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Safety Audit during Tunnel Construction

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Abstract: This paper describes the general and specific requirements for safety audit. The paper also addresses, safety measures during Highway Tunnel Construction and, during operation & Maintenance work. It throws enough light about the other allied services, necessary for the safety audit of Highway Tunnel.

I. INTRODUCTION

A. General

Safety in Construction of tunnels and underground structures should go hand in hand, since working in underground space is inherently a hazardous undertaking. As the work goes in the noisy environment, in close quarters with frequently with moving machinery, careful attention should be paid to the layout of work sites and workers must be protected all time with necessary PPE, rescue kits and quickly available emergency health services. Every step of the tunnel construction should be planned with safety in mind and with a slogan that “everyone goes safe at the end of their shift”.

- 1) *Background:* Working in underground structures such as tunnels is an inherently risk-prone activity and the risk element increases with longer lengths of the tunnels, poor rock conditions, etc. In view of this there is a responsibility on all stakeholders -owner, consultant and constructor - in tunnel projects to ensure absolute safety during construction.
- 2) *Applicable Codes/Regulations/Reference:* The various activities involved in tunnel construction are generally covered by a number of codes, acts and regulations. Some of them are:
 - a) Indian Explosive Act-1884
 - b) Mines act - 1952
 - c) The Explosive Rules - 1983
 - d) Mines Rules - 1955
 - e) IS:4081-1986 Safety Code for Blasting & Related Drilling Operations
 - f) IS:4756-1978 Safety Code for Tunneling Works
 - g) IS:14489-1998 Code of Practice on occupational safety and Health Audit
 - h) IS: SP:91-2010 Guideline for Road Tunnel
 - i) IS:7293- 974 Safety code for working with construction machinery
 - j) IS:10386- 974 safety code for construction, Operation and maintenance of RVP
 - k) IS:4081-1986 safety code for blasting and related drilling operations
 - l) IS:4138-1997 safety code for working in compressed air
 - m) AASHTO Guideline for Road Tunnel
 - n) PIARC Committee– System and equipment for Fire and Smoke Control, 2005

All the agencies involved in the construction of tunnels Should ensure that all applicable rules and regulations are duly complied with in strict conformity with the spirit and body of such regulations.

3) *Project Safety plan (PSP)*

Since each underground project has its own peculiarities and special features in view of topography, rock features, etc, it is very essential for each tunnel project to carry out a comprehensive Risk Analysis of the particular project and evolve a Project Safety Plan (PSP). While the agencies concerned may adopt the standard provisions of their respective organizations, it is essential to have a project-specific safety plan, which is fully relevant to the particular site.

The PSP Should be prepared by the concerned construction agency and got approved from the competent authority. The PSP Should address all site-specific issues encounter during construction and operation & maintenance. Also should elaborate, how to tackle all the risk elements identified.

B. Basic Aspects

Apart from this all operations connected with the construction of tunnels should be analyzed and appropriate safety precautions taken through the implementation of the PSP.

- 1) *Personal Protective Equipment:* All personnel entering the tunnel during construction should wear all applicable Personal Protective Equipment (PPE). The PPE should comprise, at minimum, Safety Helmet, safety (hard) shoes, tight clothing with no loose ends and jackets/clothing with reflective stripes. Additional PPE such as goggles, gloves, dust masks, helmet lamps, etc should also be adopted wherever conditions so warrant.
- 2) *Access Control Systems:* A proper access control system should be in place to have a clear idea at all times on the identity of all personnel who are inside the underground installations in case any accident takes place and rescue operations are to be launched. It is also essential to keep track of all equipment inside the tunnel. It is common to issue tokens to all concerned personnel and make them deposit the tokens while entering the tunnel and retrieving the same on exiting.
- 3) *Signage:* Well-illuminated sign boards should be placed at required locations to inform people of safety hazards inside the tunnel and the precautions to be taken. Some of them would include warning regarding blasting, rock falls, requirement for wearing helmets, prohibition of unauthorized entry, etc.
- 4) *Safety Systems:* The contractor's personnel should practice all standard safety systems. These would include at minimum, safety induction (initial training in basics of Safety) and training (routine training) exercises, medical screening of personnel for working inside tunnels, system of permits for simultaneous operations in various locations, pep talks (regular talks to workmen before they commence work on importance of safety and how necessary it is for them to observe safety regulations for their own welfare) and tool box talks (specific safety instructions at the site in the specific area of work for the workmen), talks on specific operations to be carried out on the day, safety walk about (general safety observance checks carried out by safety officers by going around the site and checking observance of the various safety regulations, etc), safety audits, safety reviews and mock drills.

