Safety Management of Road Tunnel During Construction-A Case Study

Ashok Kumar Sharma
Technical Adviser, Lion Group, Bhopal(M.P.), India

Abstract

The road tunnel construction is highly complex. It inherently involves many risk-prone activities like excavation and lining, transportation of materials, use of explosive, drilling and blasting, scaling and mucking, ventilation and noise protection excavation, handling of tunnel machinery etc. The risk increases especially, construction in poor rock condition and longer length tunnel. Hence, the safety during construction is crucial. The critical literature review indicated that very few studies available for safety management of road tunnel during construction in India. So the study presents the case study of safety management of two different road tunnels, (i) Chirwa Ghat twin tunnel project near Udaipur and (ii) Kuthiran tunnel in Kerala, in detail. It will provide more insight of safety during construction and it also identifies gap in safety practices for improvement.

The study describes the general and specific requirements for safety during the construction. It also throws enough light about the other allied services necessary for the safety of the road tunnel. The basic aspect of safety such as personal protective equipment, access control equipment, lighting, ventilation and safety system at workplace are presented in detail. Tools and methods for identifying risk in working conditions are also discussed in the study. Then the observations have been discussed for all general and specific requirements on both the tunnels and gaps are identified in the field practices. The remedial measures and precautions for various high risk involving activities like drilling and blasting are presented in the study

Thus the study will contribute to provide detailed insight of safety scenario during road tunnel construction and identifies the gaps for improvement in current field practice in India.

Keywords - *Safety Management***,** *Tunnel Safety, drilling and blasting.*

I. INTRODUCTION

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. 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 moving machinery, careful attention should be paid to the layout of work sites and workers must be protected all the 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'.

