SAFETY IN TUNNELING AND EXCAVATION

National Safety Council, Hqs.
98-A, Institutional Area, Sector 15,
CBD Belapur, Maharashtra
NaviMumbai – 400615.
India  www.nsc.org.in
Contact no: 022-27579924/25
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1 BACKGROUND TUNNELING

Tunneling work is widely carried out in the country in the construction of railway, road projects. The work involved is of a specialized and hazardous nature. Cramped working space in the heading, wet and slippery flooring, artificial lighting – all too often inadequate, difficult ventilation, obnoxious gases, unseen weaknesses in the rock, handling of explosives, leading and hauling muck, etc, might contribute to accidents.

The hazards involved in tunneling and underground works arise mainly due to following operations:

i. Drilling
   - All drilling equipment shall be kept in good working order. Safe handling and proper lifting methods shall be used.
   - As far as possible, only wet drilling shall be used.
   - Jumbos or other drill platforms shall be carefully designed, built and maintained to provide safe working conditions. The jumbo should be provided with a suitable railing around the top deck.
   - Drilling shall not be resumed after blasting until a thorough examination has been made by blasting foreman (head blaster) to make sure that there are no misfired charges which the drill may strike.
   - Charging of drilled holes and drilling shall not be carried out simultaneously in the same area.

ii. Explosives and blasting:
   - All necessary precautions shall be observed which are discussed separately in Safety in Handling of Explosives as a part of this e-learning course.

iii. Operation of mucking plant and equipment

iv. Supporting the excavation

i) Drilling Operations:

   - All drilling equipment shall be kept in good working order. Safe handling and proper lifting methods shall be used.
   - As far as possible, only wet drilling shall be used.
   - Jumbos or other drill platforms shall be carefully designed, built and maintained to provide safe working conditions. The jumbo should be provided with a suitable railing around the top deck.
   - Drilling shall not be resumed after blasting until a thorough examination has been made by blasting foreman (head blaster) to make sure that there are no misfired charges which the drill may strike.
   - Charging of drilled holes and drilling shall not be carried out simultaneously in the same area.

ii) Explosives and blasting:

   - All necessary precautions shall be observed which are discussed separately in Safety in Handling of Explosives as a part of this e-learning course.

iii) Mucking plant and equipment:

   - After blasting inside a tunnel or a shaft, scaling (removal of loose rocks) shall not commence unless the roof and walls of the tunnel and sides of the shaft are carefully inspected by a tunnel foreman.
   - Scaling shall be performed only by the experienced crews under the direct supervision of a competent supervisor.
If the structure of the rock is weak, poor or structurally defective, it shall be adequately supported by providing either rock bolts or timber or steel supports with proper lagging and back filling and or by shot creting. Also, if the tunnel excavation is in clay, silt, sand or weak layers, the strata shall be supported by well designed members either of wood or steel before further activities. The construction of concrete lining, roof supports or any other provision, wherever provided for these purposes, should follow immediately after the blasting. There should not be prolonged time interval between the two operations as the risk of accidents increases with such delays.

iv. Supporting the excavation:

- After the mucking operation is over, the profile of excavation should be examined by an experienced person who should decide whether the support in the form of rock bolts, steel ribs or shot-concrete is required before any further operation is carried out.
- In case of rock bolts, safety measures for drilling the holes should observed before the bolts are fixed. The normal precautions for the erection of steel works including those of welding should be taken in the case of steel ribs.

1.1 Other Safety Precautions in tunneling:

- All operations to be carried out inside the tunnel shall be carried out under guidance of competent foreman. The parameters that are to be monitored during tunneling are Pressure, Temperature and Ventilation.
- The ventilation is required to remove polluted air, gases and smoke produced and also to ensure temperatures of not more than 40\(^0\)C dry and 29\(^0\)C wet at the working place.
- 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%
  c) Carbon dioxide - not more than 0.5%
  d) Nitrogen fumes- not more than 0.0005%
  e) Methane- not more than 0.5% at any place inside the, for example, in a cavity in the roof, etc.
  f) Hydrogen Sulphide - not more than 0.001%
  g) Aldehyde – as formaldehyde not more than 0.0002%
- Testing – The tests shall be carried out once every 24 hours but in any case after every blast or a major rock-fall.
- Records for the test of gases as also for temperature measurements and ventilation measurements shall be properly maintained.
- Dust Control – Adequate steps shall be taken to prevent the liberation, accumulation and the propagation of air-borne dust. Only wet drilling shall be permitted inside the tunnel and other underground works. Besides wet drilling,
there shall be adequate ventilation for dust control and periodical medical check up of the workers, working in the tunnel shall be done to check up their physical fitness. Such check shall be at least once in three months and the results recorded in the registers provided for the purpose.