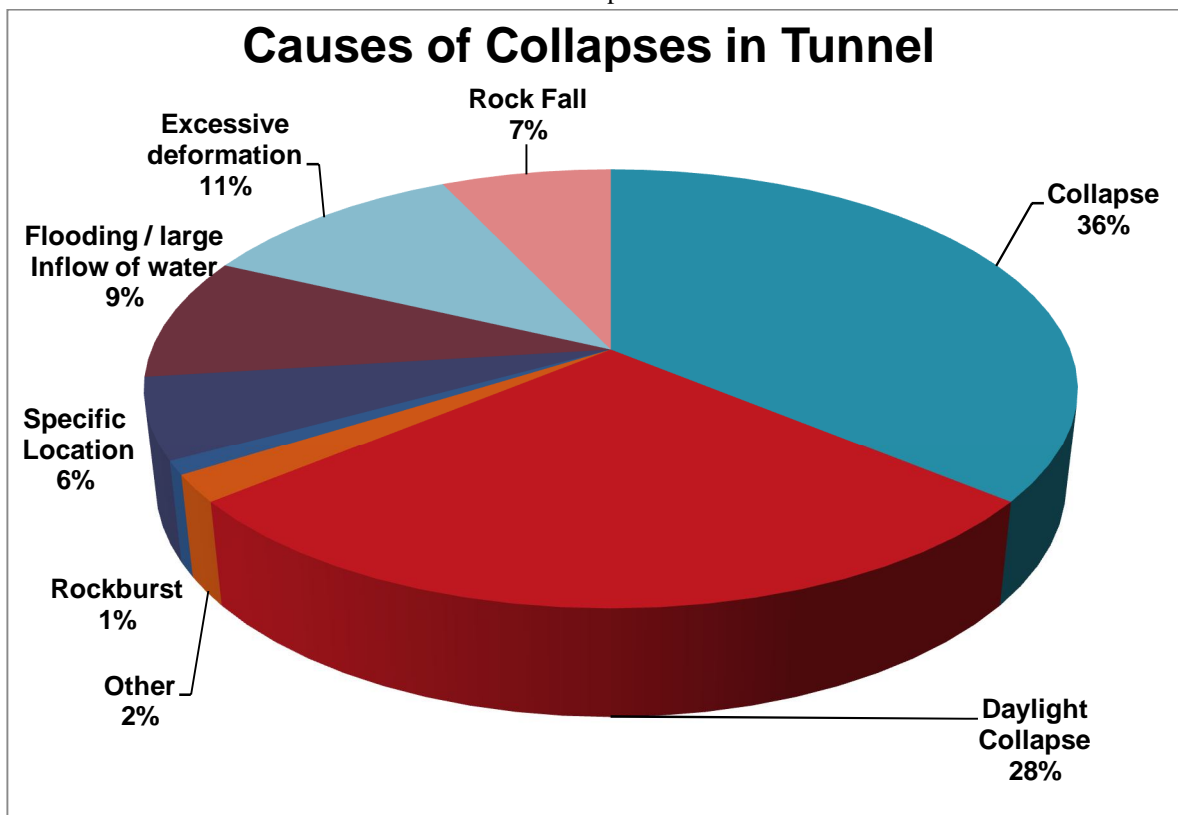
C. Drilling, Blasting & Mucking Operations

- 1) *Safety Measures to be Adopted:* The will and determination to execute the work with safety should come from the top. Safety rules and regulations should be framed and taught to everybody from top to bottom. These regulations must be followed strictly, because any minor negligence on the part of any worker may nullify the whole safety program. The working conditions on the job must be safe i.e. the equipment and tools must be in good working condition. It will not only be safe to work with them, but it will also increase the efficiency of the equipment.
- 2) *Safety against Falling of Rock:* In tunneling rock fall is the major factor causing accidents than any other cause. Except for premature explosion, falls are the most serious of all tunnel accidents, for they almost always involve one or more fatalities. Therefore following measures should be adopted to check the accidents due to rock fall.
 - a) Careful and frequent inspection of walls and roof should be done. To look for seams and planes of weakness visual inspection is sufficient.
 - b) To locate hollowness of the rock, hand hammer test is sufficient. Any spot strike with hammer, if sounds dull sound indicates hollowness and need investigation.
 - c) Scale down the freshly blasted heading and face after each shot before mucking is started.
 - d) Weak spots are to be supported by timbering.
 - e) The design of all vertical posts and planks should be checked carefully.
 - f) Defective and weak timber should not be used under any circumstances.
 - g) All persons working in tunnel should wear helmet to safeguard against head injury.
- 3) *Cramped Working Space:* Generally in all tunnels the working space in the heading is very crowded. Therefore following measures should be taken to avoid accidents.
 - a) For walking of labor and other workers in the tunnel safe and adequate walk way is essential for safety.
 - b) The walkway should be non-slippery.
 - c) Good lighting arrangement should be made at the face, and at any other point where work is in progress, such as at equipment installations, at track switches and sidings, at underground material supply and storage point etc. It is very important, if the

light is not proper, it will be difficult to see things. It is true that poor lighting and accidents go hand in hand. Thus to avoid accidents it is essential to keep the job well lighted.