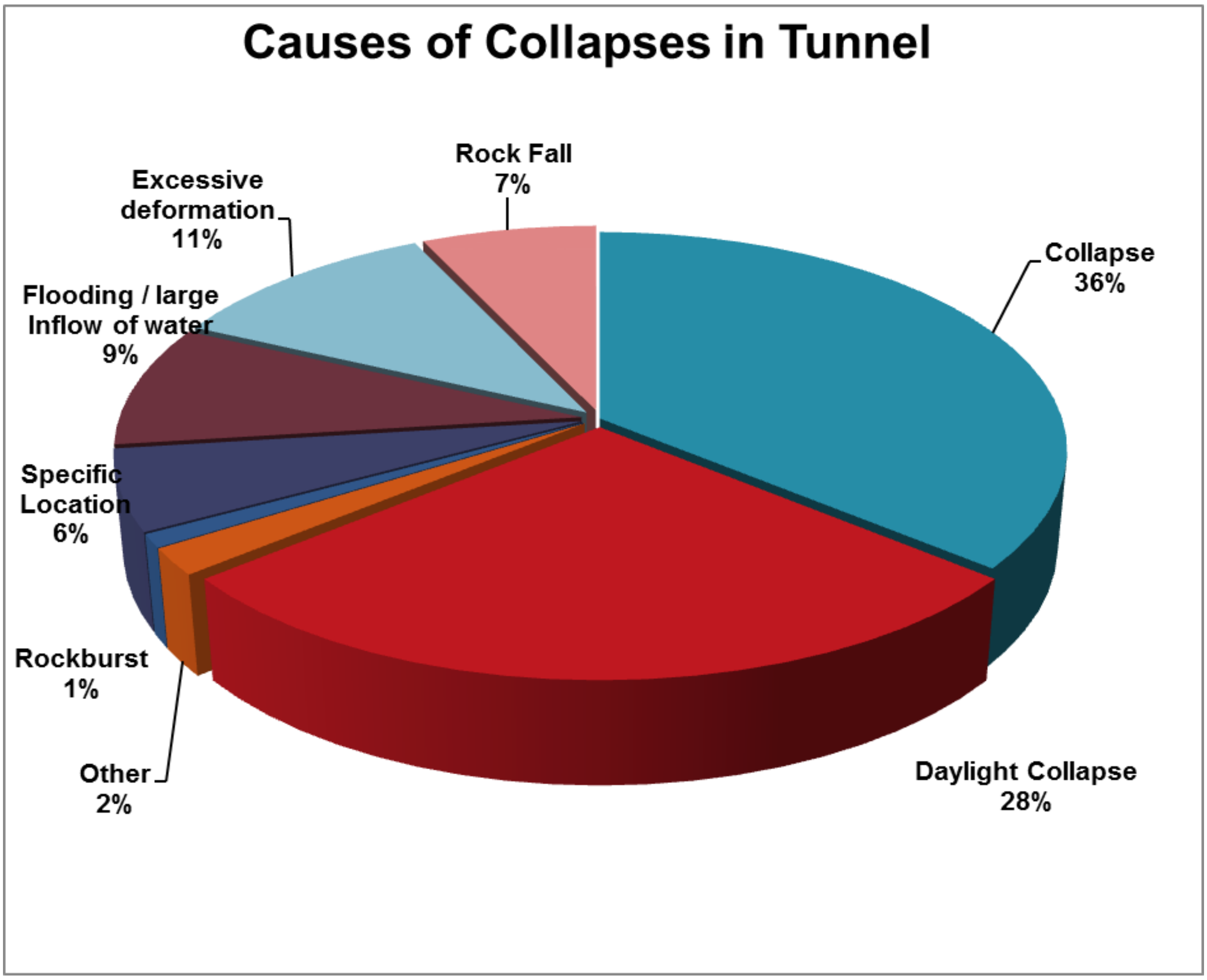
II. LITERATURE REVIEW

Existing condition of accidents in India - At one time, tunnel accidents claimed one life for every Kilometre of tunnel construction, increased concern over construction safety and its management during construction led to improvement in working condition, with a subsequent reduction in the frequency of deaths and disabilities accidents. However, due to rapid growth in transportation project worldwide and specifically in India, there is a tremendous scope for improvement in the safety management during tunnel construction for workmen, material, plant and machinery

Safety Management Technique - Since each underground project has its own peculiarities and special features in view of topography, rock features etc., therefore, 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 incorporating the geological and geotechnical data. The PSP should be prepared by the concerned construction agency and get it approved from the competent authority. The PSP should address all site-specific issues that may be encountered during construction operation. Also should elaborate, how to tackle all the risk elements identified. Apart from this all operations connected with the construction of tunnels should be analyzed and appropriate safety precautions to be taken through the implementation of the PSP. In this continuation, two tunnels were taken for case study to assess the ground reality regarding the safety management actually taken place/or not, in accordance with requirement, good engineering practices and codal provisions. Further analysis is done below for causes of collapses, problems and hazards in tunneling:

A. Risk Assessment Techniques-

- Rock Fall – Fall of rock blocks of major dimensions. The different mechanisms involved are wedge or planar failure
- Heading Collapse – failure of the heading/lining failure
- Daylight Collapse – lining failure of the heading that reaches the surface creating a crater
- Excessive deformation – excessive deformations inside the tunnel or at surface. This can occur due to deficient design, construction defects & terrain such as swelling & squeezing ground, unpredicted conditions
- Flooding – Comprises cases where the tunnel was invaded by large quantities of underground water
- Rock Burst - Spalling overstressing of massive or intact brittle rock, -the stresses development in ground exceed the local cause spalling/ worst cases sudden & violent failure of rock
- Portal Failure – Particular Locations of a tunnel, where there is less cover



III. PROJECT PROFILE

A. Technical Features of Kuthiran twin tunnel

1) Objective of Tunnel Construction:
In view of the steep gradient, sharp curves and forest on either side of the existing road, it was decided to provide a six lane tunnel in the Kuthiranmalai area.

