), Government of India.

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SYNOPSIS

Planning & implementation of an effective Inspection, Maintenance & Repair program for Tunnels is critical considering its implications on safety & cost. Present Report includes recommendations for the same along with provisions related to ensuring safety in existing tunnels. The report is based on field visits &literature survey.

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1. INTRODUCTION

Planning & implementation of an effective Inspection, Maintenance & Repair program for Tunnels is critical considering its implications on safety & cost. Present Report includes recommendations for the same along with provisions related to ensuring safety in existing tunnels. The report is based on field visits & literature survey.

2. SCOPE

This report includes provisions related to Inspection, Maintenance & Repair of Tunnels & ensuring safety in existing tunnels. Brief description of safety / maintenance practices recommended by National/International Standards/Publications have also been included in the report.

3. GENERAL

3.1 Tunnel: An underground route or passage driven through the ground without disturbing the overlying soil or rock cover, lined to extent necessary; which may be constructed by underground working or by cut –and-cover methods.

3.2 Portals: End structure of tunnel for protection against rock fall, slope failure or lateral ground pressure.

3.3 Tunnel inspection: Inspection practices which assess the tunnel structural conditions should consist of Damages and defects detection, Tunnel pathologies identification and Diagnostic of the tunnel conditions.

3.4 Maintenance of tunnel: This general term covers all measures affecting stability, designed to:

-Determine and evaluate the actual condition of a structure (Inspection)

-Preserve the nominal condition of a structure (Maintenance).

-Restoring the nominal condition of a structure (Repairs)

4.0 TUNNEL INSPECTION

4.1 Pre-requisites for Tunnel Inspection

i) Inspector Qualifications:

All officials performing tunnel in section work should possess basic knowledge of tunnel components and understand how they function. The inspecting official/s should have the ability to identify and evaluate defects that pose a threat to the integrity of a structural member & should be able to assess the degree of deterioration of structural components of tunnel.

Training courses for building competency in tunnel inspections should be organized periodically.

ii) Equipment/Tools for Inspection

Inspection is carried out mainly by soundings and visual examination. Recommended list of equipment and tools to be used for tunnel inspections is as under:

- Rail vehicle mounted access system/ Ladders / removable scaffolding.
- Calipers - Used to measure steel plate thicknesses.
- Digital Camera (with Flash)-Used to take photographs for documentation of the inspection.
- Markers – for making reference marks on tunnel surfaces.
- Chipping Hammer-Used to sound concrete
- Extension Cord - Used to get electricity to inspection area.
- Flashlights - Used in dark areas to help see during inspection.
- Plumb Bob - Used to check plumbness of columns and wall faces.
- Pocket Knife - Used to examine loose material and other items.
- Scraper - Used to determine extent of corrosion and concrete deterioration.
- Screw Driver - Used to probe weep holes to check for clogs.
- Wire Brush or Brooms - Used to clean debris from surfaces to be inspected.
- Pocket Tapes - Used to measure dimensions of defects.
- 30m(100ft)Tape(Non Metallic)-Used to measure anything beyond the reach of pocket tapes and folding rules.
- Appropriate Safety gear.

Various non–destructive inspection methods such as thermography, photography, ultrasonics, georadar, microgravimetry and seismic testing may possibly supplement the regular inspection methods; if required.

iii) Advance Preparation

a) Study of Tunnel Records

To perform the inspection efficiently, it is important to plan & organize for inspection in advance. A vital part of the mobilization phase is the study of available tunnel drawings , previous inspection reports , construction phase geological records & tunnel instrumentation data records (if available).

b) Marking of reference system

It is necessary to establish a system by which the location of a defect can be recorded and understood in reference to where the defect is observed. Establishing such a system will allow the inspections to be referenced historically for future monitoring of the condition of a particular defect and will increase the efficiency of the overall inspection process.

In addition to locating a defect by its longitudinal position, It is necessary to note the defect's position within the tunnel cross-section. Horseshoe, rectangular, and other circular tunnels can be broken down into consistently named cross-sectional elements. Nomenclature used in inspection of tunnel should be illustrated in initial page/s of Tunnel Inspection Register.

c) Tunnel Inspection Registers

To properly gather and record tunnel inspection data, it is recommended to have following two inspection/information registers for each tunnel:

1) **Tunnel Inspection Register:** For recording of Tunnel Condition Codes & comments. Recommended proforma is placed at Annexure I & II.
(Inspection register proforma used by Konkan Railway, Northern Railway and Central Railway are placed at annexure IV, V & VI for reference)

2) **Supplementary Tunnel Information Register:** For detailed sketches and/or photographs of defects found in areas of the tunnel. It would be helpful to make sketches/ take photographs of the same conditions or defects as previous inspections, so that the rate of deterioration can be ascertained.

As for as possible, Supplementary information should be recorded during the inspection itself. In cases (like photographs) where this is not possible, the date of recording Supplementary information should not be two weeks later than date of inspection)

Recommended proforma is placed at Annexure III.

d) Inspection Methodology

Identification of structural defects during the inspection can be accomplished through visual inspection or through a combination of visual inspection and non-destructive techniques. In case any special non-destructive testing is required to be used for inspection, advance planning & preparation should be made for the same.

e) Ensuring Safety

Inspection team should ensure that safety practices are followed at all times. Along with the safety of inspection personnel, the inspection team should take appropriate measures drawing inspection to prevent danger to the traffic, to staff, and to members of the inspection team.

4.2 Common structural defects for Concrete, Steel , Masonry, Shotcrete & Rock bolts

Identification of structural defects during the inspection can be accomplished through visual inspection or through a combination of visual inspection and non-destructive techniques.

The visual inspection must be made on all exposed surfaces of the structural elements. All noted defects should be measured and documented for location. Severe spalls in the concrete surface should be measured in length, width, and depth. Severe cracks should be measured in length and width. Corrosion on steel members should be measured for the length, width, and depth of the corrosion. The inspectors should clear a way debris, efflorescence, corrosion, or other foreign substances from the surfaces of the structural element prior to performing the inspection. Once the defect is noted, it should be classified as minor, moderate, or severe as explained in the following sections.

Particular attention should be paid to determining if differential settlement has occurred in transition areas of the tunnel. Transition are those in which the tunnel support conditions change, such as between sections of rock and soil tunneling.