- d) All electric lights and power lines should be properly laid and connections should be well insulated.
 - e) Extra light should be provided where essential materials are stored.
 - f) The tunnel should be provided with well drainage system and no water should be allowed to stand inside the tunnel as it will cause obstruction in walking and may lead to skidding, rusting of steel and other tools etc.
 - g) For safety and efficient working all the debris and refuse should be kept clean both on surface as well as underground
- 4) *Loading and Hauling of Muck:* Mechanical loading of muck and its haulage operations in tunneling are always dangers, but with little care the hazard can be greatly reduced. Therefore following precautions should be observed while loading and hauling the muck.
- a) The loading zone should be well lighted.
 - b) Workmen should be kept away from the vicinity of loading operations as rocks may slide from the car and injure the labor working nearby.
 - c) Loading cars should be loaded evenly and the muck should not be piled up dangerously high above the sides of the cars. It should be checked by an authorized person and should have the authority to stop mucking operations if he is not satisfied with proper loading.
 - d) Loaded cars should be inspected before they leave for their destination.
 - e) Cars carrying pipe, rails, steel and timber should be properly loaded for safe passage through the tunnel. The load should be within side limit of the cars. Loads should not project over the sides as it is dangerous for the man working in the tunnel.
 - f) Cars or trains carrying muck or other material in the tunnel should be properly controlled with signals during their journey.
- 5) *Handing of Explosives:* In Additional to above some general precautions as stated below should also be observed.
- a) After blasting inside the tunnel, no worker should be allowed to enter the tunnel till all the poisonous gases are removed.
 - b) All workers should be medically fits to work inside the tunnel and they should be periodically examined.
 - c) Smoking should not be allowed inside the tunnel.
 - d) In case of compressed air tunnels, extreme care should be taken to prevent fire.
 - e) Medical and first aid facilities should be available at the site of work.
 - f) No unauthorized person should be allowed to enter the tunnel and authorized visitors should be supplied safety hats. They should be accompanied by an authorized guide.
 - g) Emergency lights should be provided inside the tunnel at all working places to give light in case of power failure.
- 6) *Installation of Supports:* Following the basic philosophy elucidated in the earlier section, design and installation of appropriate supports within the stand-up time for the particular type of rock is the most important steps to ensure proper safety for all personnel inside the tunnels.
- Special watch should be maintained for uncontrolled collapse of the face or adjacent areas, sliding in of muck and water, etc.
- a) Rock Fall – Fall of rock blocks of major dimensions. The different mechanisms involved are wedge or planar failure.
 - b) Collapse Heading collapse – failure of the heading/lining failure.
 - c) Daylight Collapse Heading collapse – lining failure of the heading that reaches the surface creating a crater.
 - d) Excessive deformation excessive deformations inside the tunnel or at the surface. This can occur for example due to deficient design, construction defects and / or due to particular type of terrains such as swelling and squeezing ground, which had not been predicted.
 - e) Rock Burst - Spalling overstressing of massive or intact brittle rock, i.e the stresses development in the ground exceed the local cause spalling or in the worst cases sudden and violent failure of the rock mass
 - f) Portal Failure – Particular Locations of a tunnel, where there is lower
 - g) Shaft Failure – resistance of ground mass and / or concentration of stresses
 - h) Other – Other types of collapse that include slope failures etc.