- General Geology and Rock type - Igneous rock and poor to medium/fair granite
- Total length of twin tunnel - 1880 m
- Geometry of Tunnel - D-Shape (Wall & Arch)
- Construction Methodology - Drill Blast Method/NATM
- Geological Challenges Encountered - Shear Zones, Portal Collapse & Wall Collapses
- Finished width of the tunnel - 14.00mtrs
- Finished height of the tunnel - 10.00mtrs
- Width of the foot path - 1.25mtrs (Both sides)
- Lighting and Ventilation - Provided
- Distance Between 2 tunnels - 23mtrs
- Cross Passages - 2nos 300mtrs each from porta

B-Technical Features of Chirwaghat twin tunnel

1) Objectives of Tunnel Construction
In view of the Ghat section, sharp curves and forest on either side of the existing road, it was decided to provide a six lane twin tunnel in the Chirwaghat area.

- General Geology and Rock type -Metamorphic & very poor to fair Quartz arenite, With Phyllite and Schist, clay bends in-between
- Total length of twin tunnel - 910m
- Geometry of Tunnel - D-Shape (Wall & Arch)
- Construction Methodology - Drill Blast Method/NATM
- Geological Challenges Encountered - Shear Zones, Portal Collapse & Wall Collapse
- Finished width of the tunnel - 14.50mtrs
- Finished height of the tunnel - 10.00mtrs
- Width of the foot path - 1.25m+2.50m (with drain)
- Lighting & Ventilation - Provided
- Distance Between 2 tunnels - 26mtrs

KUTHIRANMALAI TWIN TUNNEL (1880M)

KUTHIRANMALAI TWIN TUNNEL (1880M)

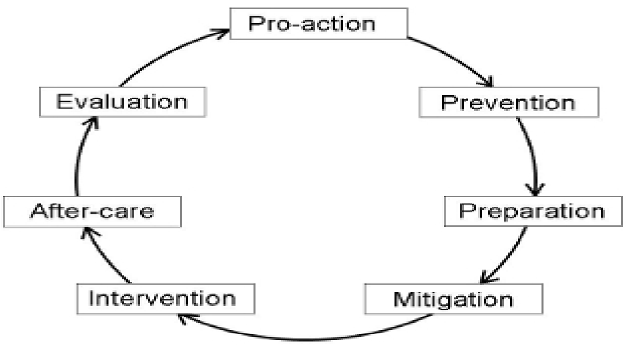
CHIRWAGHAT TWIN TUNNEL (910M)

IV. SAFETY EVALUATION

A. Risk Assessment – Mitigation and control measures. The first step in the assessment of requirements is to define the safety objectives during tunnel construction. Safety objectives may be defined in various ways but we should agree on the broad definition of objectives as being:

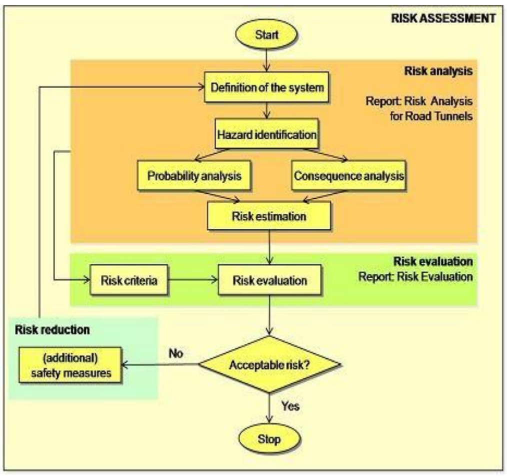
- to prevent critical events, and
- to reduce the consequences of incidents.

Safety Circle



Flowchart- Procedure for risk assessment

In the past, in many countries, the safety design of road tunnels to a great extent was based upon prescriptive regulations and guidelines. If the



applicable prescriptions of relevant guidelines were

fulfilled the tunnel was regarded as safe.

However, this prescriptive approach has some shortcomings:

- Even if a tunnel fulfils all regulatory requirements it has a residual risk which is not obvious and not specifically addressed.
- A prescriptive approach defines a certain standard of tunnel equipment etc. but is not suited to take the specific conditions of an individual tunnel into account. Furthermore, in a major incident the situation is completely different to normal operation and a great range of different situations exceeding existing operational experience may occur.