- The air-borne dust concentration at the working face shall be tested once a month and if the air-borne concentration of total dust exceeds 10 mg/m$^3$ ventilation shall be adequately improved. If required water can be sprayed to suppress the air-borne dust.
- Adequate supply of pure and hygienic air to be maintained.
- The volume of air required shall depend on the following:
  a) Length of heading,
  b) Size of tunnel,
  c) Type and amount of explosives used,
  d) Frequency of blasting, and
  e) Temperature and humidity.

On tunnel work 4.25 m$^3$ of air/min/man is usually considered the minimum requirement. In addition to this 2.00 m$^3$ of air/min shall be supplied for such brake horse power of diesel locomotive or other diesel engine used in the tunnel. Where the temperature is high or heavy blasting is done, suitably augmented volume of air shall be provided.

As far as possible, electric power shall preferably to reduce pollution and requirement of fresh air inside the tunnel

- Whenever diesel engines are used, they shall be provided with suitable filters, scrubbers, etc, to remove all carbon monoxide and oxides of nitrogen, etc. Petrol engines shall not be used.
- Use of rolling equipment with link couplers shall not be permitted. Rocker or cradle type dump cars shall be provided with a positive type lock to prevent accidental dumping in mucking yards.
- The trolley tracks shall be properly laid with points, crossings and junctions and adequately maintained.
- At each end of the track suitable blocks or buffers shall be provided.
- Deadman switches or other installation necessary shall be provided to check accidents occurring due to runway muck cars.
- Trains shall be operated with care and at a speed under control of the operator at all times. If the locomotive is pushing a string of cars, a man shall ride in the front equipped with a whistle and a flash light for warning men along the track and for signaling the locomotive operator.
- Every locomotive shall have a head light on each end. It shall be equipped with a whistle or horn with a tone of sufficient volume to be heard by men along the track even when the drilling is going on.
- The crew shall be given whistles so that they can announce the movement of tip wagons by blowing the whistles. Whistling code shall also be devised and communicated to all. For example, one long whistle to start, short blow of whistles to warn and so on.
• A shovel shall never be left unattended with engine running and brakes not set. When it is necessary to park it on a sloping ground, it shall be securely blocked. The operator while leaving the machine shall be remove ignition key and keep with him or hand it over to some responsible person so that the machine cannot be operated by unauthorized persons.

• **Transport of Materials** – Cars carrying pipe, rail and timber shall be properly loaded for safe passage through the tunnel. The load shall be kept within the side limits for the car. Loads projecting over the sides are dangerous to men working in the tunnel. If wide loads are transported, a special care shall be ensured in the operation of the train with ample warning to the workmen along the track to ensure a safe journey.

• **Transport of Employee** – If the transportation is permitted by cars hauled by the locomotive, special arrangements like scheduled movement, controlled entry, protected cars etc. shall be ensured. No one shall be allowed to ride on front steps of loco or on a coupling. If not permitted, none other than trainmen shall ride the dump cars in going to and from work at change of shift or at any other time. A safe and smooth walkway system shall be provided for pedestrians.

• The scaffolding supporting the pipe shall be designed to carry the pipe when filled with concrete plus 100 percent overload plus the estimated weight of the maximum number of workmen that may work on the pipes while the pump is operating. A factor of safety of 4 shall then be used in design.

• The pipe line shall be anchored at all curves and near the end. The connections shall be inspected before each placement to ensure tight joints. Air-release valves shall be installed at high points to release entrapped air. Use of these valves will assist in preventing line plugging and in turn reducing accidents.

• Pipes and hoses used to convey grout shall be of proper size and strength to safely withstand the maximum operating pressures. Pumps shall not be operated at pressures above their rated capacity. All couplings shall be periodically checked to avoid snapping of hoses under high pressure.

• Cleaning of pipe line shall be carefully done.

• All workmen in the vicinity of sand blasting / shotcreting operations shall wear goggles and respirators.

• Adequate first aid arrangements shall be available.

• All persons entering the tunnel shall be provided with protective wear such as helmets, safety shoe, gum boots with steel toe, safety harness etc.

• Sanitation and drinking water facility minimum 5 liters per person should be provided.