In addition to visual inspection, structural elements should be periodically sounded with hammers to identify defects hidden from the naked eye. As a result of a hammer strike on the surface, the structural element will produce a sound that indicates if a hidden defect exists. A high-pitched sound or a ringing sound from the blow indicates good material below the surface. Conversely, a dull thud or hollow sound indicates a defect exists below the surface. Such a defect in concrete may signify a delamination is present or that the concrete is loose and could spall off. Once the defect is found, the surface in the vicinity of the defect should be tapped until the extent of the affected area is determined.

For concrete or masonry surfaces that are accessible, an on-destructive, ultrasonic test method such as "Impact-Echo" may be utilized. Impact-Echo is an acoustic method that can determine locations and extent of flaws/deteriorations, voids, debonding of reinforcement -bars, thickness of concrete. The use of this method helps to mitigate the need for major rehabilitation since the deterioration can be detected at an early stage and repairs performed.

Common structural defects are briefly described below:-

4.2.1 **Concrete Structures**

1) **Scaling:** Scaling is the gradual and continuing loss of surface mortar and aggregate over an area. This is classified as follows:

   - Minor Scale–Loss of surface mortar up to 6mm(¼in) deep, with surface exposure of coarse aggregates.

   - Moderate Scale–Loss of surface mortar from 6mm(¼in)to 25 mm(1in) deep, with some added mortar loss between the coarse aggregates.

   - Severe Scale–Loss of coarse aggregate particles as well as surface mortar and the mortar surrounding the aggregates. Depth of loss exceeds 25 mm (1 in).

2 **Cracking**: A crack is a linear fracture in the concrete caused by tensile forces exceeding the tensile strength of the concrete. Cracks can occur during curing (non-structural shrinkage cracks)or thereafter from external load(structural cracks). They may extend partially or completely through the concrete member. Cracks are categorized as Transverse Cracks, Longitudinal Cracks, Horizontal Cracks, Vertical cracks, Diagonal Cracks, Map Cracks, Random Cracks etc.

All cracks (in non-pre-stressed members) may be classified as follows:

- Minor - Up to 0.80 mm (0.03 in).
- Moderate - Between 0.80 mm (0.03 in) and 3.20 mm (0.125 in).
- Severe - Over 3.20 mm (0.125 in).

3) **Spalling:** Spalling is a roughly circular or oval depression in the concrete. It is caused by the
Separation and removal of a portion of the surface concrete revealing a fracture roughly parallel or slightly inclined, to the surface. Spalling may be classified as follows:

- Minor – Less than 12 mm (½ in) deep or 75 mm (3 in) to 150 mm (6 in) in diameter.
- Moderate–12mm (½in) to 25mm (1in) deep or approximately 150 mm (6 in) in diameter.
- Severe–More than 25mm (1in) deep and greater than150mm (6 in) in diameter and any spall in which reinforcing steel is exposed.

4) Pop-Outs: These are conical fragments that break out of the surface of the concrete leaving small holes. Generally, a shattered aggregate particle will be found at the bottom of the hole, with a part of the fragment still adhering to the small end of the pop-out cone. These are classified as under:-

- Minor–Leaving holes upto 10mm (0.40in) in diameter, or equivalent.
- Moderate–Leaving holes between10mm(0.40in)and50mm (2 in) in diameter, or equivalent.
- Severe–Leaving holes 50mm to 75mm (2.0into3.0in) in diameter, or equivalent. Pop-outs larger than 75mm (3in)in diameter are spalls.

5) Efflorescence: This is a combination of calcium carbonate leached out of the cement paste and other recrystallized carbonate and chloride compounds, which form on the concrete surface.

6) Staining: Staining is a discoloration of the concrete surface caused by the passing of dissolved materials through cracks and deposited on the surface when the water emerges and evaporates. Staining can be of any color although brown staining may signify the

corrosion of underlying reinforcement steel.

7) **Hollow Area:** This is an area of a concrete surface that produces a hollow sound when struck by a hammer. It is often referred to as delaminated concrete.

8) **Honey comb:** This is an area of a concrete surface that was not completely filled with concrete during the initial construction. The shape of the aggregate is visible giving the defect a honeycomb appearance.

9) **Leakage:** This occurs on a region on the concrete surface where water is penetrating through the concrete.

- Minor –The concrete surface is wet although there are no drips.
- Moderate –Active flows at a volume less than 30 drips/minute.
- Severe –Active flows at a volume greater than 30 drips/minute.

4.2.2 Steel Structures

1) Corrosion: Corroded steel varies in color from dark red to dark brown. Initially, corrosion is fine grained, but as it progresses, it becomes flaky or scaly in character. Eventually, corrosion causes pitting in the member. All locations, characteristics, and extent of the corroded areas should be noted. The depth of severe pitting should be measured and the size of any perforation caused by corrosion should be recorded. Corrosion may be classified as follows:

   - Minor –Alight, loose corrosion formation pitting the paint surface.
   - Moderate –A looser corrosion formation with scales or flakes forming. Definite areas of corrosion are discernible.
   - Severe–A heavy, stratified corrosion or corrosion scale with pitting of the metal surface. This corrosion condition eventually culminates in loss of steel section and generally occurs where there is water infiltration.

2) Cracks: Cracks in the steel may vary from hair line thickness to sufficient width to transmit light through the member. Any type of crack is serious and should be reported at once. Look for cracks radiating from cuts, notches, and welds. All cracks in the steel will be classified as severe.

3) Buckles and Kinks: Buckles and kinks develop mostly because of damage arising from thermal strain, overload, or added load conditions. Erection damage may also cause buckles and kinks.

4) Leakage: This occurs on a region of the steel surface where water is penetrating through a joint or crack.

- Minor –The steel surface is wet although there are no drips.
- Moderate –Active flows at a volume less than 30 drips/minute
- Severe –Active flows at a volume greater than 30 drips/ minute.

5) Protection System: Steel is generally protected by a paint system or by galvanizing. Most existing structures use either paint or galvanized steel. Paint systems fail through peeling, cracking, corrosion pimples, and excessive chalking. The classification of the degree of paint system deterioration is tied to both the physical condition of the paint and the amount of corrosion of the member as follows:

- Minor – General signs of deterioration of the paint system but no corrosion yet present.
- Moderate – Paint generally in poor condition and corrosion is present but not serious. (No section loss.)
- Severe – Paint system has failed and there is extensive corrosion and/or section loss.