Hence, in addition to the prescriptive approach, a risk-based approach - called risk assessment - can be used to address the specific features of a tunnel system (including vehicles, users, operation, emergency services and the infrastructure) and their impact on safety.

Various types of risk can be addressed in a risk based approach, such as harm to a specific group of people (societal risk), or to an individual person (individual risk), loss of property, damage to the environment or to immaterial values. Commonly, risk analyses for road tunnels focus on the societal risk of tunnel users which can be expressed as the expected number of fatalities per year or as a curve in the FN diagram showing the relationship between frequency and consequences (in terms of number of fatalities) of possible tunnel incidents.

Risk assessment is a systematic approach to analyses sequences and interrelations in potential incidents, thereby identifying weak points in the system and recognizing possible improvement measures. Three steps characterize the risk assessment process:

i. Risk **analysis**: Risk analysis is concerned with the fundamental question: "What might happen and what are the probabilities and consequences?". It involves the identification of hazards and the estimation of the probability and consequences of each hazard. Risk analysis can be carried out in a qualitative or in a quantitative way or as a combination of both. Two families of approaches are suitable for road tunnels:

a scenario-based approach, which analyses a defined set of relevant scenarios, with a separate analysis for each one,

a system-based approach, which investigates an overall system in an integrated process, including all relevant scenarios influencing the risk of the tunnel, thus producing risk indicators for the whole system.

For system-based risk analyses, quantitative methods are common practice. Thus probabilities of incidents and their consequences for different damage indicators (e.g. in terms of fatalities, injuries, property damage, interruption of services) and the resulting risk are estimated quantitatively, taking due account of the relevant factors of the system and their interaction.

ii. **Risk evaluation**: Risk evaluation is directed towards the question of acceptability and the explicit discussion of safety criteria. In other words, risk evaluation has to give an answer to the question "Is the estimated risk acceptable?" For a systematic risk evaluation safety criteria have to be defined and determination to be made of whether a given risk level is acceptable or not. Acceptance criteria must be chosen in accordance with the type of risk analysis performed. For instance, scenario-related criteria can be set to evaluate the results of a scenario-based risk analysis, while criteria expressed in terms of individual risk or societal risk can be applied for a system-based risk analysis. There are different methods of risk evaluation: it can be done by relative comparison, by a cost-effectiveness approach or by applying absolute risk criteria. However, in practice a combination of different approaches is often applied. Important principles for risk evaluation as well as practically applicable risk evaluation strategies are to be planned and presented in the PSP for implementation.

iii. **Planning of safety measures**: If the estimated risk is considered as not acceptable, additional safety measures have to be proposed. The effectiveness (and also cost-effectiveness) of the additional measures can be determined by using risk analysis to investigate the impact on the frequency or consequences of different scenarios. Planning of safety has to answer the question "Which measures are best suited to get a safe (and cost-efficient) system?”

Risk assessment of road tunnels allows a structured, harmonized and transparent assessment of risks for a specific tunnel including the consideration of the relevant influencing factors and their interactions. Risk assessment models provide a much better understanding of risk-related processes than merely experience-based concepts may ever achieve. Moreover, they allow evaluation of the best additional safety measures in terms of risk mitigation and enable a comparison of different alternatives. Hence, the risk assessment approach in the context of tunnel safety management can be an appropriate supplement to the implementation of the prescriptive requirements of standards and guidelines. In practice, there are different methods to approach different kinds of problems. It is recommended to select the best method available for a specific problem.

Although risk models try to be as close to reality as possible and try to implement realistic base data, it is important to consider that the models can never predict real events and that there is a degree of uncertainty and fuzziness in the results. Considering this uncertainty, the results of quantitative risk analysis should be considered accurate only to an order of magnitude and should be supported by sensitivity studies or similar. Risk evaluation by relative comparison (e.g. of an existing state to a reference state of a tunnel) may improve the robustness of conclusions drawn but care should be taken in the definition of the reference tunnel.