• Proper housekeeping should be maintained.

• Proper system of communication should be maintained.

• All electrical installations shall confirm to the requirements of Electricity Rules.

• Adequate fire protection facility to be provided.

• Adequate lighting and ventilation shall be provided for all galleries and shafts where grouting is in progress.

• In large tunnels the walk ways shall be placed to the side of track.
• In long tunnels, shelter places for workmen shall be provided at suitable intervals during hauling operations.

• **Public Safety** – Shaft sinking and tunneling fascinate the public. Authorized visitors shall be equipped with safety hats and shall be accompanied by a guide competent to keep the visitors out of dangerous situations.

## 2 EXCAVATION

Most construction work involves some form of excavations for foundations, sewers and underground services. Excavations or trenching work can be highly dangerous and even some of the most experienced have been caught by the sudden and unexpected collapse of the unprotected sides of a trench. Buried under a cubic meter of soil, it is unable to breathe due to pressure on the chest, and quite apart from any physical injury one can quickly suffocate and even die with a comparatively small amount of soil weights over 1 ton. Water and Subsidence are probable natural hazards in excavation activity.

Excavation work involves the removal of soil or a mixture of soil and rock. Water is nearly always present, even if only as moisture in the soil and heavy rain is a frequent cause of soil slip. The possibility of flooding presents an additional hazard which should be always considered. Cracks are caused by pressure release as soil is removed, or drying out in hot weather. Commencement of excavation should be succeeded after taking approvals from utility companies like power, gas & water etc.

Soil varies in its nature (e.g. fine sand which flows easily, and stiff clay which is more cohesive). However, no soil can be relied upon to support its own weight and precautions are always required to be taken to support / protect the sides of the excavations of more than 1.2 meters in depth.

### 2.1 Common types of accidents in excavation

The main types of accidents resulting from excavation work are as follows:

- Getting trapped and buried in an excavation owing to the collapse of the sides;
- Being struck by material falling into the excavation from the sides / top;
- Falling into the excavated pit / hole;
- Drowning due to unsafe and insufficient means of access in case of flooding;
- Falling of vehicles driven into or too close to the edge of an excavation, particularly while reversing, causing the sides to collapse;
• Asphyxiation or poisoning caused by fumes heavier than air entering the excavation, e.g. exhaust fumes from the diesel and petrol engines.

### 2.2 Safety Precautions

The sides of the excavation or trench should be sloped or battered back to a safe angle of repose, usually 45°, or be supported by timbering or other suitable means to prevent a collapse. The type of support necessary will be depending on type of excavation, the nature of ground and the ground water conditions. PPEs which are must in excavation activity are Safety Helmet, Visibility Jacket, Shoes.

Planning is vital. Make sure that there is enough material to support the length of the trench to be cut, for the trench support must be installed without delay as the excavation progresses. At least random timbering or piling is required in all excavations, but excavations 1.2 meter or more in depth should be provided with adequate timbering or sheeting (Fig-1) close boarding or sheeting is required if the ground is unstable or lacks cohesion. Never work ahead of the trench support.

![Figure-1: Shoring with barriers to prevent the collapse of the sides of an excavation consisting of timber or steel frames with close boarding between frames](image)

Shoring should be erected, altered or dismantled only by a competent worker operating under supervision. Wherever practicable, it should be installed before excavating to the final depth of the trench—it is necessary to begin when the trench is less than 1.2 meter deep. The excavation and installation of shoring should then proceed by stages until the full depth is reached. One should be fully aware of the procedures to follow to rescue a fellow worker trapped by a fall of earth.
Workers often fall into excavations. Erect suitable barriers high enough (i.e. about 1 meter) to prevent falls (Fig-1). Projecting trench supports can often be used for this purpose.

2.3 Inspection

Excavations should be inspected by a competent person before work begins and at least once in each shift where work is in progress. They should be thoroughly examined by a competent person and a record to be kept for such inspections. The tension cracks (Fig2) at the surface are a sign of beginning of the collapse and hence shall act as a warning.

![Figure-2: Tension cracks are warning signs](Image)

2.4 Protecting adjoining buildings

Wherever possible, an excavation should not be as close and deep as to undermine any adjacent or structure. Precautions should be taken by shoring, supporting, underpinning etc. to prevent any collapse or fall when the stability of a building or structure may be affected by excavation work in progress (Fig-3).
Figure-3: Excavations near a building - shoring / supporting is required to prevent collapse of the adjoining building

2.5 Protecting the edges of excavation

One should not store, or move, materials and equipment near to the edge of an excavation. Danger may be caused by materials falling on those working below or by increased loading on the surrounding ground so as to cause the timbering or supports to the sides of the excavation to collapse. Spoil and waste heaps should similarly be kept well away from the edges of excavations.