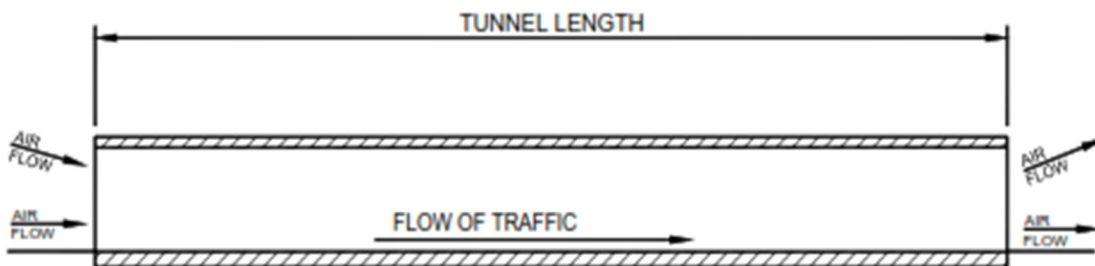
Causes of Collapses in Tunnel

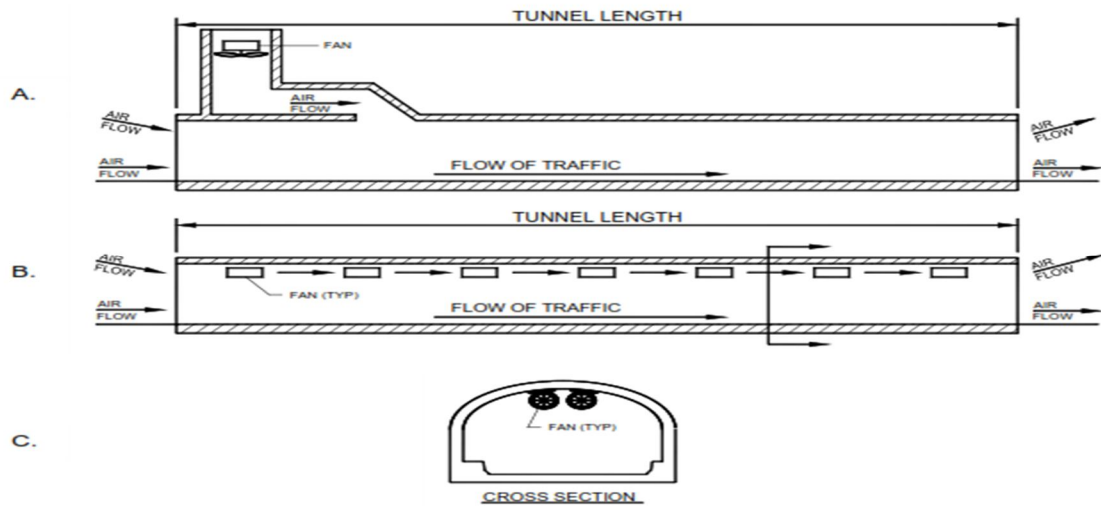


D. Ventilation and Noise Protection

Ventilation shall be carried out in tunnels to make the working space safe for working by keeping the air fresh and by eliminating harmful and obnoxious dust, explosive fumes, exhaust from the plant & equipment, particularly diesel operated and other gases. Mechanical ventilation shall be adopted, wherever necessary to force the air in or exhaust the air out from the working face to the portal through ducts. Externally located fans operate in forced ventilation and induced ventilation modes to supply air through rigid or flexible ducts. Intermediate booster fans shall also be provided to improve the supply of fresh air the minimum fresh air requirement considered in tunnelling shall, for plant and equipment. However, it may be modified as per size and shape of the tunnel.

It is important to be alert all the time for the presence of toxic gases in underground works and appropriate instrumentation should be provided to keep track of the ambient air quality at all times. Proper records should be maintained of specific measurements of air quality at regular intervals throughout the day after blasts or major rock falls. Particularly after each blasting for underground rock excavation, the ventilation measures should be set in place quickly and effectively for de-fuming and personnel should be allowed to enter only after establishing that the air quality is sufficiently acceptable.





Longitudinal Ventilation A) Saccardo Nozzle : B) Jet Fans; c) Cross Section



Typical Jet Fan Installations in road Tunnel

E. Lighting

Night lighting should be designed to avoid flicker and glare and the same illumination level I be maintained throughout the entire length.

In case of emergency/complete interruption of the tunnel lighting even for an instant cannot be tolerated which requires an uninterruptable power supply. For single utility service and standby diesel generator about a quarter of the tunnel lighting is connected to the emergency circuit which in case of power failure is immediately transferred to emergency battery system until the diesel generator picks up to carry load of tunnel lighting. Lighting in the tunnel would normally follow the luminance level as mentioned below for safe visibility during day light hours.

Open area -1000 cd/sq.m (natural day light)

Threshold zone-500 cd/sq.m

Transition zone- 150 cd/sq.m

Interior zone- 20 cd/sq.m



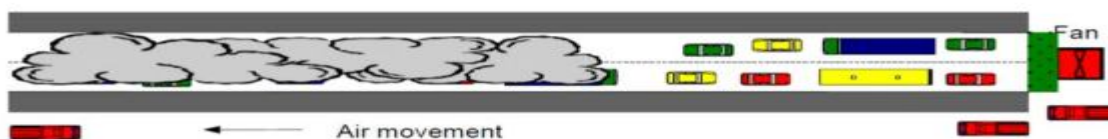
F. Communication System

1) Warning signs and notice boards

- a) Safety sign boards should be placed at various places.
 - b) A telephone point in case of emergency serves as a source of communication for help and rescue operation inside a tunnel. To facilitate the easy access for the user of tunnel the telephone point should be at a spacing of 200m (both side in case of Bi-directional traffic tunnel).
- 2) *CCTV systems:* Closed Circuit TVs are often deployed to keep a continuous watch on underground installations from the Control Room on top.

G. Protection against Fire

- 1) *General:* All combustible materials like rubbish should be continuously removed from such areas where flammable liquids are stored, handled and processed. All spills of flammable liquids should be cleared up immediately. Containers of flammable liquid should be tightly capped. All waste and combustible rubbish should be removed at least daily from the tunnel.
- 2) *Fire System:* Fire Incidence Detection Systems should be able to detect the fire very early in its development and also accurately locate the position of the fire. The degree of accuracy depends on the type of active fire safety systems that may be installed in the tunnel. It is recommended that fire-fighting equipment such as hydrants, hose reels and extinguishers are strategically located within the tunnel. Fire extinguishers and fire-buckets appropriate to the hazard should be conveniently located and identified.