PERMANENT STEEL SUPPORT WORK-IN PROGRESS

V. Table showing the applied safety measures- during tunnel construction

S.No.	Required- Safety Provision	Chirwaghat Tunnel	Kuthiranmalai Tunnel	Explanatory Remarks
1	Personnel protective equipment	Partially used	Partially used	Helmet, safety shoes, reflective jackets, gloves, goggles, dust masks, earplug/muffs, safety harness
2	Access control system	Partially used	Sparingly used	Exit/Entry control system for workmen, material & equipment, no-entry for unauthorised persons
4	Signage-Display @prominent locations	Ordinary boards used	Ordinary boards used	Well-illuminated boards -Yellow-Danger, Blue-Mandatory, Red-Prohibition, Green-Safe condition
5	Training-Better safety management	Conducted some times	Not Conducted	Safety training-initial, basic,& routine, pep talks & toolbox talks, mock drills
6	Medical/first aid facilities	Available day time only	Rarely available	Availability - Medical attendant/first aid attendant & ambulance
7	Ventilation system used	Mechanical ventilation	Natural but insufficient	Natural/mechanical ventilation system - used to force fresh air
8	Noise control	Used Earplugs/muffs	Rarely used	Protective device to be used to maintain Noise level <85dB,
9	Lighting	Adequate lighting arrangements	Inadequate/poor lighting arrangements	50/30/10 lux to be maintained @ heading, inside tunnel, portal
10	**Communication system-** Warning signs and notice boards, Telephone system and CCTV system	Adequate warning signs and display boards, telephone	Adequate warning signs, telephone	Hooter / Siren / Display of construction activities inside tunnel, CCTV system for better Monitoring of construction operation inside the tunnel
11	**Fire protection-** General items, Fire system, electrical installations	Adequate & satisfactory arrangements made	Poor and inadequate arrangements made	Removal of flammable liquid / combustible materials, water type fire extinguisher & sand bucket, fire alarm & phone no. of nearest fire brigade station
12	**Housekeeping-** General, traffic control, pipes and cables, water control	Adequate & satisfactory arrangements made	Poor and inadequate arrangements made	Keep required material only, safe walkways for workmen/ passage for vehicles, proper installation of pipe lines, dewatering system for water ingress in tunnel
13	**Protection against** –insects, leeches, vermin's and snakes	Insufficient arrangements	No-arrangements	Spray, drainage of breeding area, netting, elimination of unsanitary conditions

14	Emergency management system	In place, As per PSP	Not available	Emergency rescue measures, described in EMP, as part of approved PSP
15	Drilling Operations	Wet drilling with hydraulic/robotic jumbo	Wet drilling with hydraulic/robotic jumbo	Wet drilling is permitted to keep the safety/visibility at heading & inside of tunnel
16	Blasting Operations	Adequate arrangements were in place	Poor arrangements were in place	Nonel / explosives / detonators / 330m distance / no-cell phone are used, B.O. by experienced blaster / shot firer licensed - PESO,
17	Inspection after Blasting	Proper arrangements were in place	Proper arrangements were in place	After 5 minutes & all clear signal, shotfirer checks the exploded face
18	Checking of misfire	Proper arrangements were in place	Proper arrangements were in place	After 15 minutes of explosion- all clear signal- face inspection check for misfires status carried out with multi-meter
19	Scaling & Mucking	Adequate arrangements were made	Adequate arrangements were made	Scaling ladder / equipment used to remove the loose / distressed surface, dumping / disposal yard identified for muck disposal
20	Explosives Storage & handling	All necessary arrangements were in place	Necessary arrangements were in place	Fenced Portable magazines under watch by gun-guard, handling to workplace by mobile magazine
21	Explosives Disposal & Accounting	Necessary arrangements were made	Necessary arrangements were made	Safe disposal of packagings of explosives/ maintain approved register of received & consumed explosive material
22	Installation of supports as approved	Necessary supports provided	Necessary supports provided	Safely supported within stand-up time of rock, to avert uncontrolled collapses
23	Erection-fabricated Structural steel section	Safe practices used in Erection works	Safe practices used in Erection works	Signalmen, equipment check for hooks, cables, ropes, slings, hoists, & protection from falling objects
24	Scaffolds & Working platforms	Safe workmanship practiced	Safe workmanship practiced	Use of safety belt, suitable guard rails as safety fence on-slippery work area
25	Concreting works- Mixing & pumping	Safe workmanship practiced	Safe workmanship practiced	RMC- use dust mask, pipeline & pumping operation coordinated by signalmen
26	Grouting & Shotcreting	Safe workmanship practiced	Safe workmanship practiced	Safe condition maintained for shotcrete pump, grouting machine, experienced nozalman engaged for safety/ quality work
27	Instrumentation for monitoring-during construction	Strain gauge,& load cell for shotcrete & rock bolts used	Monitoring carried out by visual observation only	Safety & stability of excavation, supports, warning of potential ground failure, safety & serviceability of adjacent structures