2.6 Protecting the vehicles

Adequate and well-anchored stop blocks / wheel stoppers should be provided on the surface to prevent vehicles being driven into the excavation while tipping a particular hazard when reversing (Fig-4). The blocks should be placed at a sufficient distance away from the edges of the excavation to avoid the danger of it breaking away under the weight of the vehicles.
2.7 Access

If the depth of the excavation is more than 1.5 meter, make sure that there are adequate and safe means of access and egress, such as a properly secured ladder. This is more important when there is a risk of flooding and rapid escape is essential.

2.8 Illumination

There should be adequate provision of illumination around the area of an excavation, particularly at the access points and near the openings in barriers / barricade (if any).

2.9 Buried or underground services

Before any digging is done, either by hand or with an excavator, one should remember that there may be underground services below the surface. In built-up areas, always assume that electrical cables, water services and sewers are present. In some locations there may also be gas pipelines. Some of these services look alike, so when some buried services are found it is to be assumed as worst. Striking electric cables may cause death or severe injuries by electric shock or severe burns. Broken gas pipelines will leak and may cause a fire or explosion. Water and sewer pipelines if broken may create sudden risks by flooding an excavation or by causing its sides to collapse.

2.9.1 Electrical Cables

Every year workers digging on construction sites suffer severe burns when they accidentally hit live buried electrically cables. Always treat buried electrical cables as live. Before excavating, meet the electricity authority, the local authority or the site owner and enquire if they have any drawing or plan of layout of the cables in the area.
Even if layout plan exist, remember that some cables may not be marked on the plan or may not be where the plan shows, for cables rarely follow an exact straight line.

Look around for the traffic signs, street lights and substations which are usually supplied by buried cables. Use a cable locator if you have one - remember that if cables are close together the locator may not be able to tell them apart. Some types of cables cannot be traced by locators. Once such thing is found notify the supervisor and fellow workers. The position of the cable should be marked with chalk, crayon or paint or, if the ground is too soft for this, with wooden pegs (Fig-5). Never use sharp spikes. Once the approximate position of the buried cable is known, use hand tools to expose it. Use spades and shovels rather than forks or pick-axes. Keep a careful watch for evidence of cables during digging works. Power tools should not be used within half a meter of a cable.

**Figure-5: Locating buried electrical cables from a plan and marking their position**

### 2.9.2 Other Services

As with electricity supplies, inquire of the appropriate authorities and the site owner if plans are available of the layout of the gas pipelines, water pipelines, sewers and telephone cables and then use similar working methods.

Do not use mechanical excavators within a half a meter of a gas pipeline. If gas is smelled, make sure that, there are no sources of ignition near by such as lit cigarette or running vehicle engine. Keep away from the area, keep other people away and summon the gas authority. Do not use heavy plant or equipment over or near a gas pipeline, as the pipe may fracture.

All exposed pipelines and cables should be supported when an excavation is open. Do not use them to support equipment or as steps to get in and out of the excavation. While back-filling a trench with a gas pipe, make sure that the fill is adequately compacted beneath the pipeline to prevent settlement which could lead to pipe fracture.
2.10 Notes

I. Never work ahead of the side supports in a trench even when you are erecting shoring. Use trench cages (Fig 6) for working in unprotected parts of a trench.

![Figure-6: Trench Cage for protection of the worker in unprotected trenches](image)

II. Appearances can be deceptive. The shallowness of an excavation or the solids appearance of the ground is not necessarily an indication of safety.

III. Deep trenches look dangerous, but most fatal accidents occur in trenches less than 2.5 meters deep.

IV. Always wear a safety helmet when you are working in an excavation.

V. Hand dig with care, as cables may be just below the surface.

VI. Use a spade or shovel and not a fork or pick-axe, and do not spear the tools into the ground.

VII. If you find a cable embedded in concrete, do not break it out, but seek advice.

VIII. If a cable is damaged, even slightly, keep well clear of it.

IX. Do not work bare chested. Normal working clothing can provide some protection from flash burns.

X. Keep extra vigil while excavating / working at a level lower than the adjoining source of water, below the ground water table or in a dried river bed.

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National Safety Council, India