Fire and rescue operation dealing with a car fire in a Tunnel

3) Electrical installations

- a) The electrical installations should be carefully designed and executed and regular tests should be carried out to ensure safe conditions and emergency cut-off procedures. Electricity leakage monitoring systems should be in place.

H. Housekeeping

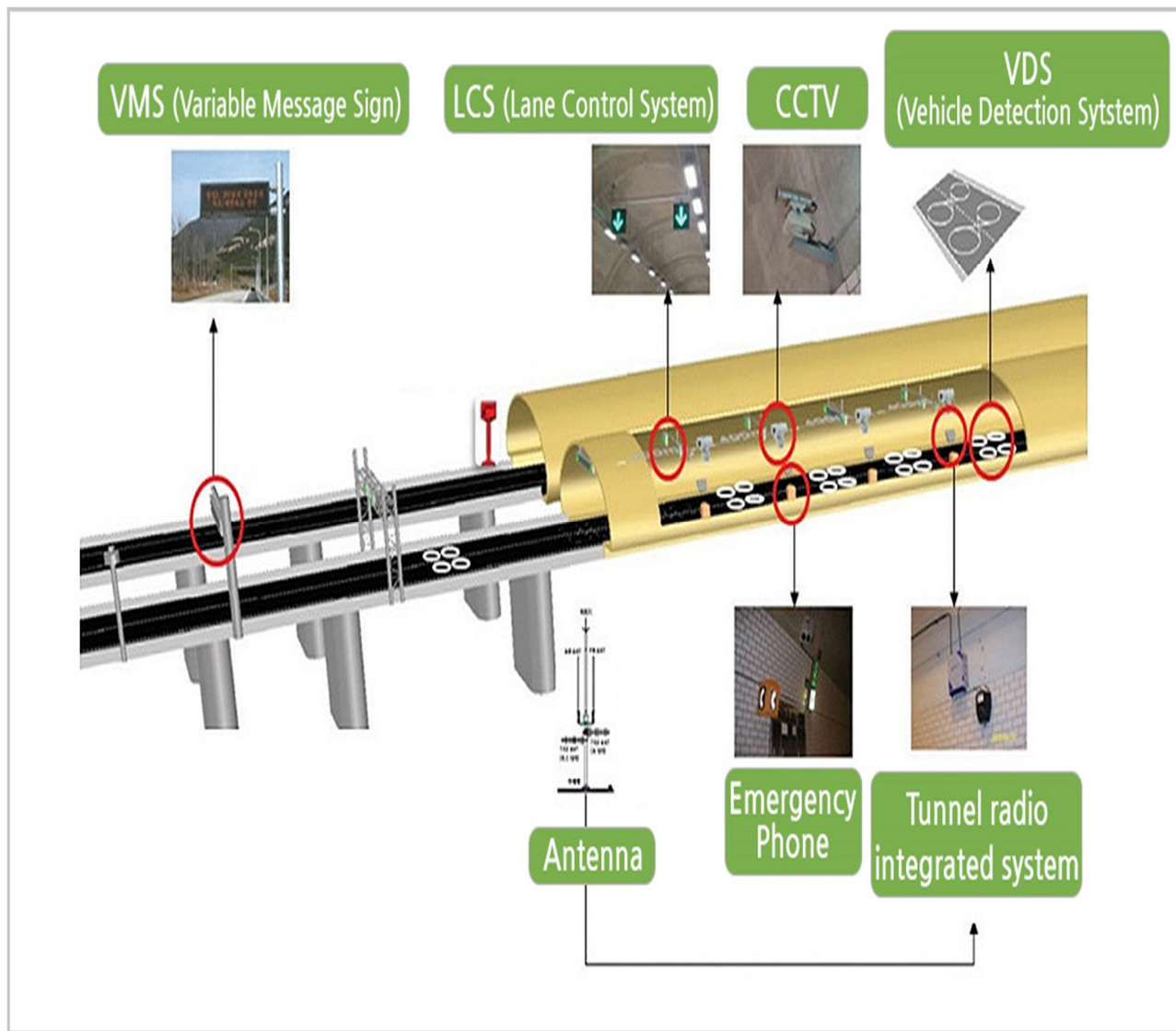
- a) *General:* Only the materials required for work in progress should be kept inside the tunnel. All other materials should be removed from inside the tunnel. Sufficient width of the formation as even as possible and without any obstacles should be created to enable the workers to get out of the tunnel quickly in case there is any collapse or any other mishap inside the tunnel.

- b) *Traffic Control:* Transport of Employees: A safe and smooth walkway system should be provided for employees, suitable separated from vehicular roads by guard railing. For transportation of employees by vehicles proper safety precautions should be taken.
- c) *Pipes and cables:* All water and air pipes as well as electrical cable should be arranged along the sides of the tunnel, duly supported at regular intervals and in a systematic and neat fashion.
- d) *Water control:* Sudden water ingress can be a catastrophic situation in certain underground areas and emergency dewatering systems should be in place to tackle such situations.