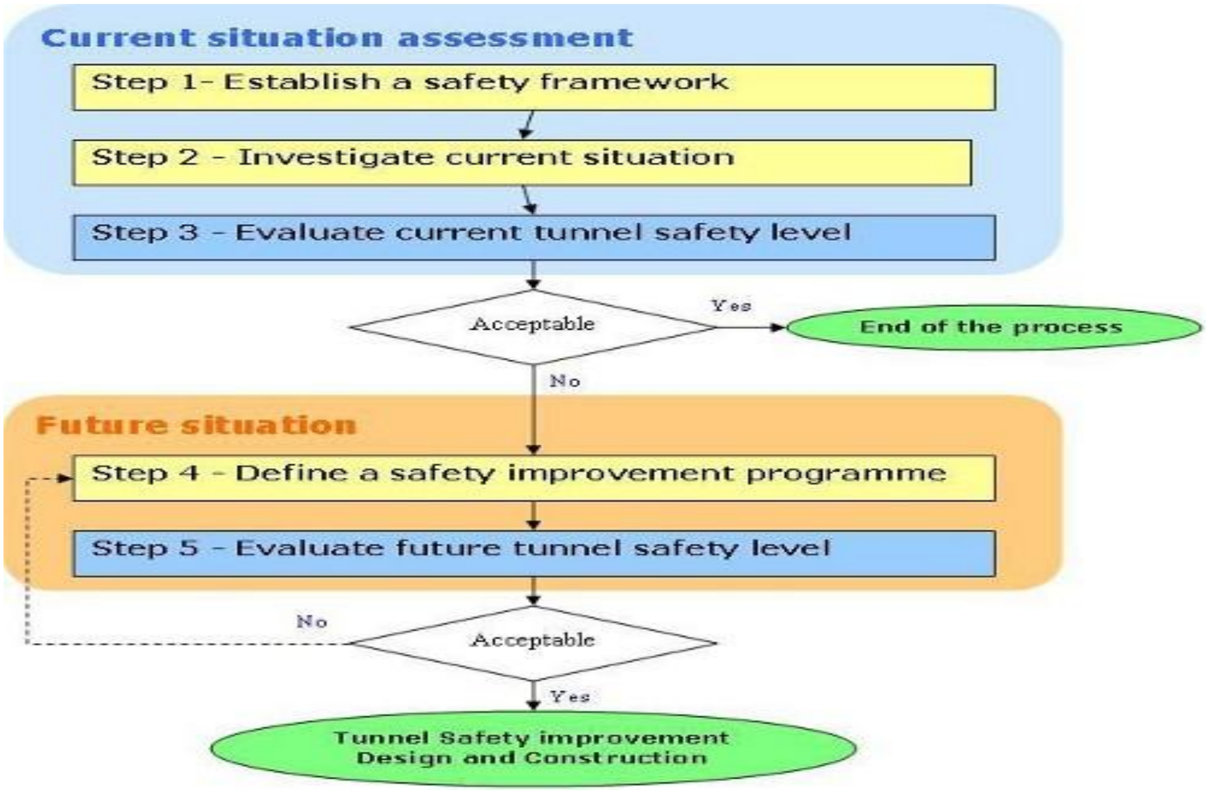
28	Welding & cutting works by gases, hoses,& torches	Safe workmanship practiced	Safe workmanship practiced	Safety goggles, mask, gas lighter, well ventilated work area
29	Electric arc welding & cutting	Safe workmanship practiced	Unsafe workmanship practiced	Proper earthing of welding sets, & armoured cable, ELCB fitted
30	Competency test of Drivers & Operators	Conducted as per PSP	Randomly conducted	For Safe & secure - pre-employment training to work in confined space of tunnel
31	Competency test for workmen	Conducted as per PSP	Randomly conducted	For Safe & secure - pre-employment training to work in confined space of tunnel