4.2.3 **Masonry Structures**

1) Masonry Units: The individual stones, bricks, or blocks should be checked for displaced, cracked, broken, crushed, or missing units. For some types of masonry, surface deterioration or weathering can also be a problem.

- Minor – Surface deterioration at isolated locations. Minor cracking.
- Moderate – Slight dislocation of masonry units; large areas of surface scaling.
- Severe – Individual masonry units significantly displaced or missing.

2) Mortar: The condition of the mortar should be checked to insure that it is still holding strongly. It is particularly important to note cracked, deteriorated, or missing mortar if other deterioration is

present such as missing or displaced masonry units.

- Minor – Shallow mortar deterioration at isolated locations.
- Moderate – Mortar generally deteriorated, loose, or missing mortar at isolated locations, infiltration staining apparent.
- Severe – Extensive areas of missing mortar; infiltration causing misalignment of tunnel.

3) Shape: Masonry arches act primarily in compression. Flattened curvature, bulges in walls, or other shape deformations may indicate unstable soil conditions.

4) Leakage: A region on the masonry surface where water is penetrating through a joint or crack.

- Minor –The masonry surface is wet although there are no drips.
- Moderate –Active flows at a volume less than 30 drips/minute.
- Severe –Active flows at a volume greater than30 drips/minute.

4.2.4 **Connection bolts**

The connection bolts on fabricated components may be discolored due to moisture and humidity conditions in the tunnel. This condition does not down grade the structural capacity of the bolt. Particular attention should be given to bolts in regions of leakage to ensure that no detrimental loss of section has occurred. If losses in section are observed, such bolts should be noted for replacement. Also, the location of all missing or loose bolts should be noted.

- Minor – Bolts are discolored, but have no section loss.
- Moderate – Bolts are deteriorated with up to 15 percent section loss.
- Severe – Bolts are deteriorated with greater than 15 percent section loss. However, bolts with deterioration approaching 50 percent or more should be replaced.

4.2.5 **Shotcrete/SFRS**: Inspector should particularly look for any cracking, spalling, scaling& water seepage and rate it as mentioned earlier for concrete structures.

4.2.6 **Rock bolts:** Generally shotcreting is done after the work of rock bolting

is complete and therefore the rock bolt ends are generally embedded in shotcrete. The protrusion of bolt end may only be visible. The surroundings of bolts should be closely watched for any signs of cracks, loosening of shotcrete, dislocation etc.

If any sign of looseness/cracks observed, sounding of the location to be done for about 10 m on either side and suitable action to be taken. Any dampness observed around the rock bolt to be recorded.

A sample rock bolt selected in random in a tunnel at the rate of one rock bolt per 500 bolts or part thereof should be subjected to pull out test as a confirmatory test once in 10 years after provision of rock bolt.

4.3 **Major Items to be inspected during inspection of various Tunnel Components**

1. Portal (including cuttings at approaches)

a) Stability of slopes
b) Possibility of boulder/loose mass fall
c) Possibility of tree fall
d) Drainage arrangements: Catch water drains, side drains & sumps
e) Weep holes: in retaining walls/breast walls & portal structure
f) Adequacy & condition of measures (like shotcreting, rock bolting etc.) taken for strengthening/ stabilization/erosion control of slopes/tunnel face
g) Structural condition of portals
h) Emergency access & communication

2. Section of tunnel in relation to moving dimensions

a) Visible signs of any convergence/deformation in tunnel supports
b) In case the conventional measurements indicate some movement/convergence, systematic convergence measurement using tape extensometer/ optical methods should be done.
c) Scrutiny of past convergence/deformation history & instrumentation data

3. Tunnel Roof, Walls & Invert

a) Signs of any structural distress in tunnel supports (concrete/RCC/Steel/Shotcrete/SFRS/Rock bolts etc)
b) Signs of problem in formation (like disturbance in track alignment, levels)
c) Seepage/dampness

4. Tunnel Refuges (Man/Trolley/Material) & Walkway/ Escapeway

a) No unwanted material
b) Firm & level

5. Drainage

a) Side drains: cleanliness & No unwanted material. Similar to the condition rating, it is recommended that the inspector use a rating scale of excellent, good, fair, poor& serious condition. The rating should be based on the particular system component's ability to convey or store the required amount of water.
b) Weep holes: Check for clogging/choking
c) Functioning of dewatering pumps
d) Desilting of sumps

6. **Track** – as per provisions of IRPWM. Detailed inspection needs to be carried out in locations where tunnel convergence/deformation has been observed

7. Ventilation & Lighting, Telephonic Communication, Firefighting Preparedness & Electrical/Mechanical Systems

a) Functioning of designed systems
b) Comments on adequacy of available systems

General comments on functioning of mechanical, electrical & signaling systems should be recorded during inspection. Any issue requiring urgent attention should immediately be brought to notice of concerned department.

4.4 Inspection Documentation

a) Recording of Defects: The inspection should be thoroughly and accurately documented. For the tunnel structure, the documentation of severe defects should include a sketch showing the location and size of the defect and a verbal description of the defect. All severe defects should be photographed; however, a representative photo of minor or moderate defects will be sufficient. All defects should be described but sketches need only to be made for severe defects.

The sketches should show the necessary plan and elevation views of the

defects in structural element to which they pertain. All defects should be located on sketches by dimensioning their location in reference to the beginning or end of the element. Each defect should be dimensioned showing its length, width, and depth(if applicable).

In documenting the inspection, consistent abbreviation system (such as that given below) should be used in description, sketches & photographs to describe the defect and to classify them as minor, moderate or severe:

Description of Defect	**Classification**
Crack- CR	1 - Minor
Scaling - SC	2 - Moderate
Spall - SP	3 - Severe
Staining - ST	
Exposed Reinforcement - E	
Corrosion - C	
Honeycomb- H	
Hollow Area - HA	
Debris - D	
Buckle- B	
Efflorescence - EF	
Leakage - LK	

For example, a moderate crack should be labeled as CR2,a severe leakage as LK3,etc.This designation should be placed on the sketch/photograph.