Excessive ingress of water can give rise to unstable conditions and has to be carefully monitored. Also, for good working conditions inside underground enclosures, continuous dewatering to remove the excessive inflow is essential.

I. Emergency Management System

An Emergency management Plan Should be part of the approved Project Safety Plan and Should be well communicated to all working personnel and well displayed at the site. Emergency Rescue Measures should be drawn up to take care of various possible contingencies. It would also be advisable to provide safe rooms in deep installations where people can take shelter for a few hours in case of an emergency. Buried large diameter pipe lines leading to outside can be provided to offer a medium for communication and feeding in air supply in case of any collapses and blockages of the entrance to underground installations.



II. INTRODUCTION

The overall aim of operation and maintenance of a road tunnel should be to maintain a specified level of safety for the road users, with an optimal level of expenditure and without adverse environmental effect. Operation and Maintenance aspects throughout the long operational life of the road tunnel. The Operation and Maintenance activities of the road tunnel should be planned to achieve the following objectives:

- 1) Safety of the road users
- 2) Ensuring free flow of traffic
- 3) Operational economy
- 4) Dealing with abnormal situations

Normal tunnel operation should provide for maintenance of the structure, Actions for imparting training to operating staff, updating of techniques and updating of O&M manuals should be taken from time to time.

Abnormal operational situations call for a command structure to deal with the situation and deployment of rescue vehicles, ambulances, signal system, communication facilities and firefighting equipment's.

A. Functional Requirement of Road Tunnel Based on IRC: SP:91-2010

Classification of Tunnel	Single Tube Bi-Directional						Double Tube Uni-Directional					
	CP	VN	LG	TE	FS	EG	CP	VN	LG	TE	FS	EG
Short Tunnel Up to 500 m	NA	--	***	---	---	---	---	---	---	---	---	---
Medium Tunnel 500m to 1500 m	NA	YES	YES	YES	YES	---	YES	YES	YES	YES	YES	*
Long Tunnel Above 1500 m	NA	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	*

** Lighting shall be provided for Urban Tunnels and preferably for tunnels longer than 100 m in Non-urban area

- NA - Not Applicable
- FS - Fire Safety - Fire extinguisher @50-100m
- TE - Telephone @200 m
- EG Egress (Such egress shall have minimum dimensions of 2 m x 2.5 m height with adequate ventilation & lighting, and isolation from main tunnel through fire proof doors)
- CP - Cross Passage
- LG - Lighting.
- VN - Ventilation

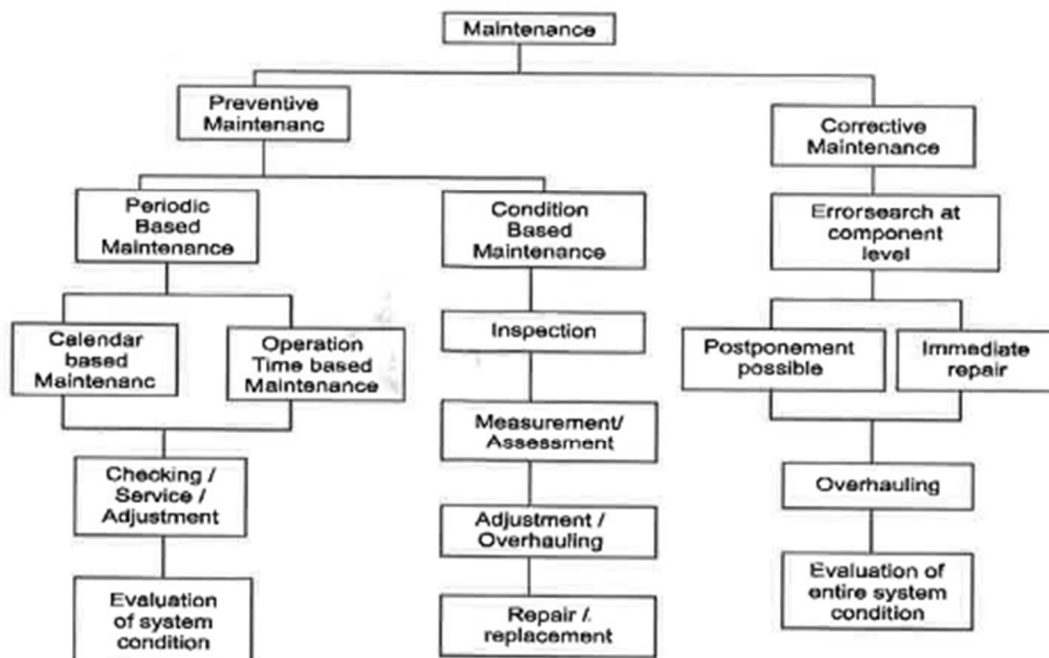
- 1) *Note 1:* In case of long tunnels, provision of refuge to park at least 6 vehicles along the length of tunnel with one-lane width, proper informatory signs, transitions and line of sight should be planned at about 750 m intervals beyond the leftmost lane.
- 2) *Note 2:* In case of twin tube tunnels, each tunnel tube with unidirectional traffic, cross passages connecting the two tubes should be @ 300 m. In the event of an incident/ accident in one of the tubes, the other tube shall be used as an escape and rescue route by diverting the traffic through cross passages to the extreme right lane of the other tube, so as to clear the tunnel in case of emergencies. The cross passages should be @300⁰ to the alignment, having single lane provisions.