KUTHIRAN TUNNEL-INTERNAL VIEW

VI. DISCUSSIONS

- It is clear that many of the labour accidents due to rock fall events happen when workers set off explosive charges or install steel arch supports in the cutting face during tunnel construction using the mountain tunnelling method, especially NATM /DBM
- Prevention measures that were proposed against labour accidents due to rock fall events during tunnel construction include shotcreting the cutting face, bolting to the cutting face, removing rock masses in the cutting face, drilling the cutting face for drainage, measuring the displacement of the cutting face, and sufficient lighting in order to observe the cutting face.
- In the prevention measures against labour accidents due to rock fall events during tunnel construction, shotcreting the cutting face is very effective because it can control any weakness in the integrity of the mountain rock, protect against exposing mountain rock to the air, and makes it easier to observe new cracks and deformations in the rock face. In addition, shotcreting the cutting face is very useful in terms of construction and economic aspects. It is, however, more important to use shotcreting in combination with other prevention measures because some labour accidents due to rock fall events occur even after shotcreting is implemented. The cause of such accidents is thought to be the insufficient thickness of the shotcrete or a weakening in the cohesive strength due to the upwelling of groundwater.
- Therefore, not only shotcreting alone, but also sufficient lighting in order to observe the cutting face, removing rock masses from the cutting face, and measuring the displacement of the cutting face, should be used in combination to ensure that all prevention measures work synergistically.
- In situations where the risk of rock falls remains high even after the above prevention measures have been applied, it is preferable for the client, contractor and the construction operator to engage in discussions to consider prevention measures from the design stage and other supplementary measures, including forehand piling to a tunnel roof, and bore holing for drainage
- A structured approach for assessing and preparing refurbishment programmes is proposed with two main tasks:
  i. The first task aims to assess the current situation of the tunnel, like an instantaneous picture of the tunnel, in order to identify the current safety level. First of all, a reference safety level must be defined, which is generally provided by regulatory frameworks. Then the current tunnel functionalities and the state of the facilities which perform them have to be analysed. On this basis it must be assessed whether the existing tunnel is currently in line with safety-relevant design criteria. Furthermore, specific risks should be assessed by risk analysis which is an appropriate tool to evaluate the current safety level of a tunnel in operation. From these initial analyses, actions can be defined and priorities can be set
  ii. The second task aims to define the future tunnel situation after renovation works which can be acceptable in relation to the defined safety level goal. This can be done by developing renovation programmes and assessing again the safety level of the renovated tunnel including all upgrading measures. Once again risk analysis can be applied to demonstrate an adequate safety level or to evaluate various alternatives of upgrading measures, including cost- effectiveness criteria. Renovation programmes depend on the specific context of each tunnel, its constraints and its environment. An iterative process of risk analysis may be followed where agreement is reached on a projected safety level that is acceptable to all stakeholders in the project.

- The multistage process for the preparation of a tailor-made renovation programme for a tunnel in operation can be summarised in the flowchart below. It describes the functional links between the various steps and their respective outputs.