Before placing any information on Supplementary Tunnel Information Register, always ensure that the structural element (that the defects pertain to) is correctly identified.

b) **<u>Condition Rating System</u>:** The tunnel components mentioned in Proforma of Tunnel Inspection Register should be rated as tabulated below:-

R	Description
	Excellent condition - No defects found.
	Good condition - No repairs necessary. Isolated defects found.
	Fair condition-Minor repairs required but element is functioning as originally designed. Minor, moderate, and isolated severe defects are present but with no significant section loss.
	Poor condition-Major repairs are required and element is not functioning As originally designed. Severe defects are present.

	Serious condition-Major repairs required immediately to keep structure open to traffic.

- The rating is dependent upon the amount, type, size, and location of defects as well as the extent to which the element retains its original structural capacity. To judge the extent to which the structural element retains its original structural capacity,t he inspector must be able to appreciate how the element is designed and how the defect affects this design.

- Defects should be described as "Minor", "Moderate" or "Severe". "Moderate" or "Severe" defects should be sketched and/or their photographs should be placed in Supplementary Tunnel Information Register.

c) <u>Repair Priority Classifications</u>: When summarizing inspection data and making recommendations for future repairs (in "Tunnel Inspection Register" and "Tunnel Inspection Report") it is recommended to mention priority of there pairs to be performed under following classification:

1. **<u>Critical</u>**: The inspection may reveal severe defects that could pose danger to the traffic or to tunnel personnel. When this occurs, this particular severe defect should be categorized for a" critical repair."

   A defect requires this designation if it requires "immediate "action including one of the following critical actions be taken:

   - Close the tunnel/keep the defect under continuous watch (with appropriate speed restrictions, if necessary) until the severe defect is removed or repaired.

   - Shore up the structural member if this is appropriate.

2. **<u>Priority</u>:** Refers to conditions for which further investigations, design ,and implementation of interim or long-term repairs should be undertaken on a priority basis, i.e. taking precedence over all other scheduled work.

3. **<u>Routine</u>:** Refers to conditions requiring further investigation or remedial work that can be undertaken as part of a scheduled maintenance program, other scheduled project, or routine facility maintenance depending on the action required.

d) <u>Specialized Testing Reports</u>: If the inspection utilizes any specialized testing agencies and equipment, all such reports derived from these special testings shall become a part of the documentation of the

particular inspection period.

e) **Tunnel Inspection Report:** Upon completion of the inspection, Tunnel Inspection Report should be developed that summarizes the findings of inspection. This report should be submitted along with Tunnel Inspection Registers & Supplementary Tunnel Information Registers to higher official/s. The report will facilitate appreciation of items in the tunnel requiring urgent attention and will help the higher authorities in their decision making.

Suggested outline for the report along with a description of the contents to be included in each section is as under.

- **Report Number/Letter number –** Identification number of report
- **Table of Contents** – Self-explanatory.
- **Executive Summary** – Provide a concise summary of the inspection, findings, and recommended repairs.
- **Major Inspection Findings**–Summarize Minor, Moderate & serious defects in the tunnels
- **Recommendations**– This section will include recommendations for repair/ rehabilitation of the tunnel components that were found to have defects. The recommendations should classify the repair/rehabilitation in to following categories:
  - Critical
  - Priority
  - Routine.

4.5 ROLE/DUTIES OF INSPECTING OFFICIALS

4.5.1 Inspection by SE/WORK/ SE OR SSE/P.WAY

1. Inspector(s) shall record the results of their inspection in prescribed tunnel inspection/information register.
2. Inspector(s) incharge of tunnel should inspect all the tunnel in his jurisdiction in detail after the monsoon and take the required necessary action.

3. The Inspector shall submit to the Assistant Engineer by the prescribed date a list of important defects with a certificate in duplicate to the effect.

   "I certify that I have personally carried out tunnel inspection of my section in accordance with standing orders for the year ending and append herewith a list of important defects."

4. The Assistant Engineer shall issue such orders as deemed necessary to the Inspector and counter sign and forward one copy of the certificate of inspection to the Divisional Engineer with remarks if any.

5. The Inspector shall accompany the assistant Engineer on the latter's annual inspection of tunnels.

4.5.2 Inspection by Assistant Engineer

1. The Assistant Engineer shall inspect every tunnel on the sub division once a year before the monsoon during the prescribed months and record the results in ink in the tunnel inspection registers.

2. The tunnel, the condition of which warrant special attention should be inspected more frequently.

3. The instructions and index as should be prefixed to each tunnel inspection register.

4. The inspection shall be detailed and cover all aspects, entries being made under each of the heads given in the register.

5. The Assistant Engineer should make an extract of all remarks concerning repairs required, send these to Inspector/Inspectors with explicit instructions and ensure expeditious compliance

6. On completion of his annual tunnel inspection the Assistant Engineer shall certify at the end of the register as follow:

"I certify that I have inspected all the tunnels shown in register during the year ending…..and have issued detailed orders in writing to the Inspectors concerned except the following on which the Divisional/ Sr. Divisional Engineer's orders are solicited".

These registers should be in the Divisional/ Sr. Divisional Engineer's office by specified date.

4.5.3 Inspection by DEN/Sr. DEN

1. The Divisional/Sr. Divisional Engineers shall carefully scrutinize the Assistant Engineer tunnel inspection register and inspect such tunnels as called for his inspection. He shall record his orders regarding the points which require a decision by him and initial against every entry of tunnel in the registers in token of scrutiny. He should endorse on each register, below the assistant Engineer certificate, as follows:

"I have personally scrutinized this register and have issued orders regarding all essential points requiring a decision by me. The following points are submitted to the Territorial Head of the Department at Head Quarters for orders."

2. The Divisional /Sr. Divisional Engineer should extract the items of inspection register requiring attention and send it to the Assistant Engineer who should intimate the same to the Inspector concerned for expeditious compliance.

3. The register should be forwarded to the Territorial Head of the Department at Headquarters who will examine each register, issue orders regarding matters referred to him, endorsing the registers to the effect and return them to the Divisional /Sr. Divisional Engineer. Subsequent action taken on the notes should be entered in the registers by the assistant Engineer.