B. Operation and Maintenance Functions/Activities

Operation and maintenance of tunnels involve following functions/activities:

- 1) Traffic related functions:
- 2) Maintenance of plant and equipment
- 3) Incidence and Emergencies Management
 - a) Vehicle related incidence
 - b) Non-Vehicle related incidence:
 - c) Weather hazards:
 - d) Human hazards
- 4) Maintenance of tunnel

The figure below illustrates the different types of planned maintenance:



C. Organization for Operation and Maintenance

- 1) The operational organization should be responsible for the operation and maintenance, firefighting and rescue procedures, as well as traffic control operation.
- 2) The structure of the operational organization depends on several factors, of which the most important are:
 - a) Type and extent of technical equipment in the tunnel,
 - b) Extent of automatic surveillance and alarms deployed,
 - c) Traffic flow details,
 - d) Geographical location,
 - e) Magnitude of the tasks to be carried out.
- 3) The tasks required to be handled by the operational organization are:
 - a) Surveillance tasks
 - b) Operational tasks
 - c) Preventive maintenance tasks
 - d) Corrective maintenance tasks

D. Documentation (For Tunnel Operation, Maintenance, Inspection & Evaluation)

In order to achieve the appropriate standards for the operation and maintenance of tunnels it is essential that the operating manuals for equipment, maintenance schedules etc. should be prepared and should be readily available for reference of the concern staff of the operational organization. The manuals should contain procedures to address a whole range of scenarios. Each procedure should contain a number of instructions to be undertaken, each of which initiates an action in one of the manuals. The individual manuals might cover the following aspects:

- 1) Administration manual
- 2) Inventory manual
- 3) Technical operation manual
- 4) Traffic manual
- 5) Maintenance and inspection manual

E. Safety Requirements

- 1) Tunnel maintenance activities both planned and unplanned should be carried out by proper traffic management. The tunnel should be: equipped in such a way that as many maintenance operations as possible can be carried out off-site in work shop or other places where it is not necessary to interference with traffic flow in any way. To plan maintenance and operation that affect vehicle traffic, as these may be cause of accidents involving user of the tunnel or the workers operating the maintenance equipment's, certain precautions as enumerated below. should be taken for safety of traffic as well as maintenance staff.
 - a) Maintenance staff working in the tunnel should be protected from errant vehicles entering into the tunnel. For that: purpose warning signs should be posted at appropriate location and one driving lane should be closed completely by barriers and providing proper warning signage/signals well in advance for safety of coming traffic.
 - b) The closer of lane should be indicated before the road enters tunnel.
 - c) Variable messages, traffic signs, barriers should be used for the purpose.
- In twin tube tunnel one tube can be closed for maintenance while temporarily bi-directional traffic flow allowed in other tube.

- ❖ CCTV
- ❖ Supervision and alarm equipment's:
- ❖ IDS (incident detection system)
- ❖ emergency lighting
- ❖ variable message signs
- ❖ Lane signals
- ❖ Blinking red light
- ❖ Variable text signs
- ❖ Barriers
- ❖ Emergency Road Sign
- ❖ hand-operated fire extinguishers
- ❖ fire hydrants
- ❖ water reservoir
- ❖ fire-hose coil with supply
- ❖ sprinkler (if used)
- ❖ closed drainage system
- ❖ fire engines (if owned)
- ❖ emergency telephones
- ❖ fire alarms
- ❖ automatic fire detectors
- ❖ instruments for measuring visibility
- ❖ instruments for measuring gas concentrations
- ❖ sensors for doors, alarm boxes
- ❖ devices for detecting vehicle height
- ❖ Emergency power UPS
- ❖ Escape routes and communication:
- ❖ emergency doors
- ❖ radio transmission
- ❖ communication equipment
- ❖ public address system
- ❖ escape route signs
- ❖ smoke-free escape routes