Flowchart of the multistage process

- In detail, the content of each step is to be adapted to the specific conditions of the individual tunnel, its environment, and of course specific local practice.
- Depending on the tunnel situation, the process can be stopped after step 3 with a simple comparison to the reference state if the analysis is demonstrating that the required safety level is already achieved. Indeed, for tunnels already renovated, step 3 can be the end of the process. If not, step 3 may highlight urgent mitigation measures which can be implemented immediately to improve the tunnel safety level with non-substantial actions such closure barriers, signalling or traffic control measures. In some cases, such measures may be sufficient to obtain the required safety level.
- If more substantial works are required, temporary modifications of the operating conditions may be a useful tool for a temporary increase in the tunnel safety level, if necessary.
- The preparation of renovation works for a tunnel in operation is an iterative process as it is a combination of technical issues, safety measures, costs implication and works phasing constraints. This is why step 4 and 5 can be refined several times to obtain an adapted refurbishment programme taking into account all relevant parameters which may influence the decision. Design activities can start after step 5.
- Typical weak points (safety deficiencies) in existing tunnels are presented and analysed. Additionally, case studies of existing tunnels in India demonstrate the strategy and upgrading measures implemented

VII. CONCLUSION

- Since tunnelling being the hazardous but environment friendly, there should be a registration of all workmen at state/national level, to provide them special training of health and safety services and system of **tunnel workmen card** should be introduced.
- There is a need for developing a mechanism to create a separate data base at appropriate level for incidents /accidents occurred, during the construction of tunnel
- Entry and Exit system should be developed and followed strictly. The use of safety permit/clearance system should become mandatory for underground activities
- Workers primarily use vehicles for transport in the tunnels. All vehicles must be situated so that they are immediately available for effective evacuation.
- Escape masks should be regarded as personal protective equipment.
- The communication and alarm system for evacuation should be available to each working team and be easy to use. In addition, fixed

stations for alarm should be placed every 75 meters, preferably together with the fire water supply.

- A plan should be available for other types of fire and rescue missions, e.g. release of trapped persons and removal of falling rocks.
- Storage of combustible materials underground should not exceed the material that is used during one shift, and not exceed 25 m2 of exposed surface (the surface that can burn). If the freely exposed surface storage area will be larger than 25 m2, special fire safety measures should be introduced, for example, covering the stored combustible material with fireproof cloth or something similar.
- If possible, avoid the risk completely, by using alternative methods or materials.
- Combat risks at source, rather than by measures which leave the risk in place but attempt to prevent contact with the risk.
- Wherever possible, adapt work to the individual, particularly in the choice of work equipment and methods of work. This will make work less monotonous and improve concentration, and reduce the temptation to improvise equipment and methods.
- Take advantage of technological progress, which often offers opportunities for safer and more efficient working methods.
- Incorporate the prevention measures into a coherent plan to reduce progressively those risks which cannot altogether be avoided and which takes into account working conditions, organizational factors, the working environment and social factors.
- Give priority to those measures which protect the whole workforce or activity and so yield the greatest benefit, i.e. give collective protective measures such as suitable working platforms with edge protection, priority over individual measures, such as safety harnesses.
- Employers and the self-employed need to understand what they need to do, e.g. by training, instruction, and communication of plans and risk assessments.
- The existence of an active safety culture affecting the organizations responsible for developing and executing the project needs to be assured
- Collection and analysis of incidents/accidents are essential for the risk assessment of a tunnel and for the improvement of safety measures. Indeed, data constitutes the basis of risk analysis which allows evaluation of the risks in a tunnel and the effectiveness of the improvement measures proposed by the tunnel owner.
- These data allow in particular evaluation of the frequency of the trigger events, and provide feedback on their consequences, on the actual role and effectiveness of safety facilities and measures. Also, collection and analysis of incident data allow the objective to be achieved.

ACKNOWLEDGEMENTS / REFERENCES / REGULATIONS

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