4.5.4 **Special Inspections**

Understanding & prediction of Tunnel behavior is a complex subject. In case regular inspections and/or instrumentation records indicate a problem that may affect safety/operation of traffic, special inspections are recommended to be undertaken with assistance of experts on relevant field/s.

It is recommended to get a detailed inspection of tunnel conducted by a tunnel expert at a frequency varying from 1 to 6 years (depending on geology/tunnel condition).

Also in case of special unexpected events like railway accident, earthquake etc. railway officials should undertake special inspection of tunnel/s.

5.0 MAINTENANCE & REPAIRS OF TUNNEL

Maintenance & Repairs activities to be carried out for various components of tunnel are as under:-

5.1 **Portal & approach cuttings**

a) Surface Drainage: Maintenance operations carried out on surface drains usually fall into one, or a combination of the following:

i) Weed control within surface drains.
ii) Removal of debris from other track maintenance activities.
iii) Removal of sediment.
iv) Re-grading (if required).

b) Catch water drain:

i) Catch water drain should be pucca with adequate slope to ensure development of self-cleaning velocity.
ii) Catch water drain should not have any weep hole
iii) The expansion joints should be sealed
iv) Catch water drains should have well designed out fall with protection against tail-end erosion

c) Removal of loose boulders/loose mass & weaktrees/branches:

i) Loose boulders/loose mass in the portal area should be removed by loose scaling or by controlled blasting.
ii) Where necessary, rock fall and debris diversion or containment features should be constructed to positively ensure that no rocks, rock-slides or other debris such as soil from mountain slopes above the portal area can reach the tracks or damage equipment or structures.
iii) Option of constructing false tunnel /cut and cover in tunnel approach should be explored, if required.
iv) Weak/leaning trees/branches that may fall on/near the track should be cut.

d) Structural repairs

i) Structural repairs including strengthening (as per requirements) in portal structure (concrete/steel/masonry)

ii) Structural repairs of supports (like shotcreting, rock bolting etc) used for strengthening/ stabilization/erosion control of slopes/tunnel face. Further strengthening of support measures to be taken up as per requirements

e) Access Road

Road access to portals (if available) should be fit for desired use particularly for evacuating passengers and for staff/material access.

f) **Weep holes**: cleaning of clogged/choked weep holes

5.2 **Inside Tunnel:**

a) Scaling/Sounding of tunnel
b) Removal of unwanted material
c) Cleaning of side drains & sumps
d) Clearing walkways & refuges
e) cleaning of clogged/choked weep holes
f) Structural maintenance & repairs (including strengthening)
g) Track Maintenance (with special attention to problematic areas)
h) Scheduled maintenance of mechanical & electrical systems (including ventilation & lighting- by respective departments)
i) Scheduled maintenance of instruments
j) Scheduled maintenance of safety, fire & communication equipment's & signage

5.3 **Systematic Approach for repairs**:

Factors affecting the repair method are the deterioration severity and the structural impact of the defect. The cause of the defect should be determined before and remedial works, otherwise the same problem may recur.

It is recommended to adopt a systematic approach to tunnel repairs involving following steps:

1. Determine the cause(s) of damage
2. Evaluate the extent of damage
3. Evaluate the need to repair
4. Select the repair method
5. Development & approval of detailed repair methodology
6. Execution of repairs

6.0 SAFETY IN TUNNELS

6.1 Extract from practices of various safety codes as mentioned in BIS are summarized below:

6.1.1 Excavation Work-Code of Safety(IS: 3764-1992)

This standard lays down the requirements for carrying out safely the excavation work, such as trenches, test pits, cellars, borrow pits, cuttings for rail, canal and road formations and all excavations on which the side of excavations are not trimmed simultaneously to a stable slope.

i) During blasting operation to avoid the public movement fences, guards or barricades should be provided.

ii) During excavation of a tunnel where gases or fumes are likely to be present or show their presence therein, sufficient ventilation to protect the health and safety of persons working shall be provided.

Air shall be considered unfit for workmen to breath if it contains any of the following:-

(a) Less than 19% of Oxygen by volume.
(b) More than 1% of Carbon dioxide by volume.
(c) More than 0.01% of Carbon mono oxide by volume.
(d) More than 0.002% of hydrogen sulphide gas by volume.
(e) More than 0.002% of nitrous oxide by volume.

iii) Protection against hazards involving insects, vermins, leeches or snakes shall include the following controls:
(a) Instruction regarding potential hazards.
(b) Boots, hoods, netting, gloves, masksor other necessary personal protection.
(c) Drainage or spraying of breading areas.
(d) Burning or destruction of nests.
(e) Elimination of unsanitary conditions which propagate insects or vermins.
(f) Extermination measures against rodents.
(g) Approved first aid remedies for the affected.

6.1.2 **Safety Code for Tunneling Work** (IS: 4756-1978)

This standard lays down the safety requirements for tunneling and underground excavations in rocks and soft strata. This code does not cover tunnels made in connection with mining operations, gassy tunnels, and also tunnels made in running ground, where special methods like shield tunneling are adopted.

The concentration of various gases in atmosphere inside the tunnel by volume shall be as follows:

a) Oxygen – not less than 19.5 percent.
b) Carbon monoxide – not more than 0.005 percent.
c) Carbon dioxide – not more than 0.5 percent.
d) Nitrogen fumes – not more than 0.0005 percent.
e) Methane – not more than 0.5 percent at any place inside the tunnel.
f) Hydrogen sulphide – not more than 0.001 percent.
g) Aldehyde – as formaldehyde not more than 0.0002 percent.

6.1.3 Safety Code for Working with Construction Machinery (IS: 7293-1974)

This standard lays down the essential requirements for safety in the operation and maintenance of earth moving, lifting and hoisting, transporting and other construction machinery. It also includes some features of design and construction which are essential for safe working of construction machinery.

The main provisions covered in the code are:

i) Siting of construction Machinery

ii) Fencing of Machinery

iiii) Maintenance of Machinery

iv) First aid and fire fighting

v) Safety provisions for driver's cabin, brakes and controls, drivers and signallers, inspection and testing, work near overhead power line for machinery.

vi) Safety provisions for power shovels, bulldozers, scrappers earth moving machinery.

vii) Safety provisions for lifting and hoisting machinery.

viii) Safety provisions for driver's cabin, brakes and controls, gears, drivers and other operating conditions for Motor Trucks, Tractors and Dumpers.

ix) Safety Provisions for concrete mixers, concrete vibrators, road rollers, asphalt plants etc.

6.1.4 Safety code for Blasting and Related Drilling Operations (IS: 4081-1986)

This standard lays down the safety requirements for blasting and related drilling operations in locations other than mines.

7.0 SAFETY IN RAILWAY TUNNELS (AS PER UIC 779-9 R)

7.1 General Aspects Of Safety In Tunnels

i) The main risks that are considered in tunnels are fires, collisions and derailments.

ii) Safety in tunnels is the result of an optimum combination of infrastructure, rolling stock and operations measures.

iii) General principle shared by all railways can be summarized as –

- Prevent Accidents
- Mitigate the Impact of Accidents
- Facilitate Self Rescue
- Facilitate Rescue

7.2 Recommended set of safety measures for tunnels

- Systematic maintenance of track and tunnel and optimization of other track discontinuities.
- Escape routes (routes, handrails, markings) yields positive benefit for both new and existing tunnels. Tunnels must have walkways in order to escape in case of fire.it is suggested that distance between two safe places should not exceed 1000m.
- Inspection of track and tunnel yield a positive benefit for both new and existing tunnels.
- Track drainage system will give positive benefit for new tunnels.
- Access to tunnel entrance and tunnel exits yield a positive benefit for both new and existing tunnels.

7.3 Track inspection

7.3.1 General description :

- Systematic monitoring of track condition in tunnels.
- Track geometry
- Height of track
- Track material(also wear and tear)
- Track stability

7.3.2 Relevant aspects :

- A sound track forms the basis of safe movement and reliable operation.
- Systematic inspection also includes consequent maintenance work after irregularities are detected.
- Conditions in tunnels are more favorable than open stretches of line, constant conditions, less influenced by the environment.
- Track inspection is part of general maintenance concept.

7.3.3 Impact on safety :

- Reducing track defects as a cause for accidents.
- During inspection other irregularities around the track may also be detected.
- Avoids vehicles or loads colliding with tunnel walls.

7.3.4 Further effects :

- A low number of track defects is necessary for reliable operations.
- Detailed inspection needs time and therefore reduce the capacity of tunnel.

7.3.5Cost effectiveness:

- Good cost effectiveness for both new and existing tunnels.

7.3.6Assessment :

- For new and existing tunnels, systematic track inspection is recommended for any safe operation.

7.3.7 Inspection of tunnel condition

7.3.7.1General description :

Using special tunnel inspection vehicles in order to avoid accidents.

7.3.7.2Relevant aspects :

- Tunnel inspection is necessary independent of all other safety measures.
- Influencing factors: tunnel age, geology, groundwater situation.
- Surroundings under builtup area, underwater.
- Installations and fastenings.
- Inspection of tunnel condition is a part of tunnel maintenance.

7.3.7.3 Impact on safety :

- Accidents due to conditions in the tunnel:
- Water; fallen installations, fallen pieces from tunnel lining.

7.3.7.4 Further effects :

- Optimise the tunnel condition and maintenance work over a long term.

7.3.7.5Cost effectiveness :

- Good cost effectiveness for both new and existing tunnels.

7.3.7.6 Assessment :

- For new and existing tunnels, systematic inspection is recommended for any safe operation & optimised maintenance over the long term.

7.3.8 Track drainage system (drainage and retaining basin)

7.3.8.1 General description :

- Track drainage system removes water from the tunnel.

7.3.8.2Relevant aspects :

- Construction of tunnel as water tight tube: only fluids from inside would be removed.
- If there is also water from outside tube: decision between mixed system and separated system.

7.3.8.3Impact on safety :

- An appropriately-dimensioned drainage system reduces the possibility of escalation.

7.3.9 Escape routes

7.3.9.1General description :

- Provision of walkways in tunnel to facilitate escape. The escape route and directions are marked by pictographs.

7.3.9.2Relevant aspects :

- In the event of fire, a quick walking speed is essential for escape.
- In new tunnels, cross-section allows for wide walkways.
- Optimal height of walkway depends on situation.
- In case of freight traffic only, walkway is irrelevant.

7.3.9.3Impact on safety :

- Walkways also serve for rescue services.
- Increases walking speed.

7.3.9.4Further effects :

- Can be used for maintenance too.

7.3.9.5<u>Cost effectiveness</u> :

- For new tunnels, good but for existing tunnels not applicable.

7.3.9.6 Assessment:

- For new tunnels, good cost effectiveness ratio and for existing tunnels, medium cost effectiveness ratio.

8.0 SAFETY DURING CONSTRUCTION/REPAIR WORK (CALIFORNIA CODE OF PRACTICE)

(Div: 1, Chapter 4, Sub-chapter 20, Article 4- Safety Precautions, Sections - 8410)

(a) The employer shall ensure that every reasonable effort is taken for the safety of employees, whether or not provided for in these orders.

(b) All dangerous places shall be properly fenced off, covered over or otherwise safeguarded to control access to all openings to prevent unauthorized entry underground.

(c) No person shall be required to work in an unsafe place except for the purpose of making it safe, and then only under direct supervision and after all necessary precautions have been taken to protect him/her while doing such work.

(d) At least one designated person shall be on duty outside of all tunnels whenever anyone is working underground. This person's duties shall not interfere with his/her ability to secure aid for those persons underground in case of emergency.

(e) No person shall be permitted to use or possess any intoxicating liquors or drugs at any place of employment where these safety orders apply. When any person is known or suspected of being under the influence of an intoxicating liquor or drugs, he/she shall not be permitted to enter or remain on the job site.

(f) Strangers or visitors shall not be allowed to enter any place where these safety orders apply, unless they are accompanied by a person designated by the employer.

(g) A check-in/check-out procedure or other method shall be provided at the surface that will ensure that above ground personnel can accurately determine the number and identity of individuals underground in case of an emergency.

(h) Solitary employment in tunnels is prohibited where hazardous conditions exist, unless an effective means of communication has been established.

(i) Bars used for scaling and those used for loading at chutes shall be blunt on one end and maintained in good condition.

(j) All spikes or nails projecting from lumber lying in working areas or passageways shall be bent down or removed.

(k) Unnecessary accumulations of muck, timber, rails and similar materials shall be avoided underground, particularly in areas at shaft stations and between the track and the sides of tunnels.

(l) Gunite, shotcrete, and concrete pump lines shall be secured against displacement and provided with safety devices to prevent accidental uncoupling of sections when pressurized.

(m) When a 3/4-inch (inside diameter) or larger air hose is used, a safety chain, excess flow valve, or other equivalent safety device shall be attached to the hose to prevent the hose from whipping in the event of an accidental disconnection.

(n) Oncoming shifts shall be informed of any hazardous occurrences or conditions that have affected or might affect employee safety, including liberation of gas, equipment failures, earth or rock slides, cave-ins, floodings, fires or explosions.

(o) The employer shall establish and maintain direct communications for the coordination of activities with other employers whose operations at the job site affect the safety of employees underground.

(p) A caution sign reading "Buried Line" or similar wording or equivalent method of identification shall be posted where air, fuel or utility lines are buried or otherwise hidden by water or debris.

The guidelines/recommendations from various National/International standards/publications cited above for safety in tunnel are for the purpose of better appreciation of National & International best practices. Applicable provisions of "Guidelines for Safety in Tunnels during Construction", IRPWM, Works Manual, LWR Manual & circulars issued by Zonal Railways should be followed for ensuring safety of existing tunnels.

Annexure-I

TUNNEL INSPECTION REGISTER

General Information (last updated on ……)

1. Tunnel No: --------- 2. Year of construction---------- 3. Gauge/Type: …….

4. Section: ……..5. Chainage:……. 6. Between stations-------

7. Length: ……. 8. Line/Road: ---------- 9. Curve / Straight----------

10. Electrified: Yes/No 11. CWR/LWR/SWR/FPJ
12. Tunnel Profile: ……..

13. Previous History of Tunnel
Year of construction---------- Drawing no----------
Date of repair---------- Drawing no----------

14. Year wise summery at----------

Year	Details

	UP		DN	
	On straight	On curve	On straight	On curve
15. Minimum height of roof above Rail Level				
16.Minimum distance from center line of track				

17. Tunnel support Information

	Chainage		length	Support Description
	from	to		
i				
Ii				
Iii				
iv				
		Total		
Note: Reference drawing Number---------- is available at ---------- office				

18. Gradient

	Chainage		length	Gradient(V:H,R/F)
	from	to		
I				
Ii				
Iii				
iv				
		Total		

19. Curvature

	Chainage		length	Curve(Deg,LH/RH)
	from	to		
I				
Ii				
Iii				
iv				
		Total		

20. Track Structure

	Chainage		length	Track Structure
	from	to		
I				
Ii				
Iii				
iv				
		Total		

21. Geotechnical Information

22. special arrangement

a) Lighting:-	**b) Ventilation:-**
c)Drainage:-	**d) Shaft/Adits:-**

e) Instrumentation	**f) Other**

Annexure-II

TUNNEL INSPECTION REGISTER

Inspection Form

Date of Inspection: ……. **Name of Inspecting Official: ……..**

S.No	Description	Remarks of Inspecting Official	Condition Rating	Reference to supplementary Information; if any
A)	PORTAL			
1	PORTAL 1 (including tunnel approach)			
2	PORTAL 2 (including tunnel approach)			
B)	Section of tunnel in relation to moving dimensions			
C)	Tunnel Walls & Invert			
D)	Tunnel Roof			
E)	Tunnel Refuges (Man/Trolley/Material)			
F)	Drainage			
H)	Track			
I)	Ventilation		NR	
J)	Lighting		NR	
K)	Walkways/Escapeways		NR	

L)	Telephonic Communication	NR
M)	Firefighting Preparedness	NR
N)	Electrical/Mechanical Systems	NR

Details of any major repairs/attention since previous inspection; if any

Details of any untoward occurrence since previous inspection; if any

Signature of Inspecting Official

Details of Action taken/Compliance (with names, signature & date of official making the entry)

Annexure-III

Supplementary Tunnel InformationRegister

1. Tunnel No: --------- **2. Section: ……..** **3. Gauge/Type: ……**

4. Line/Road: ---------- **5. Chainage:…….** **6. Length: …….**

7. Date of Inspection: ……. **8. Name of Inspecting Official: …….**

9. Nature of supplementary information: (Tick the applicable types of information) Sketch/Photograph/Detailed Description

10. Reference to supplementary information: (Provide Report no, File no etc. in case the information is not included in /attached with Supplementary Tunnel Information Register)

Description of supplementary information

Signature of Inspecting Official

Annexure-IV

TUNNEL INSPECTION REGISTOR(Konkan Railway)

TUNNEL NO	LOCATION:			
TYPE	LENGTH:			
	LINED:			
	UNLINED:			
SPECIAL ARRANGEMENT				
LIGHTING				
VENTILATION				
GRADIENT OF TRACK				
GEOTECNICAL INFORMATION				
ROOF MINIMUM HEIGHT ABOVE R.L.				
WALLS-MINIMUM DISTANCE FROM C.L. OF TRACK				
Date of inspection	Details of Inspection	Remarks		CPWI's Compliance
		PWI's	AEN's	
	1. PORTAL			
	1.1 Slip Of Slopes			
	1.2 Cracked/Bulgimg Shaken Masonry			
	2.0 Profile			

	2.1 Clearance			
	3.0 Wall & Roofing			
	3.1 Condition Of Weepholes			
	3.2 Seepage			
	3.3 Unsoundlining, Loose Rock			
	4.0 Side Drains			
	5.0 Drainage Pattern Above The Tunnel			

	6.0 Refuges			
	7.0 Shafts/Adits			
	8.0 Lighting & Special Equipments			
	9.0 Track			
	9.1 Line Level And Reference Pillars			
	9.2 Corrosion			

Signature:

Name:

Date:

Annexure-V

Tunnel inspection Register (Northern Railway)

Details of inspection	Year 1997-98				Year 1998-99		
	Date of inspection	Condition at the time of inspection	action taken and initials	Remarks	Date of inspection	Condition at the time of inspection	action taken and initials
1	2	3	4		5	6	7
1.Tunnel approach & cutting							
2.Condition of portal							
3. Tunnel walls & roofing. Comment about tunnel conforming to moving dimension							
4. drainage inside tunnel and out fall							
5. condition of tunnel refuges							

&ventilation shafts							
6.Tracks in the tunnel							
7.lighting equipment & tools							
8. any other items							

DETAILS OF TUNNEL

Details should be furnished for each one of them

Tunnel No. _____Section _____Between Stations _____

Total length_____ Kilometerage_____

Year of construction_____

Shape/Type of Tunnel_____

Curve / straight _____Details of construction_____

Brief particulars of soil met with_____

Portions lined and thickness of lining _____

Brief particulars of ventilation_____

Brief particulars of lighting (if any) _____

Brief particulars of drainage _____

Minimum height above rail level along centre line of tracks _____mm

Reference to Plan _____

Annexure-VI

PARTICULAR OF TUNNEL (CENTRAL RAILWAY)

1.TUNNEL NO.	2. LOCATION	3. ROAD
4.YEAR OF CONST.		
5.LENTH OF TUNNEL	On Straight:	On Curve:
6. WIDTH OF TUNNEL	On Straight:	On Curve:
7.DEGREE OF CURVATURE		
8. BRIEF PARTICULARS OF SOIL MET WITH		
9. PORTION LINED AND THICKNESS OF LINING		
10. BRIEF PARTICULARS OF VENTILATION		
11. BRIEF PARTICULARS OF LIGHTING		
12. . BRIEF PARTICULARS OF DRAINAGE		

13. MINIMUM HEIGHT ABOVE RAIL LEVEL ALONG THE CENTRE LINE OF TRACK.

	DN		MID		UP	
	On Straight	On Curve	On Straight	On Curve	On Straight	On Curve
RH						
LH						

14. MINIMUM DISTANCE FROM CENTRE LINE OF TRACK.

	DN		MID		UP	
	On Straight	On Curve	On Straight	On Curve	On Straight	On Curve
RH						
LH						

15. REFERENCE OF PLAN
16. PREVIOUS HISTORY OF TUNNEL.
17. ANY OTHER INFORMATION
18. TRACK STRUCTURE:-RAIL: SLEEPER:

TUNNEL NO:

LOCATION:

ROAD:

DATE OF INSPECTION	CONDITION OF TUNNEL AT THE TIME OF INSPECTION	SIGNATUE OF INSPECTING OFFICIALS	ACTION TAKEN
	(A) POATALS OF EITHER END. (B) SECTION OF TUNNEL IN RELATION TO MOVING DIMENSIONS (C) TUNNEL WALLS AND ROOFING (D) DRAINAGE (E) REFUGES (F) VENTILATION OF SHAFT (G) LIGHTING EQUIPMENT AND SPECIAL TOOLS (H) TRACK		

References:

i) Tunnel Engineering Hand Book, By: John O. Bickel, Thomas R. Kuesel, Elwyn H. King, 1997.

ii) Road Tunnel Manual, US Department of Transportation, Federal Highway Administration, FHWA-NHI-09-010, USA, March 2009.

iii) Road Tunnel Design Guidelines, US Department of Transportation, Federal Highway Administration. July, 2004.

iv) Introduction to Tunnel Construction by David Champman, Nicole Metje and Alfred Stark

v) Tunnelling and tunnel mechanics by Dimitrioskolymbal.

vi) ITA general Report on Conventional Tunneling method.

vii) ITA Report on guidelines for Design of the tunnels.

viii) IS 4880-1987 Part -1, Code of practice for design of tunnel conveying water- General Design.

ix) IS 4880-1976 Part -2, Code of practice for design of tunnel conveying water- Geometric Design.

x) IS 4880-1976 Part -3, Code of practice for design of tunnel conveying water - Hydraulic Design

xi) IS 4880-1971 Part -4, Code of practice for design of tunnel conveying water- Structural Design of concrete lining in rock

xii) IS 4880-1972 Part -5 Code of practice for design of tunnel conveying water - Structural Design of concrete lining in soft strata and soil.

xiii) IS 4880-1971 Part -6 Code of practice for design of tunnel conveying water- tunnel support.

xiv) IS 4880-1976 Part -7 Code of practice for design of tunnel conveying water- Structural Design of steel lining.

xv) IS 5878-1971 Part -1 Code of practice for construction of tunnel-precision survey and setting out

xvi) IS 5878-1970 Part -2 section 1 Code of practice for construction of tunnel-underground excavation in rock-section 1: drilling and balasting

xvii) IS 5878-1971 Part -2 section 2 Code of practice for construction of tunnel-part-II underground excavation in rock-section 2: ventilation, lighting, mucking and dewatering

xviii) IS 5878-1972 Part -3 Code of practice for construction of tunnel conveying water-part-III underground excavation in soft strata

xix) IS 11309-1992 rock bolt for mines (cement grouted)-general requirements

xx) IS 13517-1992 rock bolt-resin type

xxi) IS 5878-1971 part 4 Code of practice for construction of tunnel conveying water-tunnels supports.

xxii) IS 5878-1976 part 5 Code of practice for construction of tunnel conveying water concrete lining

xxiii) IS 5878-1975 part 6 Code of practice for construction of tunnel conveying water steel lining

xxiv) IS 5878-1972 part 7 Code of practice for construction of tunnel conveying water- grouting

xxv) IS 15026-2002 Tunneling method in rock masses-guideline

xxvi) IS 9012-1978 recommended practices for shortcreeting

xxvii) BIS Code No. 3764-1992, Excavation Work- Code of Safety

xxviii) BIS Code no. 4081-1986, Safety Code For Blasting and Related Drilling Operations.

xxix) BIS No. 7293-1974, Safety Code for working with construction Machinery.

xxx) BIS Code No. 4756-1978, Safety Code for Tunneling Work.

xxxi) IS : 13416 (part-I to V) Recommendations for falling material, hazard prevention, fall preventions, disposal of debris, timber structures, fire protection

xxxii) UIC Code no. 779-9 R "Safety on Tunnel".

xxxiii) UIC Code no. 779 -10R "maintenance of existing railway Tunnel

xxxiv) California Code Of Practice

xxxv) Harbour, Dock and Tunnel Engineering, by R. Srinivasan.

xxxvi) Tunnel in weak rocks by Bhawani Singh & R.K.Goel.