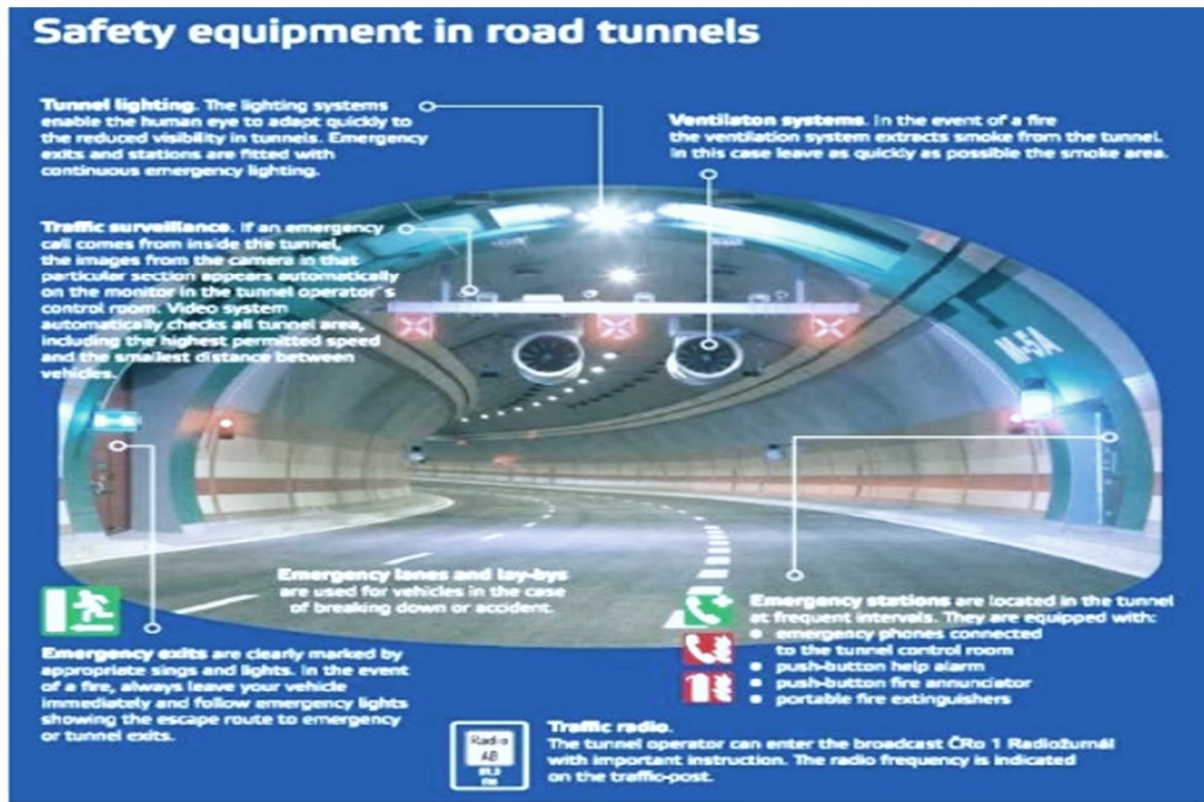
III. CONCLUSION

The paper concludes with the understanding that, this will create a general awareness about the workers safety during construction and users safety while operation & maintenance of Highway Tunnels. Further, it gives necessary guidance and mandatory requirement for various types and sizes of Tunnels. Apart from that it provides good information about the all aspects of Tunnel Construction with safety and user safety as well, which is the ultimate objective of the paper.





Safety equipment in road tunnels



Tunnel lighting. The lighting systems enable the human eye to adapt quickly to the reduced visibility in tunnels. Emergency exits and stations are fitted with continuous emergency lighting.

Traffic surveillance. If an emergency call comes from inside the tunnel, the images from the cameras in that particular section appear automatically on the monitor in the tunnel operator's control room. Video system automatically checks all tunnel area, including the highest permitted speed and the smallest distance between vehicles.

Ventilation systems. In the event of a fire the ventilation system extracts smoke from the tunnel. In this case leave as quickly as possible the smoke area.

Emergency lanes and lay-bys are used for vehicles in the case of breaking down or accident.

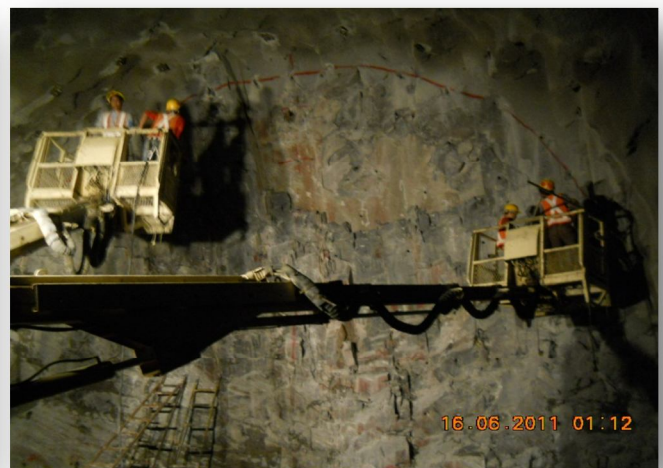
Emergency exits are clearly marked by appropriate signs and lights. In the event of a fire, always leave your vehicle immediately and follow emergency lights showing the escape route to emergency or tunnel exits.

Emergency stations are located in the tunnel at frequent intervals. They are equipped with:

- emergency phones connected to the tunnel control room
- push-button help alarm
- push-button fire annunciator
- portable fire extinguishers

Traffic radio. The tunnel operator can enter the broadcast CRo 1 Radiotunnål with important instruction. The radio frequency is indicated on the traffic-post